# Short Contributions: IoT and AI Solutions for E-Health

# Study of Middleware for Internet of Healthcare Things and Their Applications

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**Abstract.** The rapid proliferation and miniaturization of the wireless and embedded devices has led to the invasion of the Internet of Things in many domains and has reached the healthcare sector to form what is called the Internet of Healthcare Things (IoHT). The growing number of the applications in the Internet of Healthcare Things as well as the overwhelming number of heterogeneous medical devices that should interact in this network has put the researchers and developers in front of lot of challenges: How to facilitate the implementation of the various healthcare applications? And how to ease the integration of new devices and make their interoperation a transparent task for the developers? To fulfill these requirements, lot of middleware have been proposed. In this paper we provide a complete study on the existing middleware for IoHT and specify their applications, we propose a taxonomy for them and we present their main advantages and drawbacks.

**Keywords:** Middleware · Healthcare · Internet of Healthcare Things

## 1 Introduction

The interest to the healthcare digitalization is growing during these last years due to its multiple benefits [1]. Effectively, there is a growing need to monitor the patients behavior and/or status and notify the doctors and the relatives of any danger according the patient's health. Such tight monitoring cannot be ensured by nurses or caregivers. Internet of Things (IoT) represents here a suitable and efficient solution for this [2]. Effectively, IoT is made up of tiny devices that can easily communicate and cooperate together to achieve a common task. This is exactly what is needed in healthcare: tiny devices that might be portable (off the body), wearable (on the body) or implantable (in the body), track the patient's status. The application of IoT in the healthcare is called Internet of Healthcare Things. This new concept has certainly improved the healthcare services and increased its efficiency. However, it is facing lot of challenges. Effectively,


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healthcare applications are compelled to deal with medical devices having different protocols, various capabilities and working with different standards. These devices are also mobile and prone to failure. So it is important to conceive a layer between the physical devices and the application layer that hides all these diversities and deals with these challenges transparently to the end devices. This layer is called middleware [15]. We study in this paper the various middleware that have been proposed for IoHT and discuss them.

Our paper is organized as follows: We present in the second section a study of the existing middleware for IoHT. In the third section, we discuss the proposed solutions. And finally, section four concludes the paper.

## 2 Existing Middleware for IoHT and Their Corresponding Applications

We present in this section the most important middleware that have been proposed during these last years for the IoHT. We propose to classify them according to their main technical directives.

### 2.1 Fog-Based Middleware

Fog computing is considered by many researches as a middleware between the IoT and the cloud computing. This intermediate layer [3] reduces drastically the latency and affords the required processing and storage needs to the healthcare IoT devices. Effectively, many healthcare situations require a timely reaction. A IoT security middleware for use between IoT, fog and cloud computing, has been proposed in [4]. The main aim of this middleware is to ensure security and better network performance during churns. 'Session resumption' algorithm has been used by the authors to help a recently disconnected node to regain its encrypted session. This middleware can be applied in rural healthcare and public safety applications. In [5], fog nodes that are placed near to the patient's location will host a privacy middleware that ensures the user's privacy. In these nodes, data are stocked in clear and are accessed rapidly. Authors in [6] argue that using fog-based middleware in healthcare ensures the agregation of data that are generated from the patients with ensuring their privacy and confidentiality. Hence, this will lighten the burden of security processing in IoT healthcare devices.

### 2.2 Publish/Subscribe-Based Middleware

The multiplicity of events in the healthcare domain favors the use of Publish/Subscribe middleware due to their ability to deliver asynchronously multiple events from their sources to their subscribers. In [7], an IoT middleware has been proposed to help people with special needs. In this middleware, there is only one powerful component (NCeH) that will be deployed to every node that belongs to the network, in order to have a uniform configuration. This component is made up of various modules that ensure the communication between it and the other nodes and also to enable it to self-configure itself based on remote commands, and to analyze the received data so that the appropriate decision can be taken.

The proposed middleware [8] is used to classify the patients movements and count their steps number. The required materials are 2 sensors with triaxial accelerometer that should be placed on the knee and on belt, and a PDA or a smart phone to acquire the collected data by the sensors and process the classification. VIRTUS uses XMPP to know if the message is delivered to the destination or not. Also, the use of XMPP allows to verify if the destination is not connected when the message is received or not. This middleware is adaptable to modules composition changes without the need to restart the system.

### 2.3 Web of Things-Based Middleware

Authors in [20] and [10] argue that Web of Thing-based middleware are suitable to ensure interoperability since all the devices can be abstracted as a web resource.The ECOHelath middleware proposed in [10], connects doctors and patients to ease the health monitoring system and offers more accurate patients diagnosis. This middleware is based on the Web of Things (WoT) paradigm in which the physical devices are digitalized to ensure the efficient use of their data in different applications. In this middleware, there are body sensors that send their related data through a web interface that is provided by a Visualization and Management module. This interface helps doctors to track their patients' status. All the medical data are stored by the storage module in a relational database with the possible support of cloud computing. The proposed middleware has been applied to monitor the patients' heartbeats and blood pressure. ECG sensors are used to measure the heartbeats and discover heart pathologies. Blood pressure oscillometer sensor measures the arterial pressure. μWoTOP (micro Web of Things Open Platform) [11] has the ability to integrate heterogeneous biometric sensors. The data collection and notifications transmission are ensured by gateways. This middleware relies on Web technologies such as Html, REST. Its web of things strategy offered it the ability to be suitable at the same time for many healthcare applications like: Fall detection for elderlies, faint detection, abnormal behavior detection and freezing detector for Parkinson patients.

The main aim of the Sphere [12] middleware is to offer a flexible platform to integrate different sensors types and ensure their cooperation to achieve a given objective such as fall detection, Activity of Daily Living (ADL) recognition, and behavior anomaly detection.

### 2.4 SOA Based Middleware

SOA-based middleware rely mainly on services that offer a public functionnality through an interface while hiding their internal details. The main advantage of these middleware is their ability to reuse multiple devices with ensuring their communication as providers and requestors independently from any underlying architecture. Linksmart [14] is a SOA-based middleware that has proved its ability to interoperate with various devices. This middleware is widely used in healthcare to monitor patients. The Smart Homes for All (SM4All) middleware framework [13] has been proposed to help people with special needs in their homes. This middleware integrates multiple protocols such as UPnP into the OSGi framework and is able to interoperate with devices employing Zigbee, Bluetooth. This allows heterogeneous devices to connect dynamically and interact with each other in person-centric surrounding.

The main objective of Uranus middleware [16] is to afford Ambient Assisted Living (AAL) for users with vital signs monitoring. This ensures a rapid prototyping for multiple applications working on healthcare and users wellness. Authors presented two case studies that have been tested using Uranus middleware. In the first, the oxygen level in the blood of a chronically ill patient is monitored at his home. To fulfill the requirements of this case study, an oximeter should be attached to the patient to measure the oxygen level and send it to a smart phone which transmits it to the doctor. The second case study aims to monitor patients that should be injected with radioactive substance. This monitoring alerts nurses in the case of patient's complications after injection and also supervise the radiation level in order to specify the convenient examination time (Each examination type requires a specific radiation level to deliver the accurate results). To achieve this, each patient is equipped with an RFID tag, a PDA and an ECG sensor. These equipments in addition to the service discovery ensured by the middleware enable to monitor the patient's heart beats. The patient location is updated when he moves from a room to another in order to track his status (still waiting, in the examination state, injected and awaiting that the radiation level reduces). These events are traduced using semantic information.

The contribution [9] is mainly used in sleep monitoring and bedsore prevention. The patient's positions in the bed are specified and classified according to the collected RSSI of the sensors using SVM classification method. These positions give an idea about the patient's sleep and can prevent from bedsore risks. This middleware helps the caregivers and eases their job by keeping track of the patient's position in the bed and decides when and how the patient should change his position to avoid bedsores. It is made up of two layers. The middleware [17], is able to monitor and offer assistance to disabled people. The system functionalities are dispatched and divided into independent services. An ECG sensor monitors the heart activity.

### 2.5 Event-Driven Middleware

In the event-driven middleware, all the middleware functionnalities are based on events going from events production to the reaction to events. Authors in [18] consider that event driven middleware is suitable to the context of healthcare, since the sensors reading according to the patient's status and/or activity change over the time. Also, the majority of medical devices work according to the event driven process. For example, when the heartbeats rate exceeds a predefined value, a notification is triggered. Furthermore, the event driven process reinforces the data abstraction that is needed to ensure applications interoperability. The proposed middleware is dedicated for smartphone like devices that are compelled to interact with a changing set of wireless nodes in a medical environment. The proposed middleware has the ability to multiplex the received data from the various sensors in order to fit multiple applications simultaneously.

The contribution has been applied in three applications. The first is the fitness support in which the user's physical activity is tracked by dedicated sensors: a wearable accelerometer to track the user's status (walking, sitting, standing etc.) and a chest strap and two embedded sensors in the weightlifting gloves to figure out the user's body exercise. This application motivates the user and helps him to track his sports activities. The second application is the telemonitoring. The main objective of this application is to monitor remotely the patient's status. To this end, the middleware collects information about the patient's weight, pressure, heart rate, ECG, etc. When the heart rate of the patient is not suitable (abnormal) to his activities, an alarm is sent. The third application is elderly care that monitors the elderly daily activities and reminds him whenever he forgets an important task.

### 2.6 Message Oriented Middleware (MoM)

Message oriented middleware have the ability to exchange important number of messages between distributed applications. A MoM in [21] is proposed to unify the access to all the medical devices in order to ease the data collection from the patients to the doctors. To this end, "Advanced Message Queuing Protocol (AMQP)" is employed to ensure data transfer according predefined standards with the required interoperability. To increase the security of the middleware, a RESTful application has been added to verify which manager is allowed to access which data.

### 2.7 Real Time Publish Subscribe Based Middleware

The Real-Time Publish Subscribe (RTPS) middleware is well suited for the real-time distributed applications. That's why authors in [19] decided to port this middleware to healthcare. In this middleware, each medical device such as temperature probe, Capnometer, ElectroCardiogram, has the function of a publisher. It collects and publishes the patient's measurements via fast Ethernet LAN. The published information is sent to the corresponding subscribers.

## 3 Discussion

As we have stated in the previous sections, the middleware for healthcare of things have covered lot of healthcare domains. Table 1 gives an overview of these middleware, their applications and their required medical devices (NM means not mentioned in the related paper). We notice that a same application can be ensured in many cases by different middleware belonging to different classes. For example, patients monitoring applications are implemented using SOA-based or Event-driven or Web of things or Publish/subscribe middleware. There are also some middleware solutions like [11] and [9] that offered a very flexible architecture that allowed them to be applied in a wide applications range. So, we should now answer at this crucial question: What is the most suitable middleware for Internet of healthcare things?

The answer at this question is not trivial. Effectively, we see that there is no 'perfect' solution since there are miscillaneous applications in the healthcare that have different uses cases with different constraints. For example, in some healthcare applications, there are lot of events that occur and require a quick

**Table 1.** Taxonomy of middleware for IoHT

| Healthcare domain | Contribution | Required devices | Middleware class |
|---|---|---|---|
| Patients privacy preservation | [3–6] | NM | Fog-based |
| Fall/Faint detection | [12] | Wearable sensors with accelerometers | |
| | [11] | Accelerometer, blood pressure wristband | Web of Things |
| | [17] | Air pressure sensor, triaxial accelerometer | SOA |
| Freezing detection | [11] | Accelerometer | Web of Things |
| Patients monitoring | [13,14] | NM | SOA |
| | [18] | Wearable accelerometer, chest strap | Event-driven |
| | [10] | ECG sensors, blood Pressure oscillometer, Cooking health sensor, biometric chest belt | Web of Things |
| | [11] | Blood pressure, accelerometer, Mood ring | Web of Things |
| | [8] | Sensors, accelerometer | Publish/Subscribe |
| AAL+ADL | [16] | ECG sensor, Oximeter, Zigbee, THL Sensor | SOA |
| | [9] | NM | |
| | [12] | Environmental sensors, video sensors, RGB-D sensors | Web of Things |
| Bedsore prevention | [9] | Bed pressure pad, wireless PIR detectors, luminance sensors | SOA |
| Radio activity injection monitoring | [16] | RFID tag, ECG sensor | SOA |

reaction, such the case of an application that monitors the vital signs of a patient in a reanimation unit. Any modification in these signs (heart beats rate decrease, respiration problem, etc.) should trigger an event that must be handled rapidly. In these situations, an event-based middleware is a suitable candidate.

In SOA, there are service providers, service consumers and service registry. The service consumers search their required service from a service registry. They inform the corresponding service provider if the service is found. This architecture is well-suited for heterogeneous devices. And it ensures efficient service composition. However it does not fit real time applications. Many health scenario rely on one to many communication like the dissemination of a relevant healthcare information to a group of patients. In these situations, Publish/Subscribe is more suitable than the request/response strategy because it offers lower delays. But, if many situations are present simultaneously, how to choose the best middleware?

The answer is: Why to choose if we can combine? Effectively, most of these middleware classes are not mutually exclusive! We can conceive a middleware that is at the same time an event-based and a Web of Things-based for example. A middleware can even contain multiple components and each component can be based on different middleware class.

Based on the studied middleware, we can confirm that there are up to now lot of challenges that are not overcame. Indeed, the majority of the proposed middleware are conceived to a specific application and are not able to be adaptable to other applications without applying core modifications. Also, interoperability is still a crucial issue due to the continuous emergence of new medical devices with new technologies and new standards. Furthermore, the progress of the security middleware is countered by the progress of the security attacks, which lets security one of the most leading open issues that need more investigation.

## 4 Conclusion

We studied in this paper existing middleware for the Internet of Healthcare Things and specified their various applications. This study conducted us to conclude that in spite of the diversity of the proposed middleware, none of them has the ability to fulfill all the healthcare requirements. This urges to the openess and the collaboration between these middleware to have a more robust middleware verifying the trade off between the IoHT needs and devices technical limits.

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# Uncertainty in IoT for Smart Healthcare: Challenges, and Opportunities

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**Abstract.** According to Knight, uncertainty signifies deviations from the expected states, which prevent us from the use of any probability for the determination of a result for a given action or decision [1]. This paper describes the phenomenon of uncertainty in the face of technological megatrends and challenges associated with them. The article focuses on the analysis of the uncertainty in one of the most important technology trends – the Internet of Things (IoT) – on the example of Healthcare. The right decisions are not always equivalent to good results. Sometimes, the decision taken in accordance with general rules brings worse results than the one who breaks them. Such a situation is possible as a result of the uncertainty accompanying the predictions of the future. In this article the concept of the IoT is treated as a big, complex, dynamic system with specific characteristics, dimensions. structures and behaviors. The aim of the article is to analyze the factors that may determine the uncertainty and ambiguity of such systems in the context of the development of Healthcare, and recommendations are made for future research directions.

**Keywords:** Uncertainty · Internet of Things · Smart Healthcare

## 1 Introduction

The basic idea of the Internet of Things is the pervasive presence around us of a variety of things or objects – such as Radio-Frequency IDentification (RFID) tags, sensors, actuators, mobile phones, etc. – which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbors to reach common goals [7].

This The advent of the Internet of Things is changing people's lives and their integration with the surrounding environment. It is estimated that the number of connected IoT devices will outgrow the world population and increase to 50 billion by end 2020 [2]. The technical evolution of IoT also stimulates the development of smart homes. It not only makes people's daily living more convenient, but also can contribute solutions for challenges in healthcare system [3,4].

Key fields and applications (This can be portrayed in Fig. 1) for applying IoT solutions encompass [5]: smart cities, smart power networks, smart transport


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and smart buildings (intelligent solutions for living). This list also includes smart health care, one of the main subjects of this article.

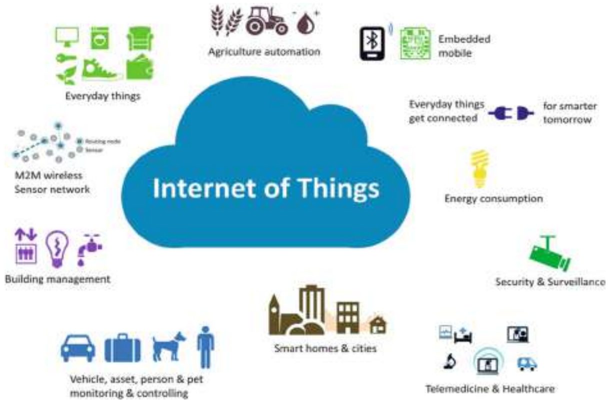


**Fig. 1.** Figure showing the Internet of Things application areas

The IoT field is a long-range technological area which presents great opportunities for development. Since the Internet of Things is a relatively new domain it carries a high level of uncertainty, both in relation to IoT technologies as well as to the aspects which are (or will be) correlated to this field, such as social, economic, technological, legal, etc. aspects [6]. Various characteristics, structures and behaviors of the IoT system are beyond areas which, so far, have been observed and are within verified knowledge, which creates significant uncertainty regarding future situations.

Healthcare is undergoing a rapid transformation from traditional hospital and specialist focused approach to a distributed patient-centric approach. The IoT applications are obscurity essential in remodeling lives of individuals than in health care. Internet of Things indicates to physical devices, like a measuring system, weight scale and patients very important watching devices (glucose, force per unit area, vital sign, and activity watching, etc.) connect with the web and transforms data from the physical to the digital world.

At present, healthcare widely uses IoT are continually evolving to accommodate the needs of future intelligent healthcare applications. This will place complex demands in terms of heterogeneity of devices, scalability, wide scale use of wireless data transfer technology, optimum energy use, data management, privacy protection bandwidth, data rate and latency, among other factors.

In the field of healthcare, various types of uncertainty are distinguished in the assessment of innovative programmes: parameter uncertainty, structural uncertainty, methodological uncertainty, variability, heterogeneity and decision uncertainty [12]. The article addresses the phenomenon of uncertainty occurring in large, developing systems namely the Internet of Things through the use of the example of the smart Health care.

## 2 The IoT in Health Care

There is a great potential for applying IoT technology across all sectors including both industrial and public to improve operation efficiency, reduce cost, and provide better service. In the healthcare, IoT plays a very important role in various applications. This criterion is divided into three phases, such as clinical care, remote monitoring and context awareness. During data collection, the risks of human error are reduced by means of automatic medical data collection method. This will improve the quality of the diagnosis and reduce the risk of human errors, who are involved in the collection or transmission of false information which is dangerous for the patients' health. There have been efforts for reviewing healthcare with different aspects.

This Arcadius et al. explained about the WBAN[1] based on IoT for the healthcare applications as it communicated with the individual to individual and the individual to things [13]. According to the author, the IoT was made to be a part of the overall Internet of the future and several technologies were used in the IoT such as communication solutions, tracking technology, wired and wireless sensor identification etc.

Jara et al. described the interconnection framework for m- healthcare application based on IoT [14]. The process of communication and the information access process had a personalized health end to end framework. The personalized data was complex and was found to be in an incomplete manner. So, the authors introduced interconnection framework for m-healthcare applications based on IoT. It made continuous and real-time vital sign monitoring system which introduced technological innovations for the health monitoring of patient's devices by means of Internet system.

Qi et al. [7] explored various applications of IoT in smart healthcare from different perspectives (i.e., Blood pressure monitoring, monitoring of oxygen saturation, heartbeat monitoring etc.). Islam et al. focused on IoT-based healthcare technologies and present architecture for healthcare network and platforms which support access to the IoT backbone and enable medical data reception and data transmission. Secondly, the paper delivers detailed research events and how the IoT can address chronic disease supervision, pediatric, care of elderly and fitness management [8].

Catarinucci et al. modeled a smart healthcare system based on IoT aware architecture [15]. The authors introduced the IoT aware architecture for automatic monitoring and tracking of patient's biomedical information. They also proposed smart hospital system, with enabling technologies, especially for wireless networks and smart mobile to enable network infrastructure. Thus, it provided highly efficient real-time monitoring of patient's biomedical information. Furthermore, privacy was an open issue in this system; Baker et al. [9] presented a new model for future smart healthcare systems, which can be used for both special (i.e., special condition monitoring) and general systems. Nowadays, all over the world, there are many people whose health might suffer due to lack of

[1] Wireless Body Area Network.

effective healthcare monitoring. Elderly, children or chronically ill people needed to be examined almost daily. Remote monitoring is an important paradigm for many real- world applications.

Context-awareness is a major criterion in the healthcare IoT applications. As it has the ability to find the patient's condition and the environment where the patient was located it will greatly assist the healthcare professionals to understand the variations that can influence the health status of these patients. In addition to, the change of physical state of the patient may increase the percentage of its vulnerabilities to diseases and be a cause for his/her health deterioration [10].

Mahmoud et al. [11] focused on different IoT-based healthcare systems for Wireless Body Area Network (WBAN) that can enable smart healthcare data reception and data transmission. the author presented a detailed of resource management, power, energy, security and privacy related to IoT-based smart healthcare.

## 3 Characteristics of the Phenomenon of Uncertainty

### 3.1 Defining Uncertainty

The concept of uncertainty encompasses multiple aspects and meanings. The widely spread use of the concept of uncertainty throughout various scientific disciplines, as well as in everyday language, has caused it to acquire many definitions.

According to F.H. Knight, uncertainty signifies deviations from the expected states, which prevent us from the use of any probability for the determination of a result for a given action or decision [1]. E. Ostrowska follows F. Knight with the measurable and immeasurable uncertainty theory which defines the former as risk and the latter as immeasurable uncertainty in its strict sense.

According to A.H. Willet uncertainty concerns changes which are difficult to estimate, or events whose probability cannot be predicted because the amount of available information is too limited [16]. A. Jøsang [17] proves that uncertainty in its strict sense can be measured using subjective logic. Subjective logic is a type of probabilistic logic that allows probability values to be expressed with degrees of uncertainty. The idea of subjective logic is to extend probabilistic logic by also expressing uncertainty about the probability values themselves, meaning that it is possible to reason with argument models in the presence of uncertain or incomplete evidence.

### 3.2 Types of Uncertainty in the Field of Healthcare

Depending on the contexts being studied in the field of healthcare, various types of uncertainty are distinguished in the assessment of innovative programmes: parameter uncertainty, structural uncertainty, methodological uncertainty, variability, heterogeneity and decision uncertainty [12].

Structural uncertainty refers to uncertainty surrounding the structure of a decision model. Variability relates to the fact that individuals are unique and therefore vary in their outcomes, which may partly be explained by individual characteristics [19]. Parameter uncertainty relates to the fact that the true value of a parameter is not known [18]. In practice, it mostly refers to imprecise estimates and standard errors surrounding a mean value, which corresponds to measurement error. Decision uncertainty is the umbrella term for all uncertainty surrounding a decision, and can be caused by any other type of uncertainty [12]. Methodological uncertainty can be defined as disparities in the choice of analytic methods that underpin an assessment [18].

### 3.3 Sources of Uncertainty in IoT Systems

Several of other factors could influence the occurrence of uncertainty in IoT. Key characteristics of IoT which influence uncertainty include:

- *heterogeneity of devices or Interoperability*: Interoperability plays an important role in smart healthcare, providing connectivity between different devices using different communication technologies. Interoperability between different devices in different domains is a key limitation for IoT success due to lack of universal standards. the large number of devices used means high diversity in their calculation and communication capabilities.
- *Resources constraints (energy and computational and storage capabilities)*: the issue of power use is crucial. IoT devices used for healthcare are connected with a collection of sensors. A continuous source of energy is required to drive these devices, which presents a severe challenge in term of cost and battery life. Their computational and storage capabilities do not allow complex operations support (e.g. cryptographic operations, etc.).
- *privacy protection*: The security protection is not about encrypting/decrypting user data, but about how a user in a heath community can use trust information to filter out untrustworthy input when gathering health information to enhance IoT health security. Due to constrained nature of IoT device (limited processing and battery life) it is difficult to implement complex security protocols and algorithms. This leads to numerous attacks and threats in term of security and privacy.
- *scalability (connectivity in IoT)*: connectivity of a growing number of devices being used every day. A smart healthcare network consists of billions of devices. can succeed only if it can provide capabilities of sensing to produce important information.
- *data management*: In smart healthcare, billions of devices are connected, which can produce a huge amount of data and information for analysis. in IoT it will be crucial to utilize appropriate data models and semantic descriptions of their content, appropriate language and format.
- *Network*: Intermittent loss of connection in the IoT is fairly frequent. In fact, IoT is seen as an IP network with more constraints and a higher ratio of packet loss problems connected with overcoming this issue are related to transfer speeds and delays in delivery of data;

– *Quality of Services (QoS)*: the quality of services is an important parameter used in the healthcare services which is a highly time-sensitive system. Numerous challenges exist to meet the quality requirements of IoT-based applications in terms of energy efficiency, sensing data quality, network resource consumption, and latency. The quality of body sensors determines the accuracy and sensitivity measurements provided by a sensor.

### 3.4 Causes of Uncertainty in IoT Systems

Uncertainty is one of the key problems for most IoT systems based on RFID (Radio Frequency IDentification) technology. Listed below are causes of uncertainty relating to the following fields [20]:

– *Inconsistent data (unbounded data, data conflict)*: RFID tags can be read using various readers at the same time therefore it is possible to get inconsistent data about the exact location of tags;
– *Incomplete data (Noisy data, data loss)*: tagged objects might be stolen or forged and generate fake data.
– *Ambiguity Data (plausibility, imprecision)*: sometimes radio frequencies might cause data to be reflected in reading areas, so RFID readers might read those reflections;
– *Missing readings*: tag collisions, tag detuning, metal/liquid effect, tag misalignment;
– *Redundant data*: captured data may contain significant amounts of additional information;

## 4 Findings and Recommendations

### 4.1 Research Challenges

a) How to guarantee connectivity of massive IoT devices in a wide range during high mobility?
b) How to guarantee resource management in highly dense network?
c) How to utilize power/energy of IoT devices?
d) How to extend IoT devices battery life?
e) Incorporating devices for retailer locked-in services.
f) Secure integration and deployment of services (cloud-based) at both device and network levels.
g) Early detection of both outsider and insider threats.
h) Standardized security solutions without delaying data integrity.

### 4.2 Major Requirements

– adaptation of trust management mechanisms, similarly to what was already adopted for P2P and grid systems and technical security policies;

- Identification of vulnerabilities at a various level in the network. which work as entry points for numerous attacks.
- adaptation of trust relationships on the following levels:
  - IoT entities;
  - data perception (sensor sensibility, preciseness, security, reliability, persistence, data collection efficiency);
  - privacy preservation (user data and personal information);
  - data fusion and mining;
  - data transmission and communication;
  - quality of IoT services;
  - acceptance of shared standards to cope with the diversity of devices and applications;
- creation of simulations and models of uncertainty phenomena;

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# Secure E-Health Platform

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**Abstract.** Currently, the Internet has become a service hosting infrastructure through its interconnection of a very large number of heterogeneous objects, thus offering users several types of services implemented by different sectors. Although these services make people's lives easier and provide them with a means of communication between their real and virtual worlds, they risk being a path of intrusion into their private lives, or in some cases an easy target for malicious individuals aiming to endanger human life. To avoid this, we have designed a secure e-health platform based on IoT that serves to monitor patients' medical profiles remotely by collecting their medical records while ensuring their confidentiality and integrity.

**Keywords:** Internet of things (IoT) · E-health · Security · Confidentiality

## 1 Introduction

With the interconnection of billions of objects around the world, IoT offers several services to individuals through many types of applications deployed in several domains, including smart grid [1], smart home, smart city, smart healthcare and applications dedicated to vehicle monitoring [2,3].

Healthcare Systems have emerged to address some of the problems facing the health sector, mainly the lack of medical staff caused by the ever-increasing population and the lack of timely diagnosis of diseases [4] by allowing constant medical monitoring of chronic patients or residents of isolated or underserved locations. In this development and deployment of e-health systems, information management by mobile devices require very short response times and latency, it introduces also several challenges including data storage and management, security and confidentiality (e.g. authorization control and anonymity) [8]. The integration of fairly strong security mechanisms is necessary for this systems where a successful security attack results in several human lives being subjected to false diagnosis or delayed surgical procedures.

We are interested to problems of storage, confidentiality and data integrity by ensuring minimal response time and low latency. Several authors have conducted works aimed at setting up remote patient monitoring platforms such as [13–16]. Nevertheless, this works present some limitations such as neglecting the security


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of the monitoring systems, the privacy of its users, the availability and the storage of data.

To address the aforementioned issues, we propose a solution to provide the healthcare community and patients with a secure medical service. Our platform offers continuous medical monitoring with the integration of medical data backup mechanisms at the Cloud level, thus ensuring the notion of fault tolerance through data replication and thus the availability of information while guaranteeing the integrity and confidentiality of the data exchanged ( using sh1 and MD5 protocols for hashage and DES ,RSA for encryption), a minimal response time and low latency due to the implementation of fog computing. The remainder of this paper is organized as follows. Section 2 reviews related works on healthcare systems. Section 3 describes the proposed solution. Section 4 presents the experiments. Finally, Sect. 5 concludes the paper.

## 2 Related Works

In this section, we discuss the related work of healthcare systems. In [5], The authors present a cloud computing solution for patient's data collection in healthcare institutions. The system uses sensors attached to medical equipment to collect patient data and sends it to cloud for providing ubiquitous access. In [6], the proposed architecture is dedicated to data acquisition via several personal health devices via USB, ZigBee or Bluetooth. But the disadvantage of the abovementioned work is that the response time and latency increases due to the long path to the cloud, which influences the user's access time to the data. In [7] who have implemented an IoT- healthcare system architecture which benefits from the concept of fog computing, thus ensuring low latency data processing and low bandwidth usage. The main disadvantage of the above works is the neglect of the notion of security. In [15] authors have proposed a robust solution in terms of response time by ensuring the confidentiality of data via an authentication protocol except that it only authenticate LPU (Local Process Unit) and not identify the users and neglects the property of data availability by centralizing storage at the level of a single server, in the event of failure of the latter, access to medical records will be suspended, which could endanger human life. While the authors of [16] Propose a secure healthcare system with the same drawback as the previous one with neglect of the quality of service criteria (response time and latency). On the other hand, our approach maintains a backup procedure to ensure continuity of service while guaranteeing the unique identity rule via the NIN [12]. According to [17] that uses Blockchain as a security method offers several advantages by allowing an agreement without the use of a trusted third party and thus avoiding the bottleneck, the antecedent medical data are also complete and coherent thanks to the chaining. However, this technology requires a significant investment which is very costly. It should also be noted that the blockchain consumes a lot of computing time, which is not ideal for e-health platforms.

## 3 E-Health Platform

In this section we present the architecture of our IoT system which is based on fog-enabled cloud computing as described in [10]. Then we will present the two main processes of our system and we finish by presenting the different security aspects available on our platform.

### 3.1 System Architecture

As illustrated in Fig. 1, the architecture of our system is mainly based on (N) local servers distributed geographically over (N) zones, in which patients and medical institutions can be located, medical sensors used for the collection of patients data and IoT equipment (smartphones); as well as a central server (cloud) dealing with global data storage.

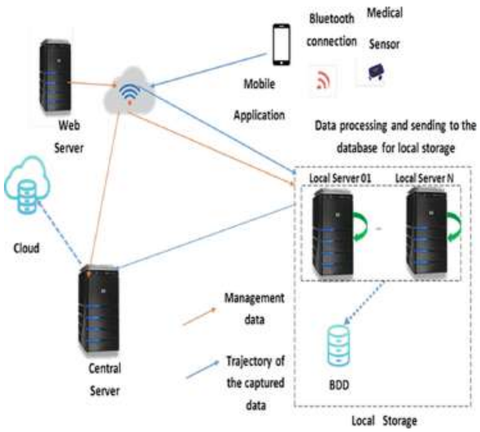


**Fig. 1.** E-health platform

The different actors and components of our architecture are explained as follows:

– **Medical sensors:** it is planted in, on or around a human body to capture the patient's health data and send it to the system periodically.
– **User:** consists of two categories of users, each of them has a unique identifier (NIN) [12]:

1. *The Patient*: person with whom one or more sensors are associated to monitor its health status.
2. *The practitioner*: person who is in charge of setting up the association between the patient and his sensor.

- **Mobile application:** a User Interface (UI); it authenticates users by submitting their identifiers (NIN) [12] with their relative passwords. It also allow the Patient/sensor association procedure, which only the practitioner is authorized to do, it allows him to consult the medical records of his patients and make diagnoses.
- **Local servers:** a distributed computing paradigm that acts as an intermediate between Cloud datacenters and IoT sensors. Its role is to lightly process the medical data collected by the sensors associated with the different patients geographically distributed over the (N) zones, followed by the backup of this data on local databases.
- **Web server:** administrates and maintains the system, including the management of the accounts of the administrator of the (N) area. All this is done by the super administrator, while each administrator is responsible for creating and managing the accounts of the users in his or her zone.
- **Cloud:** a central server, which is responsible for the global storage of medical and personal data of users in all areas, with the possibility of transferring this data to an area X to which the patient has moved, if the attending physician wants to consult the file of his new patient, who has just arrived in his new area.

### 3.2 The Main Operating Processes

Among the most important processes for the realization of our IoT service platform, the following two processes driving the operating principle of the mobile application, the association of sensors to patients and sends it as well as data storage.

- **Process of association's creation**
  The practitioner first searches the patient's profile at the local level by introducing his identifier, otherwise, the local server sends a request to the central server of the Cloud to retrieve and save it at its level.
  After retrieving the patient's profile, practitioner checks the availability of the sensor to associate it with the right patient; This procedure can be summarized by the following steps:

  1. Initiation of the association process by the practitioner.
  2. Sensor search procedure and availability test.
  3. Beginning of capture of the patient's medical constants.

  In the case of healing of the patient or the end of his or her followup by his practitioner, the latter ends this association by disassociating the patient's sensor.
- **Process of detection and data transmission by sensors**
  After the patient sensor association is established, the sensor begins to capture the patient's data and sends it through the mobile application to the local server for storage.

### 3.3 Security of the E-Health Platform

We introduced security mechanisms to protect the captured user data as it will be sent to processing equipment and then to storage spaces, which will make them subject to theft or alteration attempts [3]which represent very high risks for the functioning of IoT applications.

- **Data integrity:** Data integrity refers to the state of data that, at the time of processing, storage or transmission is not intentionally or accidentally altered or destroyed and maintains a format that allows its use. For this purpose, the programmed SQL queries will be used, and data will be encrypted using the RSA asymmetric encryption algorithm, to ensure such data integrity.
- **Backup and logging of the cloud database:** To preserve the data within our database, we have opted for the backup strategy which consists of making copies of existing data in order to improve reliability, fault tolerance, or availability. Every day, our database will be automatically replicated to the cloud to ensure continuity of service in the event of a local server failure.
- **Authentication:** The authentication process will allow us to prevent privacy breaches, unauthorized access to data, identity theft, and password attacks by limiting authentication and login attempts to the private areas of practitioner and patient users. This is done by using small gadgets called "smart cards", which each user has. These cards have the above-mentioned user ID (NIN) and a corresponding password [12].
- **Data encryption:** To prevent human attacks from the middle, the following encryption mechanisms are applied to the exchanged data in our system.

  - Encryption of data within the database, using md5 and DES encryption protocols.
  - Encryption of data circulating in the network, using SSL Sockets with certificates and Data hash by applying the SH1 protocol [9].

## 4 Implementation and Results

In this section we present the basic implementation setup, then we introduce the mobile prototype to validate our solution as well as some simulations and discussion of results.

The experiments were conducted on an IoT sensor Xiaomi Mi Band3 [11] is an intelligent IoT-based electronic bracelet that incorporates an HR (Heart Rate) heart rate sensor. The user interface (UI) was built using an Android Studio V4.4+. We have used the Google Cloud Platform for the creation of our local servers and the global server for the data storage.

### 4.1 Mobile Application Prototype

The mobile application is used to communicate with the IoT device in order to collect the data. It will be installed at the practitioner and the patient having a profile for each one of them (see Fig. 2). Both types of users will be entitled to the following functionalities:

– **For the practitioner:** Patient/Sensor Association, Monitoring,Transfer, and patients update.
– **For the patient:** consultation of his various medical information.

As can be seen in Fig. 2, each time the sensor registers a new value; it sends it to the mobile application to which it is connected. In the case of a heart defect as shown in the following figure, notifications and alerts are sent to the practitioners treating the patient, and a telephone call is made from the patient's home to the toll-free civil protection number.

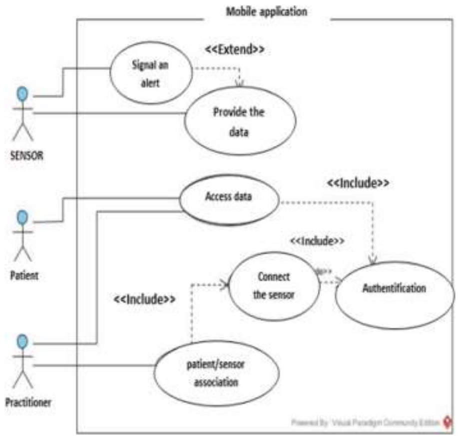


**Fig. 2.** Use case of the mobile application

### 4.2 Simulation and Discussion of Results

In order to test the performance of our system, and see how it will react to changes in the number of users, simultaneous access to the server through the use of "Threads" and the data encryption operation; we launched a simulation with a series of tests based on the response time of the local server for requests issued by the users, whether patients or practitioners, as this time may be a factor in the favorable to saving a human life.

**Test 1:** Incrementing the number of users with the use of Threads and encryption: First, we start by testing the incrementation of the number of users with the activation of simultaneous access to the server using "Threads", and the encryption and data encryption operation.

**Test 2:** Incrementing the number of users with the use of Threads without encryption: Secondly, we test the incrementation of the number of users with the activation of simultaneous access to the server using "Threads", and by disabling the encryption and data encryption operation.

**Test 3:** Incrementing the number of users without Threads and encryption: Finally, we tested the incrementation of the number of users without the activation of simultaneous access by using "Threads", and without encryption.

After completing the series of tests, and as illustrated in Fig. 3 We noticed that the encryption operation will not have much influence on the system's response time. Whilst, the use of Threads will have an impact on the load on the communication network. After analyzing the simulation results, we conclude that as the number of users increases, the number of requests to be processed by the server increases too, which will lead to congestion at the server level and additional traffic on the network, thus prolonging the response time, which is not tolerable in our system in the event of an extreme emergency. Whilst with the use of Threads, We notice that the different requests will be processed simultaneously, which will, therefore, reduce the response time, as well as the load on the network.

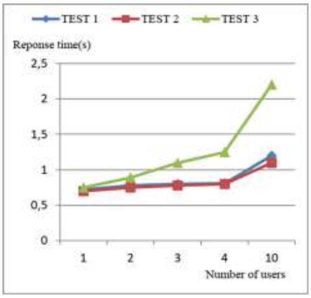


**Fig. 3.** Simulation's tests

## 5 Conclusion and Perspectives

We have developed a service platform based on IoT, with a secure online health application to establish the medical profiles of patients from distributed information, allowing their continuous monitoring in order to improve and modernize health services by ensuring the security of the data exchanged on our platform, thus guaranteeing the preservation of patients' privacy.As a future work, We plan to expand the real deployment of integrated sensors to better evaluate our system.

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# Hybrid and Secure E-Health Data Sharing Architecture in Multi-Clouds Environment

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**Abstract.** Healthcare is among the sectors showing efforts in adopting cloud computing to its services considering the provided cost reduction and healthcare process efficiency. However, outsourcing patient's sensitive data increases the concerns regarding security, privacy, and integrity of healthcare data. Therefore, there is a need for building a trust relationship between patients and e-health systems. In this paper, we propose a privacy-preserving framework, called Hybrid and Secure Data Sharing Architecture (HSDSA), to secure data storage in e-health systems. Our approach improves security in healthcare by maintaining the privacy and confidentiality of sensitive data and preventing threats. In fact, in the upload phase, Multi-cloud environment is used to store Rivest–Shamir–Adleman (RSA) encrypted medical records. We adopt a Shamir's secret sharing approach for the distribution of shares to different independent cloud providers. In the retrieval phase, the reconstruction operation is based on the $(t, n)$ strategy. To check the requester identity and to prove the hash possession, we used a zero-knowledge cryptography algorithm, namely the Schnorr algorithm. The patient has a total control over the generation and management of the decryption keys using Diffie-Hellman algorithm without relying on a trusted authority.

**Keywords:** E-health system security · Privacy preservation · Multi-cloud · Data storage · Data share · Data encryption

## 1 Introduction

Cloud computing is a new promising technology that leverages the user from the burden of hardware maintenance and offers dynamically flexible and scalable computational resources accessible from any place where a network is available. The emergence of this paradigm has deeply influenced many domains and especially the healthcare sector. However, the usage of this model in the healthcare


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domain needs the reinforcement of security measures because data are susceptible to lose, leakage or theft. Therefore, confidentiality and integrity of the stored Electronic Health Records (EHR) are deemed as one of the major challenges elevated by the external storage. Besides, the privacy of sensitive data must be guaranteed. To overcome the above cited challenges, cryptographic techniques for securing e-health systems are widely adopted. But the reliance on a single cloud storage provider has shown many drawbacks like a single point of failure, vendor lock-in and malicious insiders. To narrow down the listed disadvantages, it is advisable to use multi-cloud architecture. One of the key concepts of this model is to store data on different cloud server providers where an insider is not able to reconstruct the original data from a single share [1].

In this context, several solutions have been proposed in the literature to ensure secure multi-cloud storage in e-health systems [2–5]. They mainly have two phases: *storage* and *retrieval*. They also all use cryptographic primitives to ensure EHRs security. Authors of [2] use an Attribute Based-Encryption (ABE) for selective access authorisation and cryptographic secret sharing. The EHRs split and reconstruction is done through a proxy. In [3], ABE is used for selective data sharing with physicians without allowing them to know the precise description of the patient's illnesses. Biometrics based authentication and Kerberos tickets session are used in [4] to guarantee secure interaction with the EHR system. In addition, a steganographic technique is used to store EHR. In [5], authors propose the use of Shamir's Secret Sharing not only to distribute EHR shares among cloud servers but to retrieve the requested EHR from partial cloud servers. In summary, the main drawback of [2–5] is the reliance on a trusted third party which may not be adequate for practical use as they show security risks. Hence, a secure privacy-preserving data storage solution is still needed to improve the patient role to monitor his data on the cloud.

In this paper, we present a Hybrid and Secure Data Sharing Architecture (HSDSA), for secure and privacy-preserving storing and sharing of patient's sensitive data in a Multi-cloud environment without relying on a trusted third party. In HSDSA, cloud providers are assumed to be semi-trusted: honest but curious. HSDSA gives the patient total control over the generation and management of the decryption keys without relying on a trusted authority and thus it is more applicable for public cloud environments. To protect the data from external attackers, Rivest–Shamir–Adleman (RSA) encryption is applied before outsourcing EHR. To secure data against cloud providers curiosity, Shamir's secret sharing is adopted. The resulted shares are distributed to multiple clouds. To download an EHR, HSDSA recovers its shares using an outsourcing reconstruction operation based on the $(t, n)$ strategy. To complete the file decryption, a Schnorr-based technique is used to prove data possession and to verify the requester identity. Then a session, using the Diffie Hellman (DH) algorithm, is created to securely exchange the decryption key. Finally, the key is extracted and the original EHR could be recovered. Outsourcing reconstruction operation based on the $(t, n)$ strategy is used.

The remainder of the paper is organised as follows. Section 2 gives an overview of the overall architecture of the proposed framework and its components. Sections 3 and 4 detail the different techniques used in the storage and retrieval processes. Finally, Sect. 5 concludes the paper and highlights some open issues.

## 2 Architecture Overview of the Proposed Scheme

We recall that our goal is to securely store EHRs in multi-cloud environment and to securely share them among healthcare organisations staff. In the following, we will give an overview of the HSDSA framework in which we focus on the context of medical data storage, share and retrieval. The basics of HSDSA are shown in Fig. 1. Our system compromises three different entities: Data Owner (DO), Data Requester (DR) and $n$ CSP ($CSP_1$,...,$CSP_n$). The key components of the HSDSA framework include:

- **The storage process** which is composed of two phases, namely the **registration** phase and the **storage** phase.
- **The retrieval process** which is composed of two phases, namely the EHR **reconstruction** and the EHR **recovery** phases.

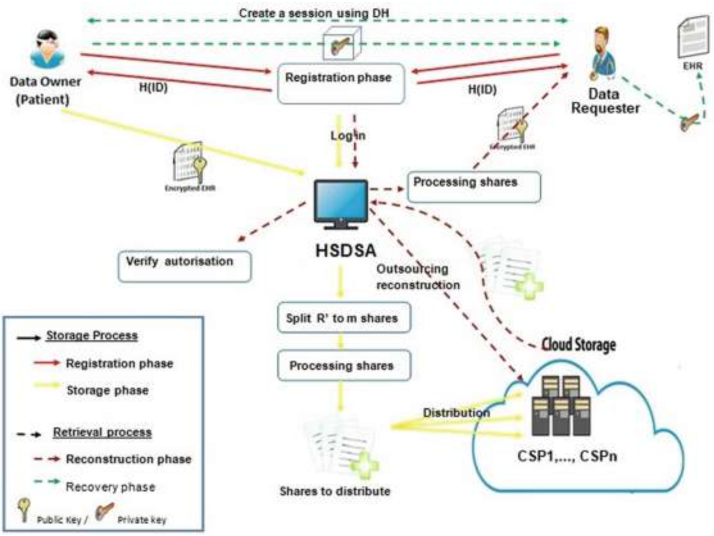


**Fig. 1.** Architecture overview

As shown in Fig. 1, the workflow of HSDSA is as follows:

- **The registration phase** starts when a DO or a DR signs in to the Framework Interface. After being signed to HSDSA, a DO or a DR receives in response the hash of his identity H($ID_{DO,DR}$).

- **The storage phase** starts when a DO wants to store his EHRs, he calculates the digital signature of his EHR ($R$), encrypts $R$ using Rivest–Shamir–Adleman (RSA) algorithm for both and logs in to the HSDSA. Then, the DO uploads his encrypted record ($R^{'}$) and the hash value of the original record H(R). HSDSA generates a unique identifier ($ID_R$) of the EHR to guarantee the anonymity of stored data in Cloud servers and stores H($ID_{DO}$), H(R) and $ID_R$. The framework calculates the hash of the uploaded EHR ($R^{'}$) and splits it into $m$ shares. Then, it performs an exclusive OR operation between each share ($S_i^{'}$) and the hash value of $R^{'}$. The distribution is done using Shamir's secret sharing algorithm and the resulted shares are sent to $n$ different Cloud Server Providers $CSP_1$, ... $CSP_n$.
- **The reconstruction phase** starts when a DO or an authorised user DR wants to get the EHR, he sends a request to the framework. After confirming the request, HSDSA assigns a CSP ($CSP_R$) to perform the reconstruction step. The $CSP_R$ gets $t$ shares or more from $CSP_1$, ... $CSP_n$. Once the reconstruction is done, the $CSP_R$ returns the resulted shares to the framework.
- Finally, **the recovery phase**, when the DR wants to get the DO's private key, he has to prove that he is the right DR and he has the correct hash value of $R$. To this end, the Schnorr algorithm is used. Once, the DO makes sure that the DR is an authorised requester and that he possesses the encrypted version of the EHR ($R^{'}$), then the DR and the DO try to establish a session using Diffie-Hellman (DH) algorithm to exchange decryption key securely. Once they agree on a session key, $K_s$. The DO encrypts his private key using $K_s$ and sends it to the DR. Once the private key is extracted, the DR can finally recover the desired EHR (R).

## 3 Analysis of the Proposed Storage Process

In the following, we detail the techniques used in the two phases of the storage process: the registration phase and the storage phase.

### 3.1 The Registration Phase

As recommended in cloud-based storage solutions, building a trust relationship between partners is a necessity. To achieve this goal, the first step is to make sure that all users are registered to the framework. If a new user wants to benefit from services provided by the HSDSA framework, he must be correctly authenticated. Once he registers, he receives a value containing the hash of his identity H($ID_{DO,DR}$) in order to maintain the anonymity of user identities.

### 3.2 The Storage Phase

HSDSA acts as an intermediary between DO and CSPs. Our goal is to provide a secure storage facility to authorised users. This phase involves Shamir's secret sharing technique to make sure that the multi-cloud environment, used to store shares, is a collusion-safe. By collusion-safe we mean that if two or more CSPs combine their keys, they cannot decrypt the data. Ten steps, illustrated in Table 1, describe the storage phase.

When a DO wants to store an EHR, he calculates the digital signature of the original EHR (R). Then the RSA is used to split the selected EHR into blocks and encrypt them. Sequential execution of RSA needs a lot of calculation. Therefore, we use the enhancement proposed in [6] where authors have parallelized the process of encryption and decryption of a large number of data blocks. The resulted file $R^{'}$ and H(R) are sent to HSDSA.

$$R^{'} = E_{PK_R}(R) \tag{1}$$

When the framework receives $R^{'}$ and H(R), it generates a unique identifier $ID_R$ corresponding to the file $R^{'}$. This is used to guarantee the unlinkability between DO and EHR. After that, HSDSA computes the hash of $R^{'}$ (H($R^{'}$)) and stores $ID_R$, H(R) and H($R^{'}$). Next the framework splits $R^{'}$ into $m$ shares [$S_1$, ... ,$S_m$], performs the exclusive OR operation of each split of $R^{'}$ with H($R^{'}$).

$$\begin{aligned}[S^{'}_1, ..., S^{'}_m] &= R^{'} \bigoplus H(R^{'}) \\ &= [S_1, ..., S_m] \bigoplus H(R^{'}) \\ &= [S_1] \bigoplus H(R^{'}), .., [S_m] \bigoplus H(R^{'})\end{aligned} \tag{2}$$

[$S^{'}_1$, ... ,$S^{'}_m$] are the shares to be stored in independent CSPs. To securely distribute the shares, we adopted Shamir's secret sharing protocol. It represents a so-called ($t$,$n$) threshold scheme with $1 \leq t \leq n$. This mechanism permits the distribution of a document among $n$ parts in a way that reconstruction is possible if at least $t$ shares are present. Suppose a share $S^{'}_i$ (for $i$ i = 1 ... $m$), Shamir's secret sharing algorithm sets $a_{i0} = S^{'}_i$, chooses $a_{i1}$, ..., $a_{it-1}$ at random, takes distinct values $x_1$, $x_2$,..., $x_m$ with $m \geq t$-1 and computes the shares to distribute, as follows:

$$\begin{cases} S_{1i} = (x_i, f_1(x_i)) \\ \quad\quad .... \\ S_{mi} = (x_i, f_m(x_i)) \end{cases}, \ for\ i = 1..n$$

In the proposed architecture, HSDSA selects $m$ polynomials.

$$\begin{cases} f_1(x) = a_{10} + a_{11}x + a_{12}x^2 + ... + a_{1t-1}x^{t-1} \ mod\ p \\ \quad\quad ... \\ f_m(x) = a_{m0} + a_{m1}x + a_{m2}x^2 + ... + a_{mt-1}x^{t-1} \ mod\ p \end{cases}$$

Where

$$\begin{bmatrix} a_{11}, ..., a_{1t-1} \\ ... \\ a_{m1}, ..., a_{mt-1} \end{bmatrix} \in \quad \mathbb{Z}_{|}$$

The HSDSA computes $n$ shares $S_{1i}$, ..., $S_{mi}$ (i = 1, ..., n) and distributes them to $CSP_1$, ..., $CSP_n$.

**Table 1.** Scenario of the storage phase

| **User** | **HSDSA** | **$CSP_1$, ... $CSP_n$** |
|---|---|---|
| 1.Calculate H(R) = $E_{PU_R}$(R) | | |
| 2. Encrypt R: $R^{'} = E_{PK_R}$(R) | | |
| 3.Log in | | |
| $\xrightarrow[H(R)]{\text{upload } R^{'}}$ | | |
| | 4.Generate an identifier of $R^{'}$ : $ID_R$ | |
| | 5.Calculate H($R^{'}$) | |
| | 6.Split $R^{'}$ to $m$ shares: $R^{'}$=$S_1$, ... ,$S_m$ | |
| | 7.Calculate $S_i^{'}$ for $i$=(1,..,$m$) | |
| | $S_i^{'} = S_i \bigoplus$ H($R^{'}$) | |
| | 8. Select polynomials:$f_i(x)$ $i$=(1,..,$m$) | |
| | 9. Compute shares:$S_{1i}$,..,$S_{mi}$ | |
| | $\xrightarrow[ID_R]{\text{Send shares}}$ | |
| | | 10.Store shares and $ID_R$ |

## 4 Analysis of the Proposed Retrieval Process

File retrieval, also known as file reconstruction, is the reversal process of file distribution and file slicing. In this framework the retrieval process starts when a data requester DR needs to get an EHR. He must log in and submit the EHR identifier ($ID_R$). HSDSA checks if the DR has the right to get the requested EHR. If the authorisation succeeded, then the reconstruction phase starts.

### 4.1 The Reconstruction Phase

Since the reconstruction of $R^{'}$ requires a massive amount of computation and that client resources are limited, we will use the reconstruction outsourcing scheme proposed in [5]. The framework assigns a CSP ($CSP_R$) to reconstruct shares $S_j^{'}$. The reconstruction is considered successfull only if $CSP_R$ gets at least $t$ shares from $CSP_1$, ..., $CSP_n$. We assume that $CSP_R$ gets $k$ shares.

$$\begin{bmatrix} S_{11}, ...S_{m1} \\ ... \\ S_{1k}, ..., S_{mk} \end{bmatrix}, (k \geq t)$$

$CSP_R$ computes $S_j^{'}$ for $j = (1, ..., m)$ using Lagrange interpolation polynomial and sends them to HSDSA:

$$S_j^{'} = \sum_{i=1}^{k} S_{ji} \prod_{l=1, l \neq i}^{k} \frac{x_i}{x_i - x_l} \ mod \ p \ (j = 1, ..., m) \tag{3}$$

To make sure that $CSP_R$ could not reveal any useful information, knowing that he is a curious and dishonest party, doing an exclusive OR operation helps to blind the content. Upon receipt of the shares, the HSDSA framework performs the exclusive OR operation between $S_j^{'}$ and H($R'$) to get $S_j$.

### 4.2 The Recovery Phase

This phase aims to securely transfer the Data Owner's private key to the right Data Requester. Table 2 illustrates the main steps related to this phase.

Once the reconstruction phase is done, HSDSA sends $ID_{DO}/ID_{DR}$ to the Data Owner and to the Data Receiver. First the DR has to prove to the DO that he holds the right hash value of the original file $(H(R))^{'}$ and that he is the correct DR. For this purpose, a Schnorr's identification protocol [7] is used not only to prove the hash possession but also to verify the DR identity. In the process of the latter algorithm the DO checks if H(R) $\stackrel{?}{=}$ $(H(R))^{'}$), and verifies if the $n$ first bits of the DR identity match the $ID_{DR}$ previously sent by FI. Then the DO and the DR must establish a secure connection for key exchange, based on Diffie-Hellman (DH) scheme Ephemeral version [8], reinforced with the hash value of the original file (H(R)). Establishing a session means that the two partners have agreed on session key ($K_s$) that will be used to crypt partners

**Table 2.** Scenario of the recovery phase

| Data Requester | | Data Owner |
|---|---|---|
| | Schnorr algorithm | |
| $\alpha = (H(R))'$, $s$: secret key | | |
| $v = \alpha^{-s}$ | | |
| 1. Choose $r$ and calculate | | |
| $x = \alpha^r \bmod p$ | | |
| | $\xrightarrow{x}$ | |
| | | 2.Choose $e$, $n$ $(3 \leq n \leq 20)$ |
| | $\xleftarrow{e,\ n}$ | |
| 3.Calculate $y = r + es \bmod p$ | | |
| Calculate $F = n$ first bits of $ID_{DR}$ | | |
| Calculate $Y = y \bigoplus F$ | | |
| | $\xrightarrow{Y}$ | |
| | | 4.Calculate $y = Y \bigoplus F$ |
| | | 5.Verify $x \stackrel{?}{=} H(R)^y.v^e \bmod p$ |
| | Diffie Hellman algorithm | |
| $s$, $p$, $g$ | | $b$ |
| 6.Calculate $A = g^s \bmod p$ | | |
| $F_1$ = premier $n$ bits de H(R) | | |
| $A_1 = A \bigoplus F_1$ | | |
| | $\xrightarrow{A_1,p,g}$ | |
| | | 7.Calculate $B = g^b \bmod p$ |
| | | $B_1 = B \bigoplus F_1$ |
| | $\xleftarrow{B_1}$ | |
| | $\xleftrightarrow{\text{Calculate } K_s}$ | |
| $B = B_1 \bigoplus F_1$ | 8. Calculate | $A = A_1 \bigoplus F_1$ |
| $K_s = B^s \bmod p$ | | $K_s = A^s \bmod p$ |
| | | 9.Encryt private key PU |
| | | $PU' = E_{K_s}$(PU) |
| | $\xleftarrow{PU'}$ | |
| 10.Extract PU | | |
| PU = $D_{K_s}$ $(PU')$ | | |
| 11. Recover R = $D_{PU_R}$ $(R')$ | | |

metadata. Next, the DO encrypts his private key (PU) using $K_s$ and sends the resulted value $PU'$ to the DR.

$$PU' = E_{K_s}(PU) \tag{4}$$

The DR decrypts $PU^{'}$ using $K_s$ to extract the DO private key. Possessing PU, the DR decrypts $R^{'}$ to finally recover the original EHR (R).

$$PU = D_{K_s}(PU^{'}) \tag{5}$$

$$R = D_{PU}(R^{'}) \tag{6}$$

## 5 Conclusion

In this paper, we presented HSDSA, a novel architecture for secure EHR. HSDSA includes several techniques, namely (i) RSA algorithm to guarantee the security of outsourced data, (ii) Shamir's secret sharing to securely distribute data across multiple clouds, (iii) a secure outsourcing reconstruction based on the $(t, n)$ strategy, (iv) a Schnorr-based technique to prove data possession and to verify the requester identity and (v) a Diffie-Hellman algorithm to securely exchange decryption key. The proposed scheme allows the patient to get total control over the generation and management of the decryption keys without relying on a trusted authority. In a future work, we plan to add governmental organisation as Data Requester. These latter need to access data without the Data Owner authorisation. Hence, we aim to protect privacy while giving them access to EHR.

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# Blockchain for Internet of Medical Things: A Technical Review

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**Abstract.** The Internet of Medical Things (IoMT) represents a network of implantable or wearable medical devices that continuously collect medical data about the patient's health status. These data are heavy, sensitive and require high level of security. With the emergence of blockchain technology, researchers are focusing on using blockchain strategies to bring security to healthcare applications. However, such integration is very difficult and challenging due to the different requirements in these two technologies. We present in this paper a technical review of existing solutions applying blockchain technology on IoMT. We analyze these studies, discuss the proposed architectures and how they managed the integration challenges. The open issues regarding the application of blockchain over IoMT are also specified.

**Keywords:** Healthcare · Internet of Medical Things · Security · Blockchain

## 1 Introduction

Recently, with the rapid development of wearable/implantable sensors and wireless communication, researchers are increasingly interested in improving the health sector in response to human needs by digitizing and decentralizing healthcare institutions and providing continuous and remote medical monitoring. Generated medical data are very critical and must be dealt with care to prevent any kind of data tampering. In this context, blockchain has emerged as the most secured, decentralized platform. It provides many powerful features without third party dealing including tamper-proof, immutability, traceability, data integrity, confidentiality and privacy.

Several research studies have identified blockchain effectiveness for the healthcare ecosystem. The papers [1,8,10,11,16] reviewed existing works related to using blockchain technology in healthcare to bring security. However, none of these works has focused on the integration of blockchain technology to the Internet of Medical Things. In this context, we propose our paper that reviews existing


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works related to the integration of blockchain with the IoMT and discuss the technical details of each work.

The remainder of this paper is structured as follows. Section 2 presents a detailed technical analysis of existing articles dealing with the integration of blockchain with IoMT. Section 3 provides an in-depth discussion based on our study and presents research gaps, while Sect. 4 concludes the paper.

## 2 Internet of Medical Things (IoMT)-Blockchain Challenges

Certainly, blockchain technology is beneficial to the internet of medical things in terms of security. However, integrating both technologies is not trivial at all and is facing several challenges due to the conflicting requirements in these two technologies:

- **Processing:** Mining process and complex cryptography in blockchain are resource-hungry, demanding intensive computation and high energy consumption which cannot be afforded by resource-constrained IoMT devices that already suffer from resource shortage and energy limitations.
- **Storage:** IoMT devices generate huge amount of data with large flow. These data must be treated and stored in the blockchain to ensure their integrity which poses a significant challenge. In fact, blockchain technology relies on its nodes to provide a distributed storage which is not affordable by IoMT devices that have limited storage capabilities.
- **Mobility:** Blockchain was designed for a fixed network topology. However, implantable/wearable medical devices are in movement all the time which continuously change the topology.
- **Real Time:** IoMT applications are generally critical and require a real time and immediate response. Whereas, blocks creation is time consuming. In Bitcoin [15], 1MB per block is created every 10 min. Grouping these streams of data on blocks while respecting real time requirement is challenging.
- **Traffic Overhead:** Blockchain nodes communicate continuously to synchronize which creates significant overhead traffic. This is not affordable by bandwidth-limited IoT devices.

## 3 Blockchain-Based Approaches in IoMT

We present in this section, the most recent researches that have applied blockchain on IoMT. We classify these researches according to the most leading technique used to integrate blockchain into IoMT.

### 3.1 Ethereum-Based Contributions

In [12], a private Ethereum-based architecture is proposed to implement smart contracts in order to manage the users/devices requests and control access based on a set of attributes including the credentials, role and the domain. It uses IPFS for data storage. An interPlanetary File (IPFS) is used to store patient health records and devices technical information. The consensus mechanism is performed by a smart contract. The authors proposed a proof of medical stack (PoMS) as an alternative to PoS consensus model to protect smart contracts from malicious actions. PoMS allows stakeholders with huge amount of medical data presented as tokens to validate and create blocks.

A private blockchain-based system for medical data management has been proposed in [9]. It works on Ethereum smart contracts to manage data access permission between entities including patients, hospitals, doctors, research organizations and other stakeholders. The smart contract contains smart representations of medical records including permissions, record ownership metadata and data integrity. The medical record data are stored in external server (off-chain) and a cryptographic hash of the record is kept on the blockchain ensuring data integrity. The proposed system eliminates mining for simplification.

In [3], authors developed a cloud-based framework to monitor the progression of a neurological disorder disease using IoMT devices. They used cloud computing to store and process IoMT data and deploy Ethereum-based Blockchain network to securely exchange and share data between healthcare users. Smart contracts are employed to control users access to data in the cloud. No technical details about integrating blockchain in the system are presented.

In [6], authors proposed a permissioned blockchain-based architecture for secure remote patient monitoring. They used Ethereum to implement smart contracts in order to analyze data and send alerts to patient and healthcare providers. They proposed the use of Practical Byzantine Fault Tolerance (PBFT) as an alternative to PoW consensus model. The proposed architecture lacks techniques to meet challenges related to IoMT-Blockchain integration. And in SMEAD [13], an Ethereum-based architecture for remotely monitoring diabetes patients, smart contracts are used to manage access to data.

### 3.2 Modified Consensus Protocol

In order to fit the IoMT specificities, some works like [12] have proposed to modify the consensus protocol. In [20], authors proposed a consortium blockchain-based architecture in order to record data generated from IoMT in a secure way while ensuring the patient's privacy. The proposed architecture implements a patient agent software (PA) that defines the Blockchain functionalities. It is deployed on the Edge computing network to perform lightweight tasks and on a cloud server to provide tamper proof storage of the large volume of health data. The authors also proposed a modified PoS consensus which consists in choosing a leader for a group of nodes to validate and create the blocks. Smart contracts are used to manage health data including filtering clinically useless health data, generating alarm for some events, migrate data to the cloud if necessary, classify data and others. Compared to PoS, authors affirm that the modified PoS is more efficient in term of energy consumption and block generation time.

### 3.3 Modified Cryptographic Technique

The authors in [14] use some features of the standard version of blockchain to provide privacy and data integrity when sharing IoMT data. They use the hashing technique and propose a newly encryption algorithm to encrypt the transactions containing personal and sensitive data about patients. The main advantage of this algorithm is its ability to cover large number of uniquely identified medical objects and its very low time complexity which fits the real time requirement of IoMT. All transactions are stored in a blockchain maintained by the healthcare providers.

In [5], Authors proposed a customized blockchain-based framework suitable for IoMT devices. First, the proposed blockchain is private: nodes must be certificated to be able to join the network and send transactions. Second, authors eliminate the POW consensus protocol. To deal with the high volume generated by IoMT devices, they group encrypted data in blocks and store the interconnected blocks in the cloud. The hashes of blocks are kept on the blockchain to ensure tamper proof storage. For anonymity and the authenticity of the user, they use a 'A lightweight privacy-preserving ring signature scheme' which allows a group of nodes to participate in the data signature. To secure data and ensure its integrity during the transmission and storage, the authors used double encryption scheme besides the digital signature. The data are encrypted using lightweight ARX algorithms and the key is encrypted using the receiver's public key. To secure the transfer of public keys, authors proposed the Diffie-Hellmman key exchange technique. To meet scalability and network delay challenges, nodes are grouped in clusters. A cluster head is chosen to verify and store hash blocks, verify digital signatures and manage interactions between nodes in the cluster. The proposed work is not implemented and not evaluated.

In addition to their modified consensus protocol, authors in [20] proposed the ring signature as an alternative to the standard public key based digital signature to ensure patient privacy.

### 3.4 Hyperledger-Based Contributions

In [2], the authors proposed an IoT-blockchain based architecture to allow healthcare remote monitoring. The architecture contains two types of blockchain: (1) Medical Devices Blockchain to store medical data generated by medical devices during treatment period, (2) Consultation Blockchain maintained by hospitals to permanently store patients records. The transactions are verified and validated using smart contracts (Chaincodes in Fabric) executed by endorsing peers following Practical Byzantine Fault Tolerance algorithm. The authors developed a user interface to visualize the patient health data.

### 3.5 General Blockchain Concept Without Technical Specifications

In [7], the authors took benefit of tamper proof feature of blockchain to securely store and share IoMT data through patients and healthcare providers.

The patient data are stored as strings in blocks in the blockchain and the IoMT data are stored in blocks in off-chain database like IPFS. Smart contracts are used to ensure the privacy and security of blockchain.

MedChain [18] is a consortium blockchain-based framework proposed to meet challenges related to efficiently sharing data streams continuously generated from medical sensors. This includes handling time-series data streams, managing mutable and immutable medical data, and allowing an efficient storage and sharing of big and sensitive data. The MedChain network includes two separate decentralized sub-networks: (1) Blockchain network to store immutable data including users identity, data digest, session and operation, and (2) P2P network to store mutable data that facilitates data query including the description of data and session. MedChain uses the BFT-SMaRt as a consensus protocol

BIoMT [17] is an optimized, lightweight blockchain-based framework proposed to meet security and privacy challenges in developing solutions for IoMT systems. The proposed architecture is made up of four stratum: (1) Device layer consists of IoMT devices and implements the Elliptic Curve Cryptography (ECC) [9] key establishment protocol and the identity-based credential (IBC) mechanism to provide decentralized privacy, (2) Facility layer for managing IoMT devices and providing unique identity based on their attributes, (3) Cloud layer that runs anonymization algorithms to allow an identity-free data analysis and storage, and (4) Cluster layer groups several entities including medical facilities, service providers, and cloud servers into clusters. Each cluster has a cluster head that manages communication with other cluster heads to decrease the network overhead and delay. This work does not provide any technical details. It is not implemented and not evaluated. In [4] and [19], a blockchain-based architecture is proposed to allow secure transmission and storage of large amount of sensitive data generated by IoMT.

## 4 Discussion and Open Issues

Table 1 presents a classification of the existing contributions having integrated blockchain to IoMT (NM means Not Mentioned). Most of the proposed solutions are private blockchain-based and used Ethereum infrastructure thanks to its flexibility that is offered by the implementation of smart contracts for management purposes. Many issues have been treated when integrating blockchain with IoMT. For storing the big IoMT data, most of works [3] proposed an off-chain storage: Some researches [7,12] proposed to use IPFS because of its distributed data structure. Other works [3,5,9,17,20] used the cloud computing to store encrypted data while keeping hash references of that data in the blockchain. Such solutions do not guarantee immutability which is the essential feature of blockchain. In fact, if data have been modified/altered, this will be detected thanks to their hash stored in the blockchain but not recovered as it is only stored in the cloud (centralized storage). Other studies proposed an on-chain storage without precising technical details about dealing with the huge amount of data streams generated by IoMT devices. In the other hand, healthcare applications require real time responses which require a fast consensus protocol. However, IoMT are constrained devices and produce huge amount of data. The majority of studied works [9] have eliminated the consensus protocol to meet IoMT requirements. Some authors [12] use smart contract to self-verify and self-execute transactions. These smart contracts are protected using a lightweight consensus mechanism. Some others [6] proposed a lightweight consensus protocol: Researchers in [12,20] modified the PoS protocol to adapt it to the IoMT requirements, other works [5,20] grouped the nodes in clusters and chose a header for each cluster to manage transactions between nodes, validate and create the blocks. For security requirements in healthcare domain, some existing works proposed solutions to manage and control access rights. The majority [3,9,12,13] implement smart contracts to allow access to only authorized users based on some attributes of the IoMT ecosystem and their interaction with the users/stakeholders. Some other works [5,14,20] focused on maintaining patient privacy by proposing a lightweight privacy-preserving algorithms like ring signature scheme.

The literature review shows that there are some significant research gaps. There are several challenges that must be addressed to reach maturity and be efficient. These challenges include:

- **Lack of standards:** The proposed solutions are proprietary. They do not define standard protocols to adapt heterogeneous technologies and promote interoperability which prevent the adoption of such solutions. It is crucial to provide universal and platform-agnostic solutions that govern the interaction between IoMT devices, blockchain, cloud computing and end-users.
- **Programming Abstractions:** The integration of blockchain technology into the IoMT opens the way to many relevant applications in the health field. However, the adoption of such technology (Blockchain-IoMT) is complex and requires in-depth interdisciplinary knowledge from low-level including the management of IoMT devices and configuring blockchain to meet IoMT requirements, to high-level knowledge including sharing, storing and treating IoMT data. In this context, it is crucial to conceive an abstraction layer hiding all these complexities and to provide developers with new application programming interfaces (APIs) and middleware allowing them to easily implement decentralized and secure applications for healthcare using IoMT.
- **Limited Application Scope:** The majority of existing works are only focusing on healthcare applications related to remote patient monitoring and IoMT data management including data sharing and storage. It is crucial to conceive tracking applications that prevent counterfeit drugs and medical errors. In this context, the use of blockchain technology accompanied by the IoMT can be an effective solution to control the activity of doctors as well as for the management of the drug supply chain.
- **Lack of Technical Details:** The integration of blockchain with the IoMT is challenging. Most of existing solutions did not reveal any technical details. There is a need that researchers demystify all the technical details of the blockchain integration into IoMT.

**Table 1.** Classification of researches applying blockchain in IoMT

| Contribution | Framework | Type | Consensus | Storage | Digital signature | Smart contract | Use case |
|---|---|---|---|---|---|---|---|
| [20] | NM | Consortium | Cluster head verifies and adds blocks | Off-chain (cloud) | Ring signature | Analyze and manage data | Manage IoMT data |
| [14] | NM | Private | NM | On-chain (hospitals) | NM | NM | Privacy and data integrity preservation |
| [9] | Ethereum | Private | NM | Off-chain (external server) | NM | Smart representations of medical records | Manage IoMT data |
| [7] | Ethereum | Public | NM | Off-chain (IPFS) | NM | Manage interactions between patients and their data and doctors | Manage IoMT data |
| [12] | Ethereum | Private | Proof of medical stake | Off-chain (IPFS) | NM | Manage access control | Manage access control to IoMT data and devices |
| [2] | Hyperledger Fabric | Private | NM | On-chain (hospitals and medical devices) | NM | Verifying and validating transactions | Healthcare remote monitoring |
| [18] | NM | Consortium | BFT-SMaRt | On-chain | NM | NM | Manage IoMT data |
| [5] | NM | Private | Cluster head verifies and adds blocks | Off-chain (cloud) | Lightweight ring signature | Analyze IoMt data and control patient health | Remote patient monitoring |
| [17] | NM | Private | NM | Off-chain(cloud) | NM | NM | Manage IoMT data and devices |
| [3] | Ethereum | Private | NM | Off-chain(cloud) | NM | Manage access control | Monitor the progression of a neurological disorder |
| [4] | NM | Private | PoW | NM | NM | NM | Manage IoMT data |
| [6] | Ethereum | Private | PBFT | On-chain | NM | Analyze data and send alerts to patients and healthcare providers | Remote patient monitoring |
| [19] | NM | NM | NM | Hybrid | NM | NM | Manage IoMT data |
| [13] | Ethereum | NM | NM | NM | NM | Manage access control | Remote monitoring of diabetes patients |

## 5 Conclusion

With the strict and severe requirements of security in the healthcare domain, several researches focused on adopting Blockchain in the Internet of Medical Things (IoMT). Majority of them were focusing on providing privacy, data integrity, confidentiality and authentication. They proposed different use cases including remote monitoring of patients (RMP) and medical data management. Our research review shows that the proposed solutions lack many technical details when integrating Blockchain in the IoMT. Majority of them did not deal with high volume of data streams generated by resource-constrained IoMT devices and did not propose technical modifications on the Blockchain architecture in order to feet these challenges.

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# Application of Blockchain Technology in Healthcare: A Comprehensive Study

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**Abstract.** Blockchain technology has been emerged in the last decade and has gained a lot of interests from several sectors such as finance, government, energy, health, etc. This paper gives a broad ranging survey of the application of blockchain in healthcare domain. In fact, the ongoing research in this area is evolving rapidly. Therefore, we have identified several use cases in the state of art applying the blockchain technology, for instance for sharing electronic medical records, for remote patient monitoring, for drug supply chain, etc. We have focused also on identifying limitations of studied approaches and finally we have discussed some open research issues and the areas of future research.

**Keywords:** Blockchain · Healthcare · Review

## 1 Introduction

In the last decade, blockchain is emerging as one of the most promising technology that captures attentions of several academic researches and industry. This concept was originally introduced by Satoshi Nakamoto in a white paper in 2008 [19]. It is defined as a decentralized, distributed, immutable ledger which is used to securely record transactions across many computers in a peer-to-peer network, without the need of third party.

The first generation of blockchain, Blockchain 1.0, is underlying on Bitcoin [19] which is the first implementation of blockchain based on cryptocurrency applications[1]. The next generation, called Block chain 2.0, is emerged with the concept of smart contract that it is considered as a piece of code defined, executed and recorded in the distributed ledger. The third generation of blockchain technology, Blockchain 3.0, deals essentially with non financial applications such as government, energy, health, etc. In fact, several organisations have adopted this technology and applied it for several use cases in the healthcare domain. The most interesting features in blockchain that are beneficial to healthcare

[1] Other blockchain 1.0 technologies have been appeared such as Dash, Litecoin, etc.


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applications is decentralization, privacy and security since blockchain technology may ensure for example a secure access to medical data for patients and various stakeholders (insurance companies, hospitals, doctors, etc.).

In this survey, we present the most relevant researches applying blockchain in healthcare sector. The studied approaches are classified according to a wide range of use cases such as electronic medical records [2,6–8,16,22,25], remote patient monitoring [11,14,21], pharmaceutical supply chain [4,5,12,15,20] and health insurance claims [10,26]. Additionally, this study discusses the applicability of these solutions and their technical limitations. Moreover, lessons learnt and some research directions are identified.

The remainder of this paper is organized as follows. Section 2 introduces the key concepts to understand blockchain technology. In Sect. 3, we provide some medical uses cases in healthcare that use this promising technology. At the end of this section, we will sum up the main results. In Sect. 4, research challenges and opportunities are highlighted. Finally, Sect. 5 concludes the paper and gives suggestions for future work.

## 2 Key Concepts on Blockchain

In this section, we discuss the core features of blockchain technology to help understanding the rest of this paper.

### 2.1 Overview and Architecture of Blockchain

Essentially, blockchain is a peer-to-peer network that sits on top of the internet [13], which was introduced in 2008 as part of a proposal for Bitcoin [19]. The blockchain is a public ledger made up of a sequence of blocks, which holds a full history of transaction records that occurred within the network. A block is consisted essentially by a header and a body. The header of each block contains the hash of the previous block. Therefore, the blocks form a chain or a linked list where each block structure is based on the previous one.

Block headers also contain a *timestamp* indicating the time of when the block was published, *a nonce*, which is an arbitrary number that miners would change frequently to get a certain hash value to solve a mathematical puzzle and a *Merkle tree* that fundamentally decreases the exertion required to check transactions inside a block.

A Blockchain transaction can be defined as a small unit of task that is stored in public blocks. Each transaction is verified by consensus of a majority of the system participants. This way, tamperproof is ensured once transactions are packed into the blockchain. In regards to blockchain immutability, a same copy of the ledger is replicated, hosted and maintained by all participants [13].

Regardless of the type of blockchain, the business logic is encoded using smart contracts, a self-executing code on the blockchain framework that allow for straight-through processing. When embedded in the blockchain, smart contracts becomes permanently *tamper-proof*, as no one can change what's been programmed, *self-verifying* due to automated possibilities and *self-enforcing* when the rules are met at all stages.

Among the important features of Blockchain, decentralization by making the ledger accessible by all participants, immutability, so blockchain is nearly impossible to tamper and is censorship-resistant, availability by providing all peers a copy of the blockchain to get access all timestamped transaction records, and anonymity, where each user can interact with the blockchain with a generated address, that does not reveal the real identity of the user.

### 2.2 Taxonomy of Blockchain Systems

Current blockchain systems are categorized into four types: public, private, consortium and hybrid blockchains [21].

- **Public Blockchains**: Public blockchains provide a fully decentralized network, where every member can access the blockchain content and could take part in the consensus process (e.g. Bitcoin and Ethereum [23]).
- **Private Blockchains**: Private blockchains are dedicated for single enterprise solutions and utilized to keep track of data exchanges occurring between different departments or individuals. Every participant need consent to join the network and considered as a known member once it has been adhered.
- **Consortium Blockchains**: A consortium blockchain is a permissioned network and public only to a privileged group. It is used as an auditable and reliably synchronized distributed database that keeps track of participant's data exchanges.
- **Hybrid Blockchains**: Hybrid blockchains combine the benefits of private and public blockchains. Therefore, a public blockchain is employed to make the ledger fully accessible, with a private blockchain running in the background that can control access to the modifications in the ledger.

## 3 Blockchain Use Cases in Healthcare

One of the fields where blockchain is considered to have great potential is healthcare. Understanding the pertinence and importance of blockchain in healthcare, in 2016, the Office of the National Coordinator for Health Information Technology (ONC), composed an ideation challenge for requesting white papers on the potential utilization of blockchain in healthcare. This challenge brought about a few proposed healthcare applications for blockchain.

In this section, we focus on the most important studies classified by several use cases such as electronic medical records, remote patient monitoring, pharmaceutical supply chain and health insurance claims.

### 3.1 Electronic Medical Records

To transform healthcare, the focus should be attributed to the management of health data that could be improved from the potential to connect heterogeneous systems and increase Electronic Health Records (EHRs) accuracy. While Electronic medical records (EMRs) and EHRs are used interchangeably, there is a difference between the two terms. EMRs term came along first, which is a digital version of the paper charts in the clinician's office. An EMR contains the medical and treatment history of the patients in one practice. However, EHRs focus on the total health of the patient-going beyond standard clinical data collected in the provider's office and inclusive of a broader view on a patient's care [1].

From the mapping study, blockchain technology supports the management of EHRs. In this context, Ekblaw et al. present [7] MedRec, an EHR-related implementation that proposes a decentralized approach to manage authorization, permissions, and data sharing between healthcare stakeholders. MedRec uses ethereum platform to enable patients to have knowledge and information on who can get to their healthcare information.

A second application that integrates EHR, is FHIRChain (Fast Health Interoperability Records + Blockchain) [25]. It's a blockchain-based application implemented using ethereum for sharing clinical data that focuses on healthcare record management. FHIRChain provides solutions for patients that meet the requirements from the ONC.

Similarly, Xia et al. present Medshare [24] an ethereum application for systems that struggle with a lack of collaboration for sharing data between cloud services due to the adverse risks towards displaying the contents of private data. Medshare provides data provenance, auditing, and control between big data entities for sharing medical data in cloud repositories.

Other blockchain-based EMR applications include MedBlock [8] and BlockHIE [16]. MedBlock [8] provides a mechanism for a record search. The proposed system maintains the address of blocks containing the records of a patient, grouped by a healthcare provider or department. Each patient inventory contains a reference to the corresponding record on the blockchain. BlocHIE [16] proposed by Jiang et al. where they present a healthcare platform based on blockchain technology.

To keep exploiting existing databases, BlocHIE combines both off-chain storage, where data is stored in external hospitals' databases, and on-chain verification. The blockchain system stores a hashed value of external records. Authors improve fairness and throughput by proposing FAIR-FIRST and TP&FAIR, two fairness-based transaction packing algorithms. There is also another healthcare blockchain-based framework, Ancile [6] which uses ethereum smart contracts to achieve data privacy, security, access control and interoperability of EMRs.

Roehrs et al. [22] present omniPHR, a distributed model that maintain an interoperable single-view of Personal Health Records (PHR). The proposed solution is based on an elastic, interoperable and scalable architecture of PHR data. Furthermore, omniPHR evaluation could ensure the division of PHR into data blocks and its distribution in a routing overlay network.

### 3.2 Remote Patient Monitoring

To be able to remotely monitor the status of the patient, remote patient monitoring covers the collection of medical data through mobile devices, body area sensors and IoT (Internet of Things) devices. Blockchain play an important role in storing, sharing and retrieving the remotely collected biomedical data.

In this context, Ichikawa et al. [14] present an application where mobile devices are used to transmit data to a blockchain-based application on Hyperledger Fabric.

Griggs et al. [11] demonstrate how Ethereum smart contracts provides automated interventions in a secure environment by supporting real-time patient monitoring application. Other proposed approaches present the great potentials of Internet of Things (IoT) in many domains, especially it's being heavily exploited and used in e-health. In this direction, Ray et al. propose IoBHealth [21], a data-flow architecture that combines the IoT with blockchain and can be used for accessing, storing and managing of e-health data.

### 3.3 Pharmaceutical Supply Chain

One other identified use case of blockchain is in the pharmaceutical industry. The delivery of counterfeit or inadequate medications can have critical consequences for the patients. Blockchain technology has been identified as having the capability to address this problem.

Bocek et al. [4] present Modum.io AG, a startup that uses blockchain to achieve data immutability. To verify the compliance to quality control temperature requirements, this startup creates public accessibility of the temperature records of pharmaceutical products during their transportation.

Counterfeit drugs also have been addressed by [5,12,20] where authors prevent counterfeiting by proposing a secure, immutable and traceable pharmaceutical supply chain based on blockchain technology.

With regards to drug regulations issues, Jamil et al. [15] addressed drugs standardization problems. Authors have highlighted the difficulties to detect falsified drugs and proposed a blockchain-based solution to detect counterfeits.

While there is a minority of papers that present an implementation of the proposed system, some interesting reviews discuss pharmaceutical supply chain issues [9,17].

### 3.4 Health Insurance Claims

Health Insurance claims are one of healthcare fields that can benefit from blockchain's immutability, transparency and auditability of data stored on it.

While Healthcare insurance claim processing is an important area where blockchain has potentials [10]. However, prototypes implementations of such systems are very limited. We can find MIStore [26], a blockchain-based medical insurance system that provides medical insurance industry with encrypted and immutably stored medical insurance data.

**Table 1.** Major contributions classified by use cases

| Use cases | Paper | Framework | Data Storage | Contribution | Year |
|---|---|---|---|---|---|
| Electronic medical records | [7] | Ethereum | Off-chain | Provides a patient-centric system for a transparent and accessible view of medical history | 2016 |
| | [24] | Ethereum | Off-chain | Propose a platform for shared medical data in cloud repositories | 2017 |
| | [22] | Specific | Off-chain | A PHR distributed model that propose solutions for latency issues | 2017 |
| | [25] | Ethereum | Hybrid | Proposes a blockchain-based EMR application that meets ONC requirements | 2018 |
| | [8] | Proprietary | Off-chain | Provides a blockchain-based EMR management system | 2018 |
| | [16] | Proprietary | Off-chain | A healthcare system that Combines both off-chain storage and on-chain verification | 2018 |
| | [6] | Ethereum | Hybrid | Proposes an electronic health records system that protects personal health information | 2018 |
| Remote patient monitoring | [14] | Hyperledger Fabric | Off-chain | A mobile Health blockchain-based system for cognitive behavioral therapy for insomnia | 2017 |
| | [11] | Ethereum | Hybrid | Proposes to use blockchain-based smart contracts to perform real-time data analysis | 2018 |
| | [21] | – | – | Propose an architecture that integrates blockchain and IoT sensory data collected from patients | 2020 |
| Pharmaceutical supply chain | [4] | Ethereum | Off-chain | Maintains public temperature records' accessibility of drugs during their transportation | 2017 |
| | [12] | – | – | Explaines blockchain usability to add traceability and visibility to drugs supply | 2018 |
| | [5] | Hyperledger Fabric | On-chain | Design a blockchain-based control system for the control of drugs turnover | 2019 |
| | [20] | Hyperledger Fabric | On-chain | Design a secure, immutable and traceable pharma supply chain | 2019 |
| Health insurance claims | [26] | Ethereum | On-chain | Proposes a blockchain-based medical insurance storage system | 2018 |

We present a summary of the studied papers in Table 1. We have noticed that the majority of these applications are developed on popular blockchain frameworks, such as Ethereum and Hyperledger Fabric.

## 4 Research Challenges and Opportunities

Based on the proposed prototypes and developed applications, we can identify different limitations of the healthcare Blockchain-Based applications.

First, EMR systems do not address semantic interoperability [3]. Consequently, manual inspection and mapping of predefined ontologies from medical and health data experts are required. Second, clinical malpractice cannot be controlled at this level. Moreover, scalability and interoperability issues represent the main focus of current and future studies in this field. Interoperability challenge reveals the fact of missing standards for developing healthcare applications based on blockchain technology. Thus, the different developed applications may not be able to interoperate. In addition, scalability is a major issue in blockchain-based healthcare systems [18] especially towards the volume of medical data involved. Due to high-volume healthcare data, it is not practicable to store it on-chain i.e. on blockchain, as this is may lead to serious performance degradation. Furthermore, there is a problem of latency caused by the speed of transactions' processing and off-chain data load in a blockchain-based system. Finally, another weakness is related to blockchain immutability and self-execution of code, since smart contracts could become vulnerable to hackers. Just between 2016 and 2018, attacks such as the decentralized autonomous organization (DAO) attack cause a loss of millions of dollars as part of the assets held by the smart contracts.

## 5 Conclusion

The present study gave an overview about the application of Blockchain in Healthcare. In fact, due to the exponential growth of this technology, blockchain has been applied in several use cases with the aim of enhancing the automation of medical services.

Our study shows that the majority of researches applying blockchain in healthcare are concentrated towards sharing Electronic Health Records. Other investigations should be considered by blockchain researchers in domains such as biomedical research, pharmaceutical supply chain, insurance. Furthermore, we noticed that rarely are papers dealing with implementation details.

Even though, blockchain technology offers promising features, there is still a need for more research to better understand, efficiently and securely develop and evaluate this technology. Ongoing efforts have been conducted to overcome limitations in scalability, security and privacy in order to improve stakeholders' confidence in using this technology and to increase its adoption in healthcare.

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# Trust Execution Environment and Multi-party Computation for Blockchain e-Health Systems

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**Abstract.** Blockchain is a rich and attractive domain for researchers since it is independent of "third party" such as Bank or government. This "open" phenomenon does not respect all the security criteria such as private data protection and confidentiality; hence, we cannot trust this approach despite its contributions. Blockchain technology has gained considerable progress in recent years in fields such as e-health. The medical data contains personal and sensitive information that must be preserved. The current Blockchain systems suffer from serious practical limitations, e.g. poor performance, high-energy consumption and lack of confidentiality. On the other hand, *Trust Execution Environment* TEE is imperfect; it is based on the centralization of data. To avoid data centralization and its limitations, an approach based on collecting the necessary data from distributed database is presented in this paper. Our goals are to protect the user's privacy and to execute it in TEE combined with *Multi-party computation* MPC. We proof by security analysis that our new solution meets the fundamental criteria of security such as confidentiality and privacy.

**Keywords:** E-health · MPC (Multi-party computation) · BC (Blockchain) · TEE (Trust Execution Environment) and Smart Contract (SC) · IPFS (Interplanetary File System)

## 1 Introduction

Technological evolution is bringing a profound change to the core of business. Nowadays IT(Information Technology) is not only a productivity tool but also a means of administration and management. It is becoming a strategic and a necessary mean to manage the evolutionary processes of the company's business lines. Therefore, the field of information and communication technologies has become one of the pillars of business.

The information system is an essential element for the company; hence, its innovation must be almost permanent and exploits to the best the new technologies. New network technologies open up new potential for communication and data exchange in different geographical areas. This context has motivated the IT community to take an interest in distributed architectures such as the Blockchain.

Modern systems like Blockchain have become increasingly complex, open, connected and are leading to new challenges. User requirements for security are increasingly demanding. The Blockchain has affected several sectors such as finance, health care, public services, electronic voting, music and the government sector. The reason


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for this enhanced interest is the disappearance of the trusted medium, to operate in a decentralized manner with an acceptable degree of confidence.

The IT community hails the Blockchain as the next great technological innovation. According to Marc Andreessen, co-founder of Netscape and co-writer of Mosaic the Blockchain: "When we sit here in 20 years, we will talk about [Bitcoin and Blockchain technology] the way we talk about the internet today" [1].

## 1.1 Blockchain

The Blockchain is a new technology for storing and transmitting data in a secure and transparent way, it works without a central control body. This technology takes the form of a transaction log in a peer-to-peer P2P network. These transactions grouped together in the form of blocks, which are linked together. Each block contains data, the hash of the previous block, and a time stamp. Figure 1 represents an example of Blockchain structure.

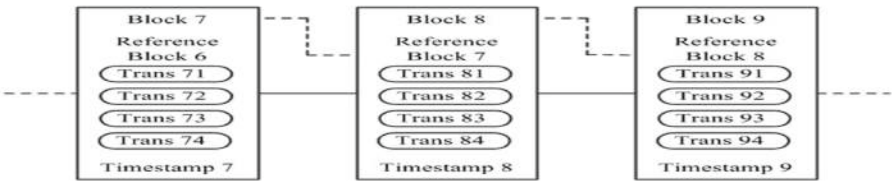


**Fig. 1.** Blockchain structure [17]

All network nodes back up and verify the data stored in the Blockchain, and consequently provides a strong resilience against attacks that can tamper the integrity of the data.

As this great feature leads to a Blockchain-based implementation of smart contract platforms such as Ethereum [2], several developers have been attracted to build decentralized applications using smart contracts that avoid the need for a central server to manage and maintain the data [3].

The first cryptocurrency based on a Blockchain was Bitcoin in 2008 [7], however the Blockchain has evolved to meet and serve a variety of purposes. The difference between a traditional database and the Blockchain is essentially the storage policy. The Blockchain resides on computer networks However, databases are stored on centralized servers (see Fig. 2). Each one of them has its own advantages and limitations.


**Fig. 2.** Traditional DATABASE VS Blockchain

### 1.2 Smart Contract

Szabo first introduced the term *smart contract* in 1994, where the smart contract is defined as "a computerized transaction protocol that executes the terms of a contract" [4].

Smart contracts are compiled as byte codes and executed in EVM (Ethereum Virtual Machine) located in miners' computers, which is very similar to Java executed in JVM. When the smart contract operates, it must be packaged by the miner and written into the Blockchain. Each Blockchain in Ethereum has various functions and purposes [5]. Compared with traditional contract, a smart contract is an executable code stored and running in Blockchain. The smart contract may execute independently and automatically without third parties, and these running results are irreversible on Blockchain and are traceable by each participant. The main features of smart contract are given as follows [6]: stability and deterministic features, the same input always produces the same output. Because smart contracts are executable codes stored in Blockchain, every network participant can inspect them. Meanwhile, all the interactions with a smart contract occur via signed messages on the Blockchain and thus every participant can verify and trace the contract's operations.

The structure of this paper is as follows. Section 2 presents a state of the art by analyzing the current situation and motivation. Section 3 describes the steps of the new solution and an e-health use-case. We present the security analysis of the proposed solution in Sect. 4. Conclusion is drawn in Sect. 5.

## 2 State of the Art

We have conducted an intensive research to get the state of the art of Blockchain and smart contracts applications. In the following, we present the existing solutions based on the technologies chosen by researchers.

### 2.1 Centralized Database

The researchers in [8] propose a solution for digitizing certificates, in university use case, in order to improve the conditions and make life much easier using the Blockchain and intelligent contracts. Therefore, it will be possible to have a certificate, wherever the student is and whatever the time, with full security since the access to the data will be done only when people are authorized.

It is true that this solution has contributions in terms of time and speed. However, in our opinion, it does not ensure total security since it puts in danger the private data when they are published in the Blockchain. In addition, the weak point of the solution is the centralization since the data are recorded in the database of the university and if it is broken down, nothing can be done.

### 2.2 PKI Public Key Infrastructure

Existing certificate mechanisms do not dynamically ensure the trustworthiness of a certificate, to solve this weakness Ahmed et al. [9] offer the "smart contract assisted

PKI". This solution manages trust dynamically in a distributed way and provides better trust experience for users. Despite its contribution, this solution neglects the protection of private data.

## 2.3 TEE Trust Execution Environment

TEE (Trust Execution Environment) [16] is a tamper-proof trusted execution processing environment. It runs on a separate kernel and it can be safely updated.

TEE resists all software and physical attacks. It represents a space for storage execution and secure execution.

In this context, Hawk [10], which is the first TEE, is a smart contract system that provides confidentiality by executing contracts off-chain and posting only zero-knowledge proofs on-chain. The zero-knowledge proofs in Hawk incurs very high computational overhead. Additionally, it was designed for a single compute node called the "manager" which must be trusted for privacy.

There are also some technical inefficiencies such as limited block size and transfer cost. In addition, once the data is stored in the Blockchain, it cannot be modified. This poses certain problems such as falsification during the execution of the contract. In some cases, the contract needs data in real time. The most relevant solution is to store the data off-chain and choose another execution platform more secure and more relevant.

To ensure confidentiality and private data protection, Rifi et al. [11] offer a solution that combines two technologies: *Trust Execution Environment* TEE and Blockchain, from where data is stored and executed in TEE. It is a platform that ensures data integrity; confidentiality and protection, but it is based on the centralization of data storage. In [11], authors concluded that in order to apply Blockchain technology to E-Health, it should be public, and has three main keys: scalability, secure access to medical data, and data privacy. In this article, the researchers prove that the Blockchain does not have good performances in terms of storage. Therefore, they proposed to store the data off-chain using the IPFS (*Interplanetary File System)*. The new Blockchain technology [15] applied in e-Health identifies new ways to share the distributed view of health data and promotes the advancement of precision medicine, improving health and preventing diseases.

## 2.4 IPFS

IPFS [12] (*Interplanetary File system)* is a decentralized file sharing platform. It identifies files by their contents. To retrieve file locations and connectivity information from the nodes, this system uses Distributed Hash Table (DHT).

As described in [13], the DHT is primarily a distributed key value store. It uses node identifiers and keys. They must have the same length and a distance metric to easily store and retrieve the information. A node tries to find the nodes in its vicinity, when searching a value and a key. To do this; it uses buckets to keep track of the nodes in the network. The spaces are organized so that each node in the network has precise information about its immediate environment.

Blockchain and IPFS [14] are based on similar concepts of decentralized networks. However, each one of them has its own characteristics. IPFS is a file-sharing system that chops its files. The search for files within IPFS is based on these hashes. Blockchain and IPFS perform very different tasks for their users. It is possible to store files in IPFS while the hashes are stored in Blockchain.

As discussed before, the TTE has many advantages but it is not based on multi-party computation. Therefore, to eliminate the centralization of data, we try to link between IPFS, TEE and the Blockchain to have efficient results that respect the security rules.

The use of TEE allows the user to store his/her data in TEE and to execute his/her smart contract. To access to the latter, the user must enter his/her public hash key; TEE compares it with the list of public hash keys; if it is compatible with a public hash key, he/she can access to it. The Blockchain is used to transfer smart contract from user to TEE (see Fig. 3 Smart contract with TEE). To import data from IPFS, the user should put the IPFS Hashes and a time stamp in the smart contract (see Fig. 3 Smart contract with IPFS). As a conclusion, executing smart contract in Blockchain suffers from many problems such as poor performance, high-energy consumption.


**Fig. 3.** Smart contract with TEE VS Smart contract with IPFS

## 3 The Proposed Solution

With the technical progress, many technologies are developing, a huge amount of exchanged data will appear, and the exchange of data is carried out from different locations and different sources. In order to ensure all these criteria, we must have a solution that provides: Confidentiality, Authenticity, Integrity, Decentralization and privacy in two phases: Data Storage and Smart contract' execution.

### 3.1 Architecture and Security Parameters

Figure 4 presents the architecture of the new solution which is composed by two phases:

a) Data Storage

In this phase, the user stores his\her encrypted data in different places. To access to it, we need to process some cryptographic steps.

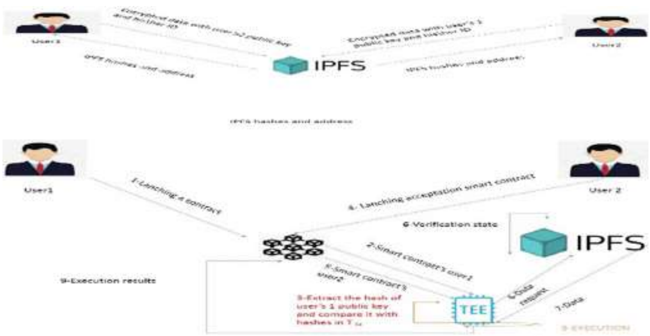


**Fig. 4.** Proposed architecture

b) Smart contract's execution

Before this operation, we need to transfer the smart contract using Blockchain. After that, the TEE "imposes" some protocols to access to it. Also, TEE controls missing data and imports them from DDB (Distributed Data Base) The approach proposed in Article [18] can be used to collect data either from IPFS or from users. After that, it executes the smart contract and returns the result to the Blockchain.

Table 1 contains all the security parameters of the communicating parties in e-health scenario.

**Table 1.** Security parameters

| Parameters | Description |
|---|---|
| $H_{IPFS}$ | Hashes IPFS |
| $H_{Kpub}$ | Hashes public key |
| $K_{pub}$ | Public key |
| $K_{priv}$ | Private key |
| $@_{IPFS}$ | IPFS address |
| $T_{ht}$ | Hashes table in TEE |
| $L_{DD}$ | List of demanded data |
| $EN_{Kpub}$ | Encrypt with public key |

## 3.2 Steps of the New Solution

Next, we describe, step by step, the exchanges in the new solution:

a) *User's subscription (Data Storage)*

A user accesses an IPFS and stores his/her encrypted message with homomorphic cryptography. The encryption ensures data security since only authorized persons have the right to access encrypted data. IPFS sends to the user its $@_{IPFS}$ and $H_{IPFS}$.

1 - User 1 sends his\her Id and $EN_{Kpubuser2}$(Data) to the IPFS.
2 - IPFS sends $@_{IPFS}$ and $H_{IPFS}$ to User2
3 - User 2 sends his\her Id and $EN_{Kpubuser1}$(Data) to the IPFS.
4 - IPFS sends $@_{IPFS}$ and $H_{IPFS}$ to User1

b) *Smart contract execution*
   1 - User 1 signs his\her smart contract with his/her private key $K_{priv}$ (this smart contract demands $@_{IPFS}$ and $H_{IPFS}$ from the acceptation smart contract) and sends it to the Blockchain.
   2 - The Blockchain sends the signed Smart Contract to the TEE
   3 - TEE extracts the hash $H_{kpub}$ and compares it with the hashes in $T_{ht}$
   4 - User 2 signs his\her contract that contains his\her $@_{IPFS}$ and $H_{IPFS}$ with his \her $K_{priv}$ and sends it to the Blockchain.
   5 - The Blockchain sends the signed Smart contract to the TEE. The latter extracts the $H_{Kpub}$ of User 2 and compares it with the hashes in $T_{h.}$ After that, it builds a file that contain missing data.
   6 - TEE sends the file that contains the $L_{DD}$ (List of demanded data), $@_{IPFS}$, $H_{IPFS}$ and timestamp (from acceptation smart contract) to IPFS
   7 - IPFS verifies the TEE request that contains $@_{IPFS}$, $H_{IPFS}$, $L_{DD}$ and timestamp after that it sends missing data to the TEE.
   8 - TEE executes the smart contract
   9 - TEE sends the executed results to the Blockchain.

### 3.3 E-Health Use Case

We present in the following the steps of our solution when applied to e-health scenario. In this use case, we have two actors, the doctor and the patient. Figure 5 shows the steps of this use case.

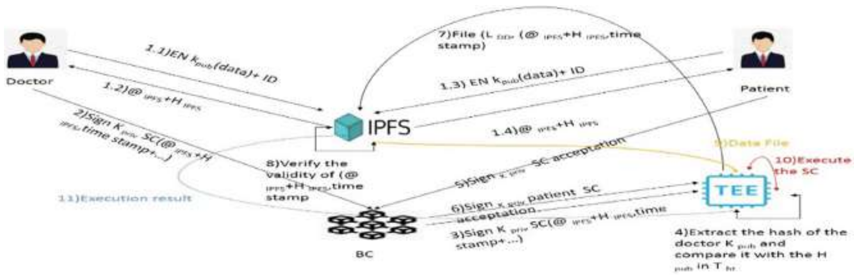


**Fig. 5.** All the exchanges in e-health scenario

1.1, 1.2, 1.3 and 1.4: Both doctor and patient send $EN_{Kpub}$ (data) + ID and receive $@_{IPFS}$ + $H_{IPFS}$

2 - The doctor sends his/her ID and signed smart contract to the Blockchain.
3 - The Blockchain sends this smart contract to TEE

4 - The TEE receives the smart contract, after it verifies the state of the doctor. Then, it extracts the public key of the doctor and calculates its hash and compares it with the hashes in $T_{ht}$
5 - The patient signs smart contract acceptation with his\her private key and sends it to the TEE using Blockchain.
6 - The Blockchain sends the signed SC patient with $K_{priv}$ to the TEE.
7 - TEE creates a file that contains a list of demanded data with IPFS hashes, $_{@IPFS}$ and the time stamp and send it to the IPFS.
8 - IPFS verifies the validity of ($@_{IPFS}$ + $H_{IPFS}$, time stamp).
9 and 10 - TEE executes the SC and returns the execution result to the Blockchain.

## 4 Security Analysis

Table 2 presents a comparison between three previous solutions and our proposed solution. We observe that the others solution does not respect all the criteria of security.

When using this approach, the 5 key criteria of security are guaranteed or maintained. in short, user data can only be modified, accessed or deleted by authorized persons (integrity; privacy and integrity).

The IPFS contains the data in a homomorphic way (decentralization) and the execution in TEE will be based on the encrypted data, without forgetting that the TEE and IPFS platforms only allow access to authorized persons.

**Table 2.** Comparison approaches

| Articles | Confidentiality | Privacy | Authenticity | Integrity | Decentralization |
|---|---|---|---|---|---|
| Hawk [10] | + | + | + | + | − |
| BC and SC for digital certificate [8] | + | − | + | + | + |
| Towards using BC technology for e-Health data access management [11] | + | − | + | + | + |
| Our solution | + | + | + | + | + |

## 5 Conclusion

The Blockchain technology has reached a great boom in many sectors such as e-health, e-commerce; e-vote… The main important Blockchain [11] characteristics are: Transparency, no need for third parties and instant access to data since it is replicated on all nodes. To create a secure smart contract based on Blockchain, a new solution is presented which combines three technologies: Blockchain, TEE, and IPFS in order to take advantage of their benefits. This approach is based on collecting the necessary data from distributed database while protecting the user's privacy and executing it in TEE.

This approach meets the various security criteria such as confidentiality, authentication, integrity, decentralization and protection of private data. this approach can be applied in different domains such as e-health to show the strong points of this one in the e-health domain it is necessary to link it with the Internet of Things domain [19].

As future work, we need to implement the new solution in order to study its feasibility and measure its performance.

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# A Fuzzy-Ontology Based Diabetes Monitoring System Using Internet of Things

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**Abstract.** The majority of the Internet-of-things (IoT)-based health monitoring systems adopt ontologies to represent and interoperate the huge quantity of data collected. Classical ontologies cannot appropriately treat imprecise and ambiguous knowledge. The integration of Fuzzy logic theory with ontology can effectively resolve knowledge problems with uncertainty. It considerably raises the accuracy and the precision of healthcare decisions. This paper presents a fuzzy-ontology based system using the internet of things and aims to ensure continues monitoring of diabetic patients. It mainly describes the ontology-based model and the semantic fuzzy decision-making mechanism. The system is evaluated using semantic querying. The results indicate its feasibility for effective remote continuous monitoring for diabetes.

**Keywords:** Fuzzy · Ontology · Internet of thing · Healthcare · Diabetes

## 1 Introduction

The increasing number of diabetic patients place a severe burden on healthcare systems and makes their monitoring a very difficult task. According to [17], the total number of diabetic patients is expected to rise from 171 million in 2000 to 366 million in 2030. Diabetes is a group of metabolic disorders of carbohydrate metabolism characterized by the variation of blood glucose level that results from insufficient production of the hormone insulin (type 1 diabetes) or an ineffective response of cells to insulin (type 2 diabetes). It requires remote continuous monitoring to prevent emergencies and long-term complications such as cardiovascular diseases. Therefore, its treatment should focus mainly on controlling and managing blood glucose levels constantly with diet, physical exercises, and medications. New healthcare systems based on IoT offer a new effective perspective in diabetes management based on the IoT data collected. They are enable to sufficiently handle imprecise and vague information related to patient and therefore fail in describing his health condition and to recommend the appropriate drug


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and food, because they adopt conventional approaches such as classical ontology and fuzzy logic. The combination of ontologies and fuzzy-logic approaches can effectively resolve the problem of uncertainty of data related to diabetic patients and thus ameliorate the accuracy of system when performing decisions related to the current health condition and recommendations. This paper introduces a fuzzy-ontology-based healthcare system integrating IoT technologies. The system provides certain and precise diabetes-related decisions that allow patients to maintain a lifestyle in which the diet is coordinated with exercise and activities. The remainder of this paper is organized as follows. Section 2 presents related works. Section 3 then describes the architecture of the proposed system and the knowledge construction mechanism. Next, Sect. 4 introduces the fuzzy-ontology generating model. Section 5 describes the semantic fuzzy decision-making process for diabetes system and summarizes the evaluation results. Conclusions and perspectives are finally drawn in Sect. 6.

## 2 Related Works

The increasing number of chronically ill aged people worldwide has drawn the attention of a diverse array of fields including Internet of Things (IoT) and Artificial Intelligence (IA), explaining why IoT based healthcare systems using ontology and fuzzy-logic have been adopted for continues real-time monitoring. For instance, Mumtaj et al. [10] proposed an IoT-based system combining ANN and fuzzy logic and aims to ensure the monitoring of elderly and supports caregivers to diagnose diseases by sending alerts in case of any abnormalities. Huang et al. [6] introduced predictive symptom checker system based fuzzy logic that helps the elderly to decisively determine the most appropriate illness and any health-related threats. Another system presented in [11] aims to evaluate the likelihood of developing heart diseases in patients. Another work presented in [3] introduced an expert fuzzy system for heart disease diagnosis. IoT allows users to share information everywhere and every time. However, the huge exploitation of the connected objects becomes a source of a mass of heterogeneous data. Ontologies play an important role to deal with the huge quantity of data by offering a semantic representation of the domain knowledge. Recently, different ontologies related to IoT based healthcare are proposed. For instance, [12] describes an ontology-based framework using the semantic IoT that provides continuous monitoring of patient status. Another work in [14] presents an IoT based system where an ontology is introduced to provide semantic interoperability among heterogeneous devices and users to ensure remote control of patient affected by chronic diseases. In [2], the authors proposed a context management system for smart environments that uses an ontology to model the uncertainty and vagueness of the contextual information collected to reach a richer inference process. Authors in [9], propose an ontology-based context management system that allows the monitoring of the elderly citizens' behavior and the detection of risks related to mild cognitive impairments and frailty. The work proposed in [8] describes a decision support system aiming to ensure the treatment and care delivery pathways for patients with Head and Neck Cancer. In [15] a personalized ontology-based food recommendation system is proposed for supporting travelers with long-term diseases and follow a strict diet. Although classical ontologies provide a formalized and accumulated knowledge base for users to investigate and share, they cannot appropriately treat imprecise and vague knowledge for healthcare applications [18]. Thus, the combination of fuzzy logic theory with ontology is considered the solution for uncertainty. For example, the system presented in [5] enables elderly citizens suffering from chronic diseases to live safely and independently by generating more effective and accurate recommendations. [7] proposed a fuzzy expert decision system for diabetic patients. The system aims to model diabetes knowledge with uncertainty. [1,13] propose recommender fuzzy-ontology based systems that efficiently monitor the diabetic patient and recommend appropriate foods and drugs.

## 3 Architecture of Fuzzy Ontology-Based Healthcare System

This section describes the overall architecture of the proposed system (Fig. 1). Different medical and ambient sensors and devices are used to monitor the patient's vital signs and his home surroundings. These measurements data combined with patient profile data, lifestyle data including diet, physical exercises and medication intake constitute the sensing layer. The data collected is transferred to the server using the interconnected IoT technologies that constitute the network layer. On the server-side, the middleware management layer, which acts as the central part of the system, is deployed. It is responsible for data collection and management, sensors and devices control and services generation. Its main Components are:

- Collection and fusion engine: receives data from medical and ambient IoT devices and other data related to patient's profile and lifestyle (foods, medication, and exercise) and extracts features/inputs to send them to the fuzzification component and to the knowledge base.
- Database: stores patients' profile data, symptoms, medical history, medication intake, exercises, meals and foods, examination results, etc.
- The knowledge base: comprises the fuzzy-ontology that formulates data representing the patient, his environment, his lifestyle, his examinations and rule-based reasoning model fusing SWRL and fuzzy-logic theory to deal with vagueness and uncertainty and thus ameliorates the efficiency of decisions making results.
- Fuzzification: transforms raw feature/input values to fuzzy variables. This is to determine the membership function of each variable in the set.
- Fuzzy inference: maps input variables to output variable through a number of fuzzy if-then rules.
- Defuzzification: transforms fuzzy variables to output values. These crisp values are necessary for the generation of healthcare services.

– Query engine: handles queries received from the application layer.
– Reasoning Engine: checks the consistency of raw data and deduces the high-level data from low-level data.

The results of diagnosis representing healthcare services are delivered to the end users (doctors, patient, nurses, and family members). Multiple programming interfaces are developped to display the results that answer users' queries.

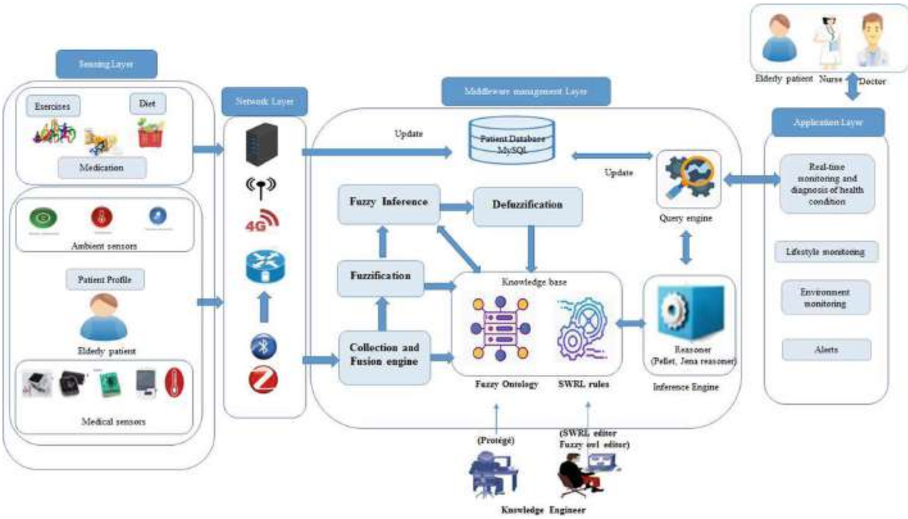


**Fig. 1.** The architecture of fuzzy ontology-based healthcare system

## 4 Proposed Fuzzy-Ontology

Ontologies have been adopted in IoT-based healthcare applications, as they are capable of modeling and representing the whole concepts related to the health domain and describing the relationships among them. However, classical ontologies are unable to handle imprecise and vague knowledge and thus fail to provide accurate and efficient diagnoses. This limitation has leading us to develop a fuzzy-ontology capable of managing health-related knowledge. The ontology proposed uses fuzzy members and gives a semantic description related to diabetes disease. It supports the patient in monitoring their health condition and their lifestyle and generating efficient recommendations. It is an extension of our classic ontology proposed in [14]. Protege tool is used to develop and maintain our proposed fuzzy-ontology. It allows reasoning through different plugins: Fuzzy owl is used to add fuzzy sets to fuzzy variables. SWRL is adopted to manage fuzzy rules. DL and SPARQL queries are employed to retrieve the results and answers. The ontology includes multiple classes representing the concepts, data and object properties and fuzzy data types representing the intervals of the membership fuzzy variables. The fuzzy concepts define concepts and relations to describe uncertain and vague knowledge. The main difference between fuzzy and classic concepts is that in classic concepts the membership degree of each property is equal to 1 or 0 while in fuzzy concepts it is equal to a certain degree belongs the interval [0, 1]. The classes extended are the following:

- Fuzzy patient class: represents all the information required to supervise the condition of the diabetic elderly. It describes 5 fuzzy variables which are height, weight, gender, disease history and age. The fuzzy variable weight has the fuzzy sets “Light”, “Normal”, and “Heavy” and “Obese”. The fuzzy variable gender has the fuzzy set “Male” and “Female”. The fuzzy variable age has these sets, “Young”, “Adult” and “Old”.
- Fuzzy MedicalProperty class: describes and manages the medical observations. It has the following Fuzzy sub-classes: blood pressure, blood glucose, BMI, heart rate, temperature. These measurements are used as the input variables to identify the health condition of the patient which is the output variable. Each fuzzy variable has several fuzzy terms. For example, the blood sugar glucose variable has the fuzzy sets: (very-low 0–90, low 71–130, medium 125–154, high 142–180, very-high 165–250).
- Fuzzy Health condition class defines the patient’s health condition calculated based on medical data collected. The health condition is the output variable determined based on fuzzy input variables defining the medical measurements and the fuzzy rules. This variable has fuzzy sets “Healthy”, “Moderate” and “Serious”. The system acts automatically based on the patient’s health condition: If it is healthy, the system indicates to the patient to maintain his lifestyle. If it is moderate, the system recommends the appropriate drugs, foods and physical exercises required for the patient to establish his normal health condition and notify the corresponding caregiver to do the regular health services. If it is serious, the system generates alarms to call the medical staff and recommends different foods and drugs.
- Fuzzy Food class: defines the food eaten by a diabetic patient. Foods are distributed in meals. According to the nutritionists, a diabetic patient should maintain a healthy diet that allows him to maintain a normal blood glucose level. The meal eaten is considered healthy or UnHealthy based on the percentage of carbohydrate PC, protein PP, and fat consumed PF, BMI, the difference between the calories consumed by the patient and the planned total calories required for patient’s body defined by nutritionists DCP. The total calories needed to maintain or lose weight is calculated based on the basal metabolic rate BMR and the activity level. The BMR is calculated based on patient’ age, gender, weight and height using Mifflin St Jeor formula [4]. The nutritionists recommend that the planned total calories should be divided into the five meals: Breakfast, breakfast, snack 1, lunch, snack 2, and dinner with the respective percentage: 25%, 12.5%, 25%, 12.5%, and 25%. For each meal, the number of calories should be distributed in three nutrients, which are carbohydrates, fat, and protein with the respective percentage 50%, 30%, and 20%. Therefore, four fuzzy variables are described by this class which are

PC, PP, PF, DPC. These variables are considered as inputs variables combined with the fuzzy variables Age, BMI and physical activity to deduce if the diet is healthy or not which is expressed by the fuzzy variable Diet status.
- Fuzzy physical activity: expresses the level of physical activity practiced by the diabetic patient. The level of physical activity is used to calculate the total calories needed by the diabetic patient to maintain or lose weight. In fact, according to the level of activity, a factor is multiplied by the BMR as following: little = BMR * 1.2, light = BMR * 1.375, moderate = BMR * 1.55, strenuous = BMR * 1.725, extra strenuous = BMR * 1.9.

## 5 Health Condition and Diet Status Calculation Process

This section details the process calculation of health condition and diet status values for the diabetic patient using the following components: fuzzy-ontology, fuzzification, fuzzy rule-base, fuzzy inference, and defuzzification. The crisp inputs related to patient's profile and sensors data are collected and then fuzzified using the fuzzy sets of each variable. Health condition is calculated using blood glucose, blood pressure, BMI, heart rate, body temperature fuzzy inputs. Diet Status is calculated based on PC, PP, PF, DCP, activity, Age, BMI. The fuzzification step is proceeded by the fuzzy inference step. This later uses the fuzzy-ontology and a fuzzy-rule base that includes a set of fuzzy-rules. The proposed fuzzy rules are categorized in: (1) Rules to determine the health condition of the patient (2) Fuzzy rules to determine the status of diet consumed by the patient. (3) Rules to determine the BMR and planned calories needed by the patient according to his physical activity level, height, weight, and age. (4) Rules to recommend drugs, foods and physical activity according to health and diet conditions calculated. Following, are example of two SWRL rules. Rule 1 deduces the health status of the patient based on his physiological signs and generates Health services. Rule 2 deduces the diet status based on the composition of meals eaten by the patient, his activity and the difference between the planned and consumed calories, and generates appropriate recommendations. The rules determining the status of diet are implemented according to these two conditions: (1) the diet is more healthy if PC, PF, PP, activity are more balanced and (2) the planned caloric intake is closer to the one consumed. The Fuzzy inference is based on Mamdani's method to determine the fuzzy output variable and send it to the defuzzyfier. The defuzzyfier adopts 'Center of gravity' [16] method to deduce the crip value of the output variable.

**Rule 1:** Patient(?p), HasBloodGlucose(?p, HighBG), HasBloodPressure(?p, HighBP), HasHeartBeat(?p, HighHB), HasBMI(?p, OverweightBMI), HasBody Temperature(?p, NormalBT), greaterThan(?HighBG, 180), SystolicBPValue (?HighBP, ?s), DiastolicBPValue(?HighBP,?d), greaterThan(?d, 86), lessThan (?d, 90), greaterThan(?s, 131), lessThan(?s, 139), greaterThan(?NormalBT, 37), lessThan(?NormalBT, 38), greaterThan(?HighHB, 100), greaterThan(?Over weightBMI, 38), lessThan(?OverweightBMI, 40), Alarm(?a), EmergencyButton(?e), UseActuatingDevice(?p, ?e) -> HasHealthCondition(?p, Serious), HasAlarm(?p, ?a), HasServiceMessage(?a, “You are in danger, Call a doctor”), HasActuatorState(?e, “Device is swiched On”)

**Rule 2:** Patient(?p), HasAge(?p, Old), HasBMI(?p, OverWeight), HasPC(?p, HighPC), HasPP(?p, HighPP), HasPF(?p, LowPF), HasDCP(?p, MLUnAcceptableCDP), greaterThan(?Old, 65), HasActivity(?P, LightAC), Recommandation (?R), greaterThan(?OverWeight, 38), lessThan(?OverWeight, 40), greaterThan (?HighPC, 65), lessThan(?HighPC, 100), greaterThan(?HighPP, 20), lessThan (?HighPP, 100), lessThan(?LowPF, 25), greaterThan(?LightAC, 8), lessThan (?LightAC, 30), greaterThan(?MLUnAcceptableCDP, 50), lessThan(?MLUn AcceptableCDP, 200)-> HasDietStatus(?p, UnHealthy), HasRecommandation (?p, ?R), HasServiceMessage(?R, “Do more exercises, Eat More Fat, Less Carbohydrate, Less Protein”), NeedFood(?p, LowCalorie).

The proposed system is implemented on java. Fuzzy components are implemented using jfuzzylogic plugin to calculate the output variables, which are health condition and diet status. The ontology is evaluated based on the querying-answering approach using DL and SPARQL queries and is then integrated into the java application using Jena API. The evaluation includes: (1) Technical evaluation to check the consistency and the coherence of the ontology using Jena reasoner as well as the response time that the system takes to execute user queries and display the result. Results show that the time consumed depends on the number of inputs that the query needs to calculate the output. The more the inputs are, the more the response time is. (2) Functional evaluation, which evaluates the efficiency of the system and the accuracy level of the decisions for which the system was queried. Results demonstrate that the accuracy of our system can reach 100% for diet status related queries, 96% for health condition related queries and on average 94% for queries related recommandations. Therefore our system is capable of acting more similar to human expertise.

## 6 Conclusion

This paper proposes a fuzzy-ontology based diabetic monitoring system using IoT technology. The fuzzy-logic is adopted to infer the health condition and the diet status for the patient and then presents the result to the ontology to generate convenient recommendations. Evaluation indicates that the performance of the system is increased considerably and the system gives results with more accuracy compared to the system using classic ontology.

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# Short Contributions: Biomedical and Health Informatics

# A Hybrid Approach for Heart Disease Diagnosis and Prediction Using Machine Learning Techniques

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**Abstract.** Heart disease is considered as one of the major causes of death throughout the world. It cannot be easily predicted by the medical practitioners as it is a difficult task which demands expertise and higher knowledge for prediction. Currently, the recent development in medical supportive technologies based on data mining, machine learning plays an important role in predicting cardiovascular diseases. In this paper, we propose a new hybrid approach to predict cardiovascular disease using different machine learning techniques such as Logistic Regression (LR), Adaptive Boosting (AdaBoostM1), Multi-Objective Evolutionary Fuzzy Classifier (MOEFC), Fuzzy Unordered Rule Induction (FURIA), Genetic Fuzzy System-LogitBoost (GFS-LB) and Fuzzy Hybrid Genetic Based Machine Learning (FH-GBML). For this purpose, the accuracy and results of each classifier have been compared, with the best classifier chosen for a more accurate cardiovascular prediction. With this objective, we use two free software (Weka and Keel).

**Keywords:** Machine learning · Data mining · Healthcare informatics · Heart disease · Classification · Prediction models · Medical decision support system

## 1 Introduction

One of the most common reasons of death in Algeria or other Maghreb countries is chronic disease. Nevertheless, chronic disease is a vital issue to be fixed for a healthy human life. More recently, Cardiovascular Disease (CVD) is the leading cause of death for both men and women globally. Though real-life consultants can be able to predict the disease with an enormous number of tests and requiring a huge processing time, sometimes, their prediction may be incorrect because of lack of skilled knowledge [1]. Meanwhile, the introduction of artificial intelligence and machine learning has helped to extract relevant data from large databases which are available in hospitals to make a good decision. It involves data mining techniques to analyze medical data [2]. For this reason, data mining has gained popularity due to its tools with the potential to identify trends within data and turn them into knowledge that could serve as the strong basis for the analysis [3]. To that end, the key issue in the field of CVD prevention is to give an accurate


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prediction of whether a person is probable to have this disease. Motivated by the growing mortality of CVD patients every year and the accessibility to a huge amount of patient data from which to obtain valuable knowledge, we found it useful to use data mining methods for assisting healthcare professionals in the diagnosis of CVD. The objective of this research work is not to replace the specialist physician, but to assist the doctor in obtaining an alternative opinion and its various feasibility in critical situations.

The rest of this paper is organized as follows. Section 2 describes the literature review. Section 3 presents the proposed approach used for predicting heart disease. Experimental results are analyzed in Sect. 4 and Conclusion and References are given in Sect. 5 and 6.

## 2 Literature Review

In previous studies, researchers expressed their efforts in finding the best model for predicting cardiovascular disease. In the meantime, various studies give only a glimpse into predicting heart disease using machine learning techniques and fuzzy logic systems. This section explores the research works that are related to the proposed approach. A machine learning model has been proposed in [2] by combining five different algorithms. In fact, the integration of the machine learning model with medical information systems would be useful to predict the Heart Failure (HF) or any other disease using the live data collected from patients. A new hybrid approach for heart disease prediction that combines all techniques into one single algorithm has been proposed in [4]. The result confirms that accurate diagnosis can be made using a combined model from all techniques. An "Optimal Multi-Nominal Logistic Regression (OMLR) algorithm has been proposed in [5] and is used to train the data set for heart disease. Experiments are conducted on the dataset of UCI heart disease and the results show 92% accuracy in the detection of heart severity. The Fast Correlation-Based Feature Selection (FCBF) method has been exploited in [6], to filter redundant features in order to improve the quality of heart disease classification. Then, the authors performed a classification based on different algorithms such as K-Nearest Neighbour, Support Vector Machine, Random Forest and a Multilayer Perception optimized by Particle Swarm Optimization (PSO) combined with Ant Colony Optimization (ACO) approaches. A predictive model for heart disease diagnosis using a fuzzy rule-based approach with decision tree has been proposed in [7]. In this study, the authors have obtained the accuracy of 88% which is statistically significant for diagnosing the heart disease patient and also outperforms some of the existing methods. A new method namely Hybrid Differential Evolution based Fuzzy Neural Network (HDEFNN) which can predict the heart disease occurrence fastly and accurately has been proposed in [8]. The performance of this method in terms of accurate diagnosis of heart disease is attained by improving the initial weight updating of a neural network which is done by introducing the genetic algorithm. The genetic algorithm can select the most optimal weight values for the hidden layers of the neural network. A neuro-fuzzy genetic approach has been proposed in [9], to predict chances of cardiovascular disease. The proposed approach also helps to make the system more accurate and efficient with the help of a genetic algorithm.

## 3 Proposed Approach

(See Fig. 1).

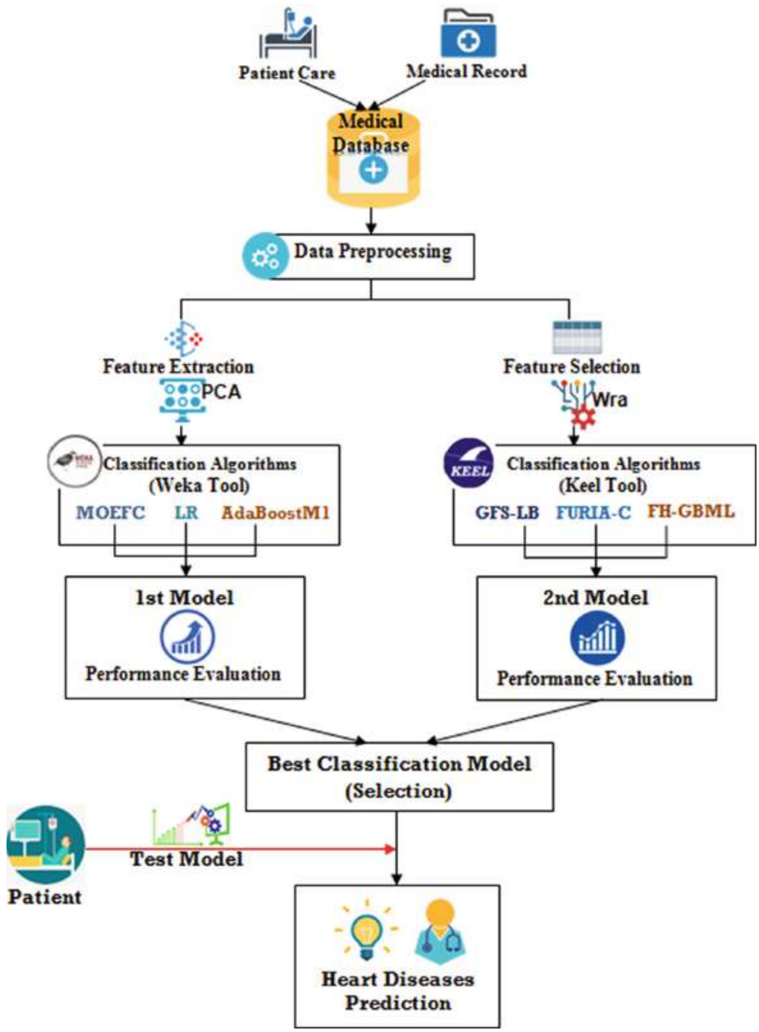


**Fig. 1.** General architecture of the proposed approach

### 3.1 Description of the Dataset and Attributes

The dataset used in this article is taken from the UCI Repository Of Machine Learning Databases[1]. Formally, it is named Heart Disease Dataset. The Cleveland (Cleveland Clinic Foundation) database was selected for this research because it is a commonly used database for machine learning researchers with comprehensive and complete records. In this field, the dataset is a collection of medical analytical reports with a total of 303 records with 14 medical features. The various features and their description are shown in Table 1. Besides, the categorical feature "Class" contains whether a patient has a presence or absence of heart disease. Its original values 1, 2, 3 and 4 were transformed in one that is the presence (1) of heart disease.

**Table 1.** UCI dataset attributes detailed information

| Num. | Code | Feature | Type | Description |
|---|---|---|---|---|
| 1 | Age | Age | Continuous | Age in years |
| 2 | Sex | Sex | Discrete | sex (1 = male; 0 = female) |
| 3 | Cp | Chest pain type | Discrete | 1 = typical angina; 2 = atypical angina; 3 = non-angina pain; 4 = asymptomatic |
| 4 | Trestbps | Resting boold pressure (mg) | Continuous | At the time of admission in hospital [94, 200] |
| 5 | Chol | Serum cholesterol (mg/dl) | Continuous | Multiple values between [Minimum Chol: 126, Maximum Chol: 564] |
| 6 | Fbs | Fasting bood sugar > 120 mg/dl | Discrete | 1 = yes; 0 = no |
| 7 | Restecg | Resting electrocardiographic results | Discrete | 0 = normal; 1 = ST-T wave abnormal; 2 = left ventricular hypertrophy |
| 8 | Thalach | Maximum heart rate achieved | Continuous | Maximum heart rate achieved [71, 202] |
| 9 | Exang | Exercise induced angina | Discrete | 1 = yes; 0 = no |
| 10 | Oldpeak | ST depression induced by exercise relative to rest | Continuous | Multiple real number values between 0 and 6.2. |
| 11 | Slope | The slope of the peak exercise ST segment | Discrete | 1 = upsloping; 2 = flat; 3 = downsloping |
| 12 | Ca | Number of major vessels (0–3) colored by fluoroscopy | Discrete | Number of major vessels coloured by fluoroscopy (values 0–3) |
| 13 | Thal | Exercise thallium scintigraphy | Discrete | 3 = normal; 6 = fixed defect; 7 = reversible defect |
| 14 | Class (Target) | The predicted attribute | Discrete | 0 = no presence; 1 = presence |

[1] Repository Of Machine Learning (UCI Databases). Heart Disease Data Set. [Online]. Available: https://archive.ics.uci.edu/ml/machine-learning-databases/heart-disease/heart-disease.names [Accessed: June 20, 2019].

### 3.2 Data Pre-processing

In medical informatics, the diagnosis of diseases becomes quicker and easier if data is free from missing, redundant and irrelevant data. In this study and after collection of various records, we begin the preprocessing process. The dataset contains a total of 303 patients records, where 7 records are with some missing values. Those 7 records have been removed from the dataset and the remaining 296 records are used in the process.

### 3.3 Feature Selection

Feature selection is a process of selecting a relevant feature of original features according to definite condition. Further, feature collection algorithms intended with different evaluation criteria mostly fall into three categories: the filter, wrapper, and hybrid models [10]. In our work, we used only the wrapper method under Keel tool. As per our objective, from among the 14 attributes of the dataset, two attributes pertaining to age and sex are used to identify the personal information of the patient. The remaining 12 attributes are considered important as they contain vital clinical records.

### 3.4 Feature Extraction

Feature extraction is a process that extracts a subset of new features from the original set by means of some functional mapping. In order to meet the goal of the work, we used PCA as one of the most widely used dimensionality reduction technique for the medical applications under Weka tool, where the extracted information is represented by a set of new variables, termed components or features. With PCA, we reduced the attributes number to 6 which contributes more towards the diagnosis of the CVD.

### 3.5 Classification Algorithms

Under Weka tool, different predictive algorithms were chosen to build the first model, namely: Multi-Objective Evolutionary Fuzzy Classifier (MOEFC), Logistic Regression (LR), Adaptive Boosting (AdaBoostM1), while Genetic Fuzzy System-LogitBoost (GFS-LB), Fuzzy Unordered Rule Induction Algorithm (FURIA) and Fuzzy Hybrid Genetic Based Machine Learning (FH-GBML) were used under Keel tool to build the second model. Therefore, we selected the best model in order to achieve the highest possible performance on medical datasets and allow effective data classification.

### 3.6 Test Model

In the second stage, we tested our selected model only when the model is completely trained. Its accuracy on the test data gives a realistic estimate of the model performance on completely unseen patient data and confirms the actual predictive power of the model.

# 4 Experimental Results

In this paper, the experimental effects of the cardiovascular diseases' diagnosis and the following algorithms LR, AdaBoostM1, MOEFC, FURIA, GFS-LB and FH-GBML are examined in this phase with the use of Keel and Weka tools. Meanwhile, machine learning algorithm efficiency is derived using values like True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN). These measures are used for the calculation of the sensitivity, specificity, accuracy and error rate.

$$\text{Sensitivity (Recall) or True positive rate (TPR)} = \text{TP}/(\text{TP} + \text{FN}). \tag{1}$$

$$\text{Specificity} = \text{TN}/(\text{TN} + \text{FP}) \tag{2}$$

$$\text{Accuracy (ACC)} = (\text{TP} + \text{TN})/(\text{TP} + \text{TN} + \text{FP} + \text{FN}). \tag{3}$$

$$\text{Error rate} = (\text{FP} + \text{FN})/(\text{P} + \text{N}). \tag{4}$$

## 4.1 Evaluation of Results

**Setting up the Experiment under WEKA Software.** In our experiment, the problem has been transformed into binary classification with 0 presents absence and 1 presence of heart disease. For this, Table 2 shows the results obtained by binary classification and 10-fold cross-validation. The highest accuracy 80.20 is gained by majority voting, while LR obtained lowest accuracy and AdaBoostM1 has the highest accuracy when applied without ensemble.

**Table 2.** Multi-class classification results by 10-fold cross-validation

| Algorithm | Sensitivity | Specificity | Accuracy |
|---|---|---|---|
| MOEFC | 79.96 | 75.44 | 79.42 |
| LR | 78.22 | 71.34 | 78.77 |
| AdaBoostM1 | 80.11 | 75.40 | 80.01 |
| Vote | 84.76 | 74.82 | 80.20 |

**Setting Up the Experiment under KEEL Software.** Our purpose is to make a comparison of three methods that belong to different ML techniques. In this step, we have used a GFS-LogitBoost-C classifier with a previous pre-processing stage of prototype selection guided by a Generational Genetic Algorithm for Feature Selection (GGA-FS) model. We have also used a FURIA classifier with a previous preprocessing stage of replacing missing values guided by a KNN-MV (K-Nearest Neighbor Imputation) algorithm as well as prototype feature selection guided by SSGA-Integer-knn-FS (Steady-state GA with integer coding scheme for wrapper feature selection with K-NN) and an FH-GBML that uses a Generational Genetic Algorithm for Feature

Selection (GGA-FS). After the models are trained, the instances of the dataset are classified according to the training and test files. These results are the inputs for the visualization and test modules. The module Vis-Clas-Tabular receives these results as inputs and generates output files with several performance metrics computed from them, such as confusion matrices for each method. There is also another type of results flow which interconnects each possible pair of methods with a test module. In this case, the test module used is the signed-rank Wilcoxon non-parametrical procedure Clas-Wilcoxon-ST which compares two samples of results. The experiment establishes a pair-wise statistical comparison of the three methods. Once the experiment has been run we can reach results shown in Table 3 and Table 4.

**Table 3.** Performance of the KEEL model - training datasets

| Evaluation criteria | FURIA-C | GFS-LogitBoost-C | FH-GBML-C |
|---|---|---|---|
| Sensitivity | 88.62 | 94.99 | 87.47 |
| Specificity | 76.26 | 93.20 | 78.66 |
| Error rate | 0.17 | 0.06 | 0.17 |
| Accuracy | 82.95 | 94.17 | 83.44 |

**Table 4.** Performance of the KEEL model - testing datasets

| Evaluation criteria | FURIA-C | GFS-LogitBoost-C | FH-GBML-C |
|---|---|---|---|
| Sensitivity | 84.76 | 80.49 | 82.82 |
| Specificity | 74.82 | 80.58 | 74.26 |
| Error rate | 0.20 | 0.19 | 0.21 |
| Accuracy | 80.20 | 80.53 | 78.93 |

## 5 Conclusion

Efficient classification of healthcare dataset is a major machine learning problem then and now. Diagnosis, Prediction of cardiovascular diseases and the precision of results can be improved if relationships and patterns from these complex healthcare datasets are extracted efficiently. This paper analyses some of the different classification algorithms like Logistic Regression (LR), Adaptive Boosting (AdaBoostM1), Multi-Objective Evolutionary Fuzzy Classifier (MOEFC), Fuzzy Unordered Rule Induction (FURIA), Genetic Fuzzy System-LogitBoost (GFS-LB) and Fuzzy Hybrid Genetic Based Machine Learning (FH-GBML). The performance evaluation of these algorithms is done based on Accuracy, Sensitivity, Specificity and Error rate using WEKA and KEEL tools.

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# Context-Aware Healthcare Adaptation Model for COPD Diseases

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**Abstract.** Nowadays, ubiquitous computing and mobile applications are controlling all our life's aspects, from social media and entertainment to the very basic needs like commerce, learning, government, and health. These systems have the ability to self-adapt to meet changes in their execution environment and the user's context. In the healthcare domain, information systems have proven their efficiency, not only by organizing and managing patients' data and information but also by helping doctors and medical experts in diagnosing disease and taking precluding procedure to avoid serious conditions. In chronic diseases, telemonitoring systems provide a way to monitor the patient's state and biomarkers within their usual life's routine. In this article, we are combining the healthcare telemonitoring systems with the context awareness and self-adaptation paradigm to provide a self-adaptive framework architecture for COPD patients.

**Keywords:** Software architecture · Self-adaptation · Context-aware system · COPD · Healthcare systems

## 1 Introduction

Chronic obstructive pulmonary diseases (COPD) have attracted research interest as a major public health problem, because according to the World Health Organization (WHO) [1], COPD is currently considered the fourth, and will soon become the third, most frequent cause of death worldwide. It is also a disabling disease and therefore associated with high costs for treating and managing patients. As the disease progresses, patients become more susceptible to respiratory exacerbations which cause frequent hospital admissions and, thus, have a huge impact on patients' quality of life and healthcare costs [2, 3]. Monitoring patient's health conditions from home and transmitting these data to a healthcare center could be a great solution that facilitates the management of the growing number of patients with COPD and reduce the burden on health services. This approach is called Home Tele-monitoring, which can be used for a timely assessment of acute exacerbation or as a mechanism to generate alarms to the patients and/or healthcare professionals when clinical changes that may constitute a risk to the patient occur [4]. There are many systematic reviews and studies on the topic of telemonitoring in respiratory patients, specifically in patients with COPD [5–8]. All these


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studies are focusing on proving the effectiveness of applying home telemonitoring on COPD patients, by studying the services that could be provided and their impacts on the patient's quality-of-life. However, none of these studies has provided a comprehensive proposal for a telemonitoring system that helps to control the burden of COPD.

We aim to design a telemonitoring healthcare application that helps COPD patients with self-management and improve their quality of life, therefore reducing pressures on healthcare resources. We must develop a system that uses this data to provide an effective intervention that prevents exacerbation through the early recognition of symptoms and prompt treatment which may reduce the risk of hospitalization and control the burden of COPD. Based on this healthcare requirement, we realized the need of combining context awareness and self-adaptation with health telemonitoring, which will give our system the ability to be aware of the patient's data and context, then to adapt the required changes and act accordingly.

The remainder of this paper is structured as follows. Section 2 introduces the concept of context-awareness and reviews the most common forms of self-adaptation frameworks. Section 3 highlights the characteristics of self-adaptive systems. Section 4 presents our self-adaptation healthcare system for COPD. Section 5 then validates the proposed approach. Finally, Sect. 6 presents our conclusions.

## 2 Context Awareness and Self-adaptation Systems

### 2.1 Background

The notion of context has appeared implicitly for the first time in the ubiquitous computing area in 1993 by Weiser "all the information that should be taken into consideration for an adjustment" [9]. Lieberman et al. [10] proposed another interpretation of the context that exists within the field of computing: "context can be considered to be everything that affects the computation". This definition focuses on the application instead of the user, but nowadays with the widespread of mobile applications that focus on the user's lifestyle, health, and activities the factors that affect the user and these that affect the computation process become almost the same.

In software systems, context awareness notion is mostly coupled with self-adaptation capability otherwise, there is no point in collecting contextual data. Self-adaptation is a set of simultaneous and successive processes as an organized reaction to changes in the resources or environment of the system [11]. Self-adaptive systems dynamically modify their behaviors to respond effectively to changes in their operational environment [12]. In the next section, an overview of many self-adaptation frameworks is provided.

### 2.2 Self-adaptations Frameworks

Rainbow framework provides general mechanisms for developing reusable self-adaptive systems at a variety of different levels [13]. Model-Driven Approach is an automated self-adaptive model that supports adding and removing technical resources at run-time [14]. Meta-Self is a service-oriented framework that provides a solid platform for the development of SAS [15]. This framework allows designers to identify system properties, architectural patterns, and different adaptation mechanisms. FUSION is a reusable feature architecture that incorporates a learning-based adaptive cycle. The adaptation cycle consists of three main steps—detect, plan, and effect [14]. MOSES is a service-oriented framework that focuses on quality of service (QoS) requirements at runtime. MOSES provides a reusable implementation strategy of the adaptation logic following the MAPE cycle (Monitoring, Analysis, Planning, and Execution) [14]. The Contract-Based Adaptive Software Application framework (CASA) [16] is specialized in handling resources instability. The framework assumes that a system should not make any assumptions about the resources that will be available and should be prepared for any resource availability scenario cases. Service-Oriented Architectures (SSOA) is a software framework that specifies any kind of adaptation by decomposing of functionalities [17]. Each of these functionalities shall be specialized to fit a particular purpose. CareDroid is an adaptation framework for android context-aware applications [18]. This framework CareDroid monitors the contexts at run-time, and active methods only when it intercepts calls to sensitive methods.

## 3 System Requirements and Self-adaptation Characteristics and Taxonomy

### 3.1 Requirements Extraction and Gathering

The first step to designing a self-adaptive system is to well identify the system requirements; we will depend on W5H-Pattern [19], which presents six questions that would help us in eliciting adaptation requirements (Table 1).

**Table 1.** Requirements extraction

| | |
|---|---|
| Where | Where do we need to make a change inside our system when a context's change does happen? Depending on the model presented by Ajami and Mcheick [20], the change needs to be done in the Application layer on both sides: user interface and physician interface |
| When | When do we need to make these changes? Whenever an urgent update happens in the user contextual data like vital signs, environmental risk factors, and planned activities or periodical changes like the evaluation of treatment and decision support suggestions |
| What | What do we need to change? We need to update some system attributes that present the system state and these attributes in its turn could trigger new functions or activate new components |
| Why | Why these changes are required? In healthcare monitoring applications especially these related to chronic diseases, taking precluding actions is crucial in treatment plans. Also being able to notify the patient and the medical experts about any threatening situation or abnormal signs make these kinds of applications more efficient |
| Who | Is any human intervention is required in the adaptation process? From the patient side, all his biomedical data and surrounding environments data will be collected from sensors. However, because physical activities do affect the COPD patient's state, he needs to detect his planned physical activity (running, swimming) |
| How | How to determine what changes and actions are needed to be done in the adaptation process? Ajami and Mcheick [20] provided a rule-based reasoning engine, depending on these generated rules all the required actions and changes can be deduced |

### 3.2 Adaptation Characteristics and Taxonomy

Christian et al. [21] presented a taxonomy of the different properties of self-adaptive software. We will analyze this work and do a projection on our system requirements and use the results to build our system.

**Time:** Handte et al. [22] provided two perspectives of temporal aspects: (i) Reactive is when we have to adapt whenever a change in the context does happen. (ii) Proactive is when the monitored data is used to forecast system behavior or environmental state [21]. In our case, the adaptation will be reactive depending on the changes that happen in the user contextual data.

**Reason:** The adaptation could be triggered for three reasons: (i) change of the context, (ii) change in the technical resources, and (iii) change in the users. In our case, the adaptation is triggered due to contextual changes, which provide a potential solution for the multiscale nature of COPD.

**Level:** In our system, the change needs to be done on the application layer, where we need to update the acceptable range for the different datasets or we need to activate new components or call new functions.

**Technique:** McKinley [23] provided two techniques for adaptive software: parameter adaptation and compositional adaptation. Parameter adaptation achieves a modified system behavior by adjusting system parameters. Whereas compositional adaptation enables the exchange of algorithms or system components dynamically at runtime. We will use the first approach because it is suitable for a rule-based system.

**Adaptation Control:** Two approaches for implementing the adaptation logic can be found in the literature. The internal approach, which twists the adaptation logic with the system resources. The external approach splits the system into adaptation logic and managed resources, The IBM Autonomic Computing Initiative provided MAPE Model [24], which is an external, feedback control approach. Another aspect of the adaptation logic is the degree of decentralization. We will follow a decentralized approach by implementing independent units that control different aspects of adaptation.

## 4 Self-adaptation Healthcare System for COPD

### 4.1 Proposed System

Ajami and Mcheick [20] have proposed an ontology-based approach to keep track of the physical status of patients, suggest recommendations and deliver interventions promptly, by developing a decision support system based on an ontological formal description that uses SWRL rules. The main goal of this paper is to provide an adaptation architecture design for the application layer, which will address the connection between three different entities:

1 - The end-user application: which is supposed to provide a certain service for both patient and physician.
2 - The data sources (sensors and patient's records): that provides a continuous stream of contextual data and historical data about the patient.
3 - The rules base: which presents the knowledge base in our system (Fig. 1)

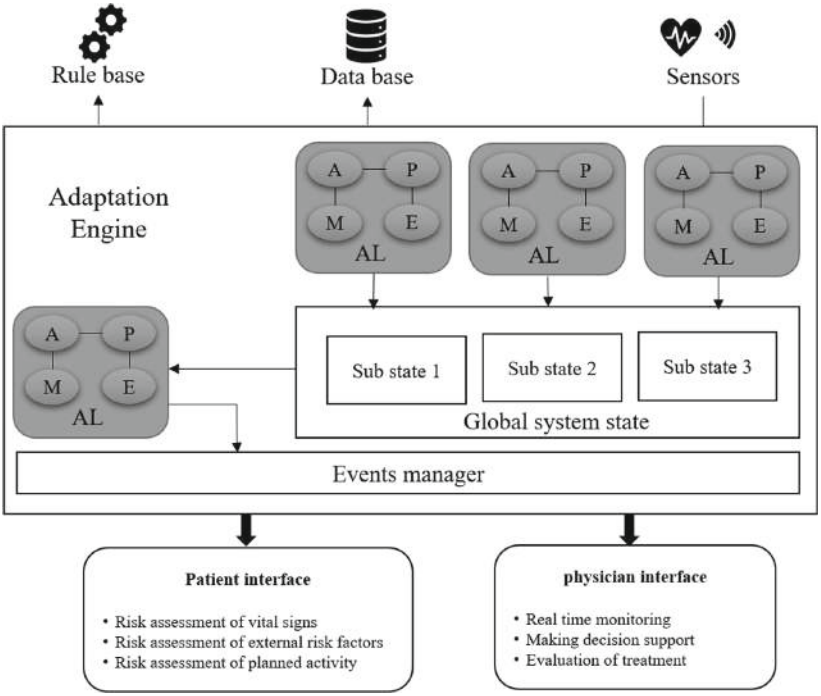


**Fig. 1.** Architecture for COPD context-aware system

### 4.2 The Adaptation Engine and Monitoring Units

The adaptation engine consists of a central adaptation unit and multiple sub adaptation units. Each subunit is responsible for monitoring and managing changes for a specific category tuple (data, rules, services).

The system variables will be saved in a shared memory called the global state, which is a composition of sub-states. Each sub-state is considered as a container for saving category-specific data and it will be updated and managed by the adaptation subunit that is responsible for monitoring the same category. We will divide all our sets of data, rules, and services into three categories (Table 2):

**Table 2.** Categorization of data

| | Biometrics | Environmental | Activities |
|---|---|---|---|
| Data | Biometrics data | Environmental data | Activities data |
| Rules | Biometrics rules | Environmental rules | Activities rules |
| Services | Biometrics services | Environmental services | Activities services |

Now each subunit will be responsible for a specific category of the tuple. Therefore, we will have three subunits: 1 - The biometrics unit 2 - The Environmental unit 3 - The Activities unit (Fig. 2).

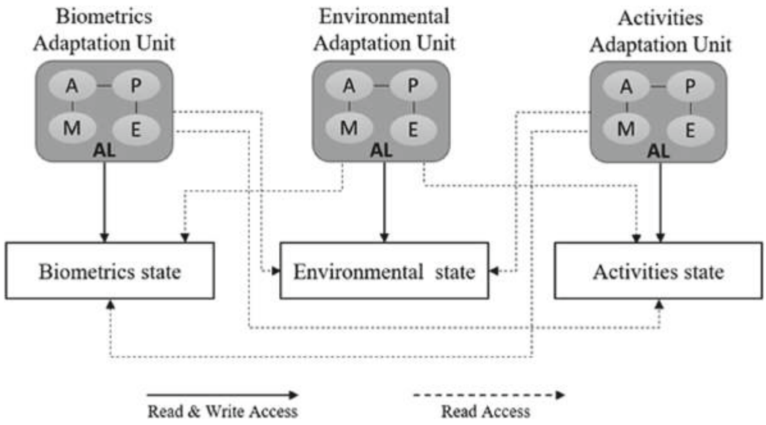


**Fig. 2.** Subunits and sub stats

– The Biometrics Unit will be responsible for monitoring all the patient's biomarkers upcoming from the biometrics sensors, and it will read all the stored data in the other two sub-states (the environmental state & the activities state), then depending on the vital related rules in the rules engine, it will update The Biometrics State with the safe ranges for all the vital biomarkers and the current measurements for them. The same workflow will be applied in both the Environmental Unit and the Activities Unit.
– The Central Adaptation Unit: it is considered the main core of our system; it will be responsible for monitoring the global state, which will get rid of the burden of dealing with the continuous streaming of the patient's biometrics and the environmental data. By collecting all the contextual data in the global state, each category in its sub-state, we will have access to all the current biometrics and external factors value with the safe range for each one of them as well the current physical activity and the planned list of activities.

Depending on the previous data, the central unit will be able to detect any potential risk or abnormal situations by comparing the current value of each factor in the sub-states with its normal range, which had been adapted by every sub adaptation unit.

When an abnormal situation is detected, the central unit will detect what action should be taken to prevent an exacerbation in the patient's health state.

## 5 Validation

In order to test and validate our proposed system, we implemented a simulation app using some data obtained from medical records to simulate the streamed data and a set of COPD rules extracted in [25] to create some testing scenarios. The main focus of the validation process was on the efficiency of the system to provide continuous monitoring of the patient status, and the ability to apply and adapt the required changes to prevent any dangerous exacerbation. The testing scenarios we had performed, proofed the ability of our system to handle the complexity of monitoring the enormous amount of contextual data, and keep track of the latest updates in the global state. Also, following an aspect-oriented approach facilitates the implementation of the adaptation logic, by separating the categories of data that each Adaptation Unit needs to be responsible for observing. After testing some rules that lead to call a sequential set of actions and multiple updates in the state units, the system was able to adapt the safe ranges for the different environmental and biometrical factors and detect suitable action in an abnormal situation. Nevertheless, our system still needs to be tested when it is connected to the whole rules engine when all COPD rules are inserted into the engine, which will be done in future work.

## 6 Conclusion

In this paper, we have presented an architecture for a context-aware self-adaptive system that is used to develop a COPD healthcare telemonitoring system. The system is backed out by a medical rules engine in the COPD domain that is used as the knowledge base to determine the safe ranges for patient's biomarkers and external factors, then detect the precluding actions needed to be taken to prevent severe exacerbations in patient's health state.

Our main contribution in this work is providing a context-aware self-adaptive system architecture that is dealing with the huge variety and complexity of contextual data and different sets of services by implementing a decentralized adaptation unit, which makes the monitoring and adaptation task easier and less complex by applying the separation of concerns principle.

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# Study of Healthcare Professionals' Interaction in the Patient Records Based on Annotations

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**Abstract.** The annotation practice is an almost daily activity; it is used by healthcare professionals (PHC) to analyze, collaborate, share knowledge and communicate, between them, information present in the healthcare record of patients. These annotations are created in a healthcare cycle that consists of: diagnosis, treatment, advice, follow-up and observation.

Due to an exponential increase in the number of medical annotation systems that are used by different categories of health professionals, we are faced with a problem of lack of organization of medical annotation systems developed on the basis of formal criteria. As a result, we have a fragmented image of these annotations tools which make the mission of choice of an annotation system by a PHC, in a well-defined context (biology, radiology…) and according to their needs to the functionalities offered by these tools, are difficult.

In this article we present a classification of thirty annotation tools developed by industry and academia based on 5 generic criteria. We conclude this survey paper with model proposition.

**Keywords:** E-heath · Annotation · Classification · Health record · Annotation system · Healthcare professionals

## 1 Introduction

The paper annotation practice is very common. Indeed, during our reading we are all accustomed to scribble our comments in a margin of document, to highlight, to circle sections, to paste post-it…, which aims to enrich and add value to information [40, 43]. Annotation is a central practice in many professions: teachers annotate copies of students; professors exchange annotated documents during their work; Engineers co build engines by annotating sketches of plans to make them evolve, doctors comment on patient folder, etc. [39, 44].

Annotations thus, take various forms and are used for different functions [28]. Moreover, computerization of documents offers us new perspectives to use these annotations (indexation, creation, document, assistance, etc.) which do not exist on paper [41]. Assistance is a very important function that can be related to the annotation activity.


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Annotative activity is different when dealing with the professional annotator case. These annotations are created in a specific context, will follow a path, developed for the purpose of determining a specific task etc.

The annotation is expanded in a document flow. The latter is a carrier of the ratings. These annotations processed in this context are complementary. They provide us with information scattered over different documents. In fact, if we try to understand each one separately, in other words; if we separate an annotation from its creative context, we find that it does not make sense. In short, the annotation can be understood only in its semantic field.

For this reason, the study of annotation in a professional context obliges us to implement an annotation model that describes what actually happens. This model must provide us with the necessary links either at the level of the annotated documents or at the level of the tasks made without forgetting to take into account the specificity of the annotation's production domain. The documents that usually belong to a folder that is made for the purpose of carrying out a task has a definite circuit that repeats itself each time one needs to do this task. The proper understanding of annotations can be done in its creative context.

Doctors in/after consultation [45] use internet to search information that can help him. Based on their annotations it's possible to assist doctors and to gives him automatically pertinent information, from the net, after studying and analyzing their annotations.

This paper is organized as follows: Sect. 2 gives a classification of these tools based on several criteria; Sect. 3 gives a model proposition. Finally, Sect. 4 concludes this article.

## 2 Health Record Annotations and Medical Annotation Systems

In this work, we started with an exhaustive reading for the available papers on medical annotation systems (academic annotation system) and viewing the existing industrial annotation systems in the e-health domain. Although the medical annotation systems have already been studied in a variety of contexts, yet when it comes to the PHC to choose which system to use it is not a trivial task neither for a researcher to identify future research areas. This is because the annotation systems are so common and many of them share similar objectives. Moreover, there are no formal criteria to facilitate the comparison between those systems and to guide PHC choice or a researcher. As a result, there is a fragmented picture of these annotation tools. As far as we know, this is the first work to consider the classification of medical annotation system. When we determined the study of these systems we deduced that there are several common criteria which can classify these later. Several studies have proposed classifications of annotation systems in several fields [34, 35, 37] or in the field of e-health [42, 43]. We propose a classification based on 5 criteria which are: type of medical annotation object, the medical annotation activity, healthcare professional (Practitioner), type of annotation system, type of annotated resource.

### 2.1 Type of Medical Annotation Object (Cognitive/Computational)

- **Cognitive:** this annotation is created to be used by a human agent. In this case, the annotation requires a cognitive and intellectual effort to be interpreted. This annotation has a visible visual form on the document [34].
- **Computational:** this annotation is intended to be processed and manipulated by software agents. These annotations are also called meta-data. They allow us to annotate computer resources to facilitate their exploitation by machines.

### 2.2 The Medical Annotation Activity (Manual, Automatic, Semi-automatic)

Annotation activity begins with the choice of anchor and annotation form in the annotation toolbar related to the annotation software. Then, the annotation must complete the properties of the annotation; this process ends with the attachment of the annotation to a well-defined target. Based on this process we can classify the annotative activity as: manual, semi-automatic or automatic [38].

- **Manual:** the process already mentioned will be carried out totally by the user himself, who selects the form of the annotation, selects the anchor and creates the annotation. This process is similar to the process of annotation when a paper support is available.
- **Automatic**: the annotation process already mentioned is carried out totally by the machine. These annotations are based on either context sensors or pattern recognition techniques, etc.
- **Semi-automatic:** in this case, the process will be done from the start by the user. After a while, the system acquires and understands the way the user annotates. It moves to a suggestion of annotations that are automated, based on an annotation model built with rules under development. At this stage, human intervention remains just to validate or not validate and to refine the annotation rules created at a certain level, where there are no corrections and there is complete acceptance of the suggested rules, human intervention is canceled and the process becomes totally automated.

### 2.3 Healthcare Professional (Practitioner)

It is the annotator that is equipped with an annotation system to use all the functionalities offered by the latter. In our case, the practitioners are healthcare professionals (doctor, nurse, biologist, and radiologist). The healthcare cycle is composed of four phases (diagnostic, treatment, advice, follow up and observation). Each practitioner, with a medical annotation system, intervenes in one or many phases, according to their role, to accomplish a specific task in which annotation is made.

### 2.4 Type of Annotation System

- **Application:** an application is created to annotate the resources already consulted. These applications offer several functionalities as the types below.
- **Plug-in:** these are the expansion modules, an external module that is added to a website or software and which will make it possible to provide annotation functionalities to the latter.
- **Website:** these are specialized websites to annotate consulted resources by registered users on the web.

Knowing the type of annotation system facilitates the development of a patient record model which will be proposed in future research. This model allows communicating with different types of medicals annotations systems.

### 2.5 Type of Annotated Resource

Annotated resources can be: word document, pdf, image, text, video, html, audio, etc.

Table 1 presents a comparative study of the medical annotation systems seen in the bibliographical study using the 5 criteria already explained.

Table 1 presents a comparative study of thirty medical annotation systems seen in the bibliographical study using the 5 criteria already explained. These annotation systems are ranged on the table according of the chronological order of their publication year.

## 3 Model Proposition

Several models are already seen in the literature [33, 35, 36] and [ 37], these models present many problems, like the inexistence of the modeling of the cycle of care, the consideration of the annotation as an objective, no invocation of the services linked to the annotation, that not allows to use it in the healthcare domain. For this reason and based on the classifications already seen (Sect. 2) we propose an annotation model that preserve the semantic of annotative activity in the health domain.

### 3.1 Concept of Model

Our model must reflect the annotation process actually done; it must contain the following concepts:

- Basic_Concept: This group contains the concepts that can exist in each domain.
  - Place: this is the physical place where the annotation is produced by the annotator.
  - Anchor: this is the position of the annotation on the document.
  - Shape: represents the visual aspect of the annotation.
  - Annotated_content: this is the annotated passage.
  - Annotating_content: this is the comment written by the annotator about the Annotated_content.

**Table 1.** Comparative study of the medical annotation systems using 5 criteria

| Name of annotation system | | Year | Healthcare professional (Practitioner) | Annotated resource type | Category of annotation system | | | Annotation type | | Type of annotation activity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Application | Plug-in | Web | Cognitive | Computational | Manual | Automatic | Semi-automatic |
| Santo | [1] | 2018 | D | Text | | | × | × | | | × | |
| Clean tools | [2] | 2018 | D | Image 3D | × | | | × | | × | | |
| Epivizr | [3] | 2018 | B | Document | × | | | × | | × | × | |
| ODMSummary | [4] | 2017 | D | HTML | | | × | × | | | × | |
| 3dBionote | [5] | 2017 | B | Image | | | × | | × | × | | |
| Verdant | [6] | 2017 | B | Text | | | × | | × | | × | |
| Best slice | [7] | 2017 | R, D | Image | | | × | × | | × | | |
| MicroMD | [8] | 2017 | R, D | Image | × | | | × | | × | | |
| GIDAC | [9] | 2016 | R | Image | × | | | × | | × | | |
| Vcf-miner | [10] | 2016 | B | Text | | | × | | × | × | | |
| Plexo | [11] | 2016 | R | Image | | × | | × | | × | | |
| BioDigital human | [12] | 2016 | D | Image 3D | × | | | × | | × | | |
| Icare | [13] | 2015 | N | Document | × | | | × | | × | | |
| Heideltime | [14] | 2015 | A | Time | × | | | × | | × | | |
| Domeo Annotation | [15] | 2014 | B | HTML | | × | | | × | × | × | × |
| BioR | [16] | 2014 | B | Text | | × | | | × | × | × | |
| 3dmarkup radiologist | [17] | 2014 | R | Image | | | × | | × | × | | |
| Vita | [18] | 2014 | R | Image, video | × | | | × | | × | | |
| Marky | [19] | 2014 | R | All type | × | | | | × | | | × |

*(continued)*

**Table 1.** (*continued*)

| Name of annotation system | | Year | Healthcare professional (Practitioner) | Annotated resource type | Category of annotation system | | | Annotation type | | Type of annotation activity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Application | Plug-in | Web | Cognitive | Computational | Manual | Automatic | Semi-automatic |
| Cliosoft dental | [20] | 2014 | D | Image | | | × | × | | × | | |
| Medetect | [21] | 2013 | D | HTML | × | | | | × | | | × |
| Flersa | [22] | 2012 | R | Image | × | | | × | | × | | × |
| SMItag | [23] | 2012 | R | Image | | | × | | × | × | | |
| Mammoapplet | [24] | 2012 | R | Image | | | × | × | | × | | |
| Brat | [25] | 2012 | A | Text | × | | | × | | × | | |
| Idash | [26] | 2012 | D | Text | × | | | × | | × | | |
| MedAt | [27] | 2011 | D | Document | × | | | | × | | | × |
| @note | [28] | 2009 | B | text | × | | | | × | | × | |
| Arthemis | [29] | 2007 | R | Video | × | | | × | | × | | |
| DocAnnot | [30] | 2006 | D, N | Document | × | | | | | | | × |

B: Biologist, D: Doctor, N: Nurse, R: Radiologist, A: all healthcares professional

  - Type: the annotated content can have a type that enhances its content and facilitates access, filtering, searching later.
  - Device: it is the device used to read and annotate the document.
  - Date: represents the creation date of the annotation.
  - Name: the name of PHC.
- Department: it is a part of decomposing the tasks of an organization (Hospital) according to the functions or the nature of these activities. This appointment is used in the professional field.
  - Service: It is a part of decomposing the tasks of a department according to the functions or the type of these activities.
  - Professional (PHC): it is the person (professional healthcare) who reads a document and makes the annotations.
  - Role: it is the function occupied by a professional.
  - Authority: it's the set of tasks that can be done by a professional in his role.
  - Name: it's the name and surname of the annotator.
- Package_document: it's a grouped document set.
  - Document: it's the annotated document.
  - Part_document: professional documents are usually divided into parts.
  - Element: each Part_document consists of a set of elements.
  - Part_element: it is the smallest granularity of document; it is a word, letter etc. In short, it is the annotated passage.
- Specific_concept: in each domain where the annotators are professionals, there are specific concepts related to the latter.
  - Validity: annotation can be associated with date which contains: Start_date, Finish_date, and Cyclic_date. Example: control the vital parameters of the patient today from 8 h (Start_date) to 19 h (Finish_date) every 2 h (Cyclic_date).
  - Scope: specifies the professional that can view the annotation.
  - Importance: a value affected to the annotation which valorizes it.
- Medical_care: each healthcare cycle consists of a set of Healthcare_cycle. Each Healthcare_cycle consists of a:
  - Diagnostic: Contain a detailed anamnesis of:
    - Patient history
    - Family history
    - Socio-economic question
    - Symptom of illness
    - Date of illness
    - Treatment already followed
    - Physical examination of patient
    - Complementary examination: medical image, biological analysis….
- Treatment: it contains the treatment written by the doctor.

- Advice: patient education: how to live with this disease, how to act in case of emergency, how to take their drugs…
- Follow up and observation: this is the last step of the care cycle in which the doctor follows his patient until the stabilization of his condition. In this step, it can also make a strengthening of advice….
- Service aspect: this aspect allows us to clarify the semantic of the annotation. It is used to interpret the meaning of the annotation by the annotator himself or by the software agents.
  – Effect: the effect of annotation is the result of web service called from this annotation.

### 3.2 Relationships Between Concepts

The relationships between the concepts of ontology are described through the data model presented in Fig. 1 as follows. There are only three type of cardinalities used in this model 1..*, 1 and *. An annotation is created by the PHC with a device, at a date and in a place. This annotation is presented by a particular shape. It is pointed to an anchor and related to an annotated content that can be related to another annotated content. This annotated content is a part of the read document. The annotation contains an annotating content that can be related to others annotating contents. An annotating content can have a type. An annotation has an annotated content that is alone, and at the base of this content, annotating content can be created for one or more professionals since this content can be written differently for each destination. Each domain has some specific concept. An annotation is related to Specifics concept.

The annotator, which is a PHC, is identified by a name. The place is a location in a medical department especially in a specific service. Each service has its own PHCs that are classified into categories (medical, paramedic). In the category a PHC can have a role and each role is related to a specific authority. A document is an element of a document package. A document package consists of the already known set of documents grouped together to perform a specific task. A document decomposed to parts, each one of it contains a set of elements (text box, radio button…). The annotated content can be an element or a part of an element (word, sentence…). A professional can have a power to launch tasks (Medical_care). Each healthcare cycle is divided into healthcare phases (Diagnostic – Treatment – Advice - Follow up and observation); the latter are linked together so we can fuse them once again when they are completed and we can follow the annotations of a healthcare cycle at the level of its phase. Each healthcare phase can be divided itself. A healthcare cycle can also be linked to other healthcare cycle that has a relationship between them.

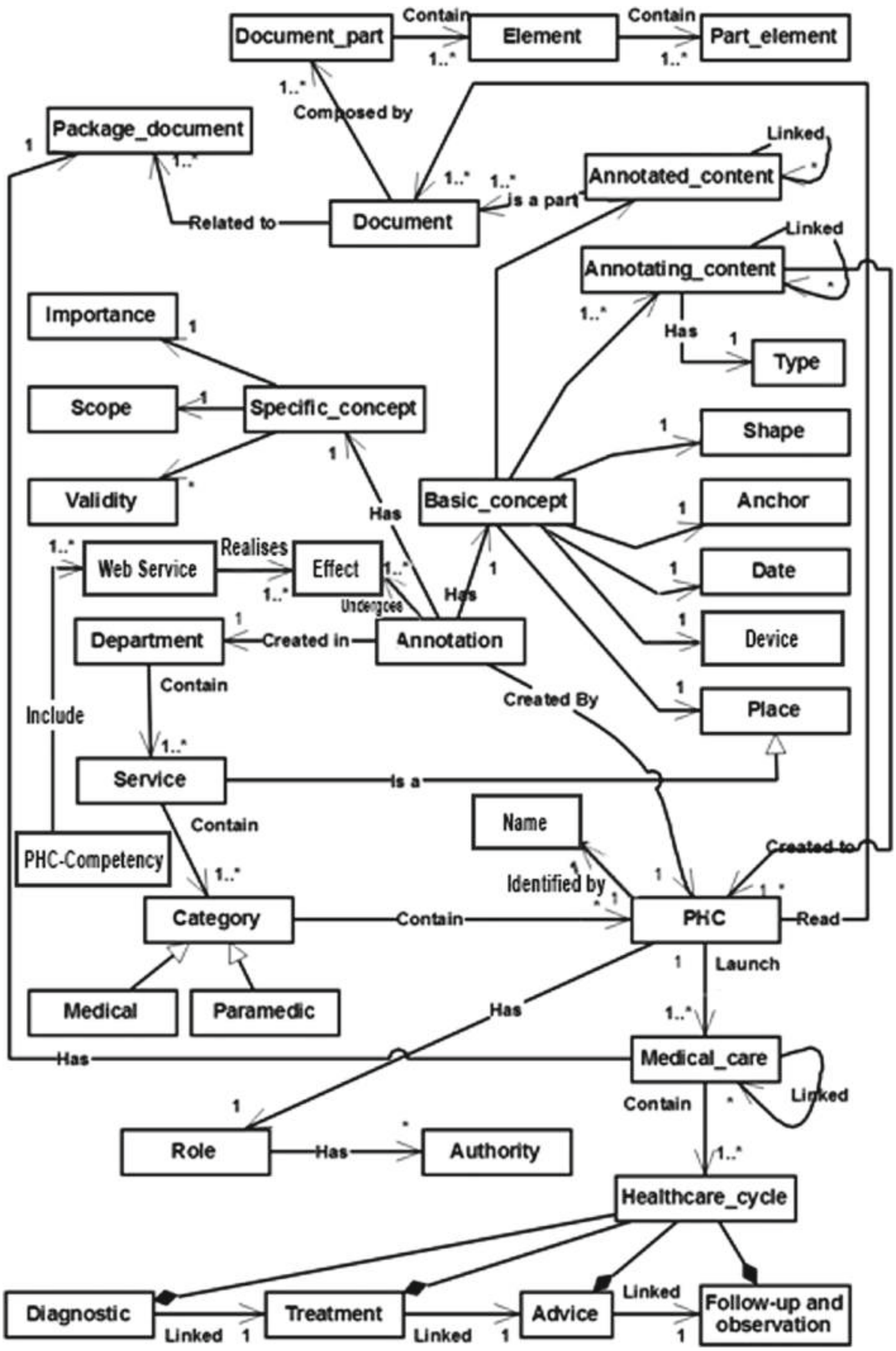


**Fig. 1.** PHC annotation model

## 4 Conclusion and Future Work

In this paper, we studied annotation systems of the digital health domain available in industrial and research areas in order to propose a unified classification of this kind of system that is omnipresent in hospital information systems. This panoramic view provided is based on the classification of thirty different annotation systems developed in the literature over the past two decades. This organization of annotation tools is built on the basis of five criteria: type of annotation (computational/cognitive); category of annotation system (application/plug-in/website); type of annotative activity (manual/semi-automatic/automatic); type of annotated resource (text/Web page/video/image/database) and practitioner (biologist/doctor/radiologist/nurse, etc.). This classification based on criteria, already explained in our study, which are transversal organizational criteria, facilitates the identification of limitations and possible challenges in the area of the medical annotation systems. Based on this, we proposed an ontology that covers the identified challenges and lead to a more intelligent annotation system. In future research, we try to use the results of this study to create an annotation template for PHCs and then try to generalize them to be functional for all professionals in different domains. We are also trying to create the computer services which allow the PHC to be assisted throughout the care cycle.

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# Multirate ECG Processing and k-Nearest Neighbor Classifier Based Efficient Arrhythmia Diagnosis

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**Abstract.** The goal of this work is to make a contribution to the development of computationally efficient multirate Electrocardiogram (ECG) automated detectors of arrhythmia. It utilizes an intelligent combination of multirate denoising plus wavelet decomposition for an effective realization of the ECG wireless implants. The decomposed signal subband features are mined and in next step these are utilized by the mature k-Nearest Neighbor (KNN) classifier for arrhythmia diagnosis. The multirate nature substantially reduces the processing activity of the system and thus allows a dramatic decrease in energy consumption compared to traditional counterparts. The performance of the system is estimated also in terms of the classification performance. Obtained results reveal an overall 22.5-fold compression gain and 4-folds processing outperformance over the traditional equals while securing 93.2% highest classification accuracy and specificity of 0.956. Findings confirm that the proposed solution could potentially be embedded in contemporary automatic and mobile cardiac diseases diagnosis systems.

**Keywords:** Multirate processing · ECG · Arrhythmia · Wavelet · Features extraction · Classification

## 1 Introduction

Cardiovascular diseases have drawn global attention. This is due to its increasing prevalence and incidence [1, 14]. Electrocardiogram (ECG) measures electrical activities with respect to time. Manual examination of cardiac arrhythmias can be time consuming and complicated. This challenge may be solved using computer-aided automatic cardiac decision tools. The computer-aided or pattern-based recognition systems could increase the effectiveness of cardiac health analysis by detecting subtle differences in frequency and amplitude components of the heartbeat [2].

Many scientists have previously explored computer-assisted solutions for cardiac health monitoring as reviewed in [7]. Preprocessing is the first ECG processing stage. The popular ECG denoising methods are the finite impulse response (FIR) filtering,


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principle component analysis (PCA) and Kalman filtering [2, 8]. The extraction of features is one of the essential steps of computer-aided ECG diagnostic solutions. Certain extensively used ECG signal feature extraction approaches are the “Wavelet Transform” (WT), “Discrete Cosine Transform” (DCT) and “Short Time Fourier Transform” (STFT). The pertinent signal features are afterward employed for the classification purpose. Techniques adopted for this purpose are the “Naïve Bias”, the “K-Nearest Neighbor” (KNN), the “Artificial Neural Networks” (ANN) and the “Support Vector Machine” (SVM).

Classical ECG systems are by definition time-invariant [3, 4]. This can lead to inefficient use of system resources and energy consumption [2, 5]. For such signals, an effective solution can be achieved by diminishing the rates of data collection, processing and transmission [5]. In this framework, multirate signal processing tactics have been employed [6]. The subsampling is intelligently employed in the suggested framework. It allows overcoming the downsides of the counter fix rate ECG processing approaches [3, 4]. Therefore, it allows realizing a simplified and power efficient ECG wireless implant with a real-time compression of data.

## 2 Materials and Methods

Figure 1 illustrates the adopted system block level diagram. A description of the different modules of the system is given in the coming subsections.

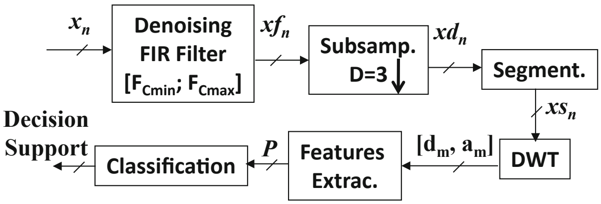


**Fig. 1.** Block diagram of the adopted system

### 2.1 Dataset

In this study, the ECG signals, obtained from a standard ECG dataset are used [1]. 3 different ECG classes the “Wolff-Parkinson-White” (WPW), “Right Bundle Branch Block” (RBBB) and the “Normal Sinus Rhythm” (N) are considered. ECG analog signals are band limited up to 60 Hz and each channel is recorded via an 11-Bit resolution analog to digital converter (ADC). The employed sampling frequency is of 360 Hz. The digitized versions of intended ECG signals are splitted into fixed length segments to split the continuous time signals into ECG impulses. Each impulse is considered as an instance. In order to avoid any biasing an equal representation is selected for each considered class. In this framework, 150 instances are considered for each class. It results in total 450 instances from 3 ECG classes.

## 2.2 Denoising

The digitized signal $x_n$ is denoised by using an offline designed band-pass FIR filter. The denoising diminishes the noise like the "Power Line Interference" (PLI) and "Baseline Wander" (BW) from the ECG signal. It improves the efficiency of collection and classification of the features. The ECG signal's useful frequency range lies between [0.5; 50] Hz [9, 10]. Accordingly, a band-pass linear phase filter is configured offline for the cut-off frequencies of [$Fc_L$ = 0.5; $Fc_H$ = 50] Hz it resulted in a 122[nd] order filter designed for $F_S = 360$ Hz. For proper filtering, $Fc_H$ is kept less than half of the signal sampling rate [5]. Therefore, $F_S = 360$ Hz fulfils this criterion.

## 2.3 Subsampling

The functioning of conventional ECG acquisition and analysis processes is of time-invariant nature [2–4]. Consequently, a worst-case parameterization is enforced [5]. It causes the processing ineffectiveness in the case of time-varying and sporadic ECG signals. These inadequacies can be diminished by using multirate processing approaches [2, 5, 6]. In this framework, the denoised signal $xf_n$ is subsampled with a factor of $D = 4$ to obtain $xd_n = xf_{Dn}$. Subsampling without a prior digital antialiasing filtering can cause aliasing [6]. However, a proper choice of $D$ allows to perform subsampling without prior filtering. In this case, the selected value of $D$ should respect the condition: $D \leq \frac{F_S}{F_{Nyq}} = 3.6$. Here, $F_S = 360$ Hz, $F_{Nyq} = 2.f_{max}$ and $f_{max}$ is the bandwidth of $xf_n$ and is equal to $Fc_H$ = 50 Hz. It shows that for the chosen $D = 3$ subsampling does not cause aliasing.

## 2.4 Segmentation

In order to split the continuous time ECG records into ECG pulses, $xd_n$ is divided in 0.9-s length segments. Each segment, $xs_n$, contains one ECG pulse. The segmentation is realized by using fixed length rectangular windows [6]. The process can be mathematically depicted as:

$$ys_n = \sum_{n=\tau-\frac{L_T}{2}}^{\tau+\frac{L_T}{2}} yd_n w_{n-\tau}.$$

Here, $L_T$ and $\tau$ are respectively the length in seconds and the central time of an intended segment.

## 2.5 Discrete Wavelet Transform

The "Wavelet Transform" (WT) can be mathematically expressed by Eq. (1) where, s and u respectively represent the dilation and the translation parameters.

$$W_x^{\psi}(u,s) = \frac{1}{\sqrt{S}} \int_{-\infty}^{+\infty} x(t)\psi * \left(\frac{(t-u)}{s}\right) dt. \tag{1}$$

A discrete time wavelet transform (DWT) is used for decomposing the $xs_n$. A translation-dilation representation is attained by employing digital filters. In this case, each segment $xs_n$ is decomposed through the "Daubechies Algorithm" based wavelet decomposition process. It consists of half-band low-pass filter and high-pass filter with subsampling with a factor of two. It allows the computation of approximation, $a_m$ and detail, $d_m$, coefficients at each level of decomposition.

The mathematical processes of computing $a_m$ and $d_m$ are respectively depicted by Eq. (2) and Eq. (3). Where, $m$ represents the level of decomposition. In this study a third level of decomposition is employed. Therefore, $m \in \{1, 2, 3\}$. $g_{2n-k}$ and $h_{2n-k}$ are respectively the half-band low-pass and high-pass filters using a subsampling factor of two.

$$\boldsymbol{a_m} = \sum\nolimits_{k=1}^{K_g} \boldsymbol{ys_n} \cdot \boldsymbol{g_{2n-k}}. \tag{2}$$

$$\boldsymbol{d_m} = \sum\nolimits_{k=1}^{K_g} \boldsymbol{ys_n} \cdot \boldsymbol{h_{2n-k}}. \tag{3}$$

### 2.6 Features Extraction

The wavelet coefficients, obtained for each intended subband, $d_1 = [60, 120]$ Hz, $d_2 = [30, 60]$ Hz, $d_3 = [15, 30]$ Hz and $a_3 = [0, 15]$ Hz are used for mining the discriminative and classifiable features. 4 statistical features are extracted from each subband. These are described in the following.

***Energy (E)*** is calculated by adding all the absolute values of subband coefficients. ***Kurtosis of the signal (K)*** is a measure of the curvature of the considered subband coefficients. ***Peak positive value (PV)*** is the maximum positive value of the intended subband coefficients. ***Peak negative value (NV)*** is the maximum negative value of the intended subband coefficients.

### 2.7 Classification

After features extraction, each instance is presented in the form of a reduced data matrix, composed of 16 features. The intended dataset is composed of 3 ECG classes namely the "Normal Sinus Rhythm (N), the "Right Bundle Branch Block" (RBBB) and the "Wolff-Parkinson-White" (WPW). For equal representation, 150 instances are taken into consideration for every class. Thus, in total 450 ECG instances are considered. After features extraction, the resulting data matrix has a size of 450 $\times$ 16. To classify this data matrix, the "k-Nearest Neighbor" (KNN) classification algorithm is employed.

The KNN is well known for its ability of delivering high quality results even for applications wit high complexity [16]. In a data set, the features' distance is used by KNN to decide which data belongs to what class. When the distance in the data is near, a group is formed, and when the distance in the data is far, other groups are formed. A category membership might be the output of the KNN classifier. The categorization of an object is done through the majority vote by its neighbors. That is, the object is added to the class which is most common among its $k$ closest neighbors ($k$ could generally be a small positive whole number). The object is assigned solely to the nearest neighbor's single classification if the $k$ equals one [11].

### 2.8 Evaluation Measures

**Compression Ratio** compares the designed system performance in terms of reduction in the amount of information to be classified compared to the conventional approach where acquired ECG data points are transmitted towards classifier without performing any features selection. If $\boldsymbol{N_r}$ and $\boldsymbol{P}$ are respectively the count of data points to be classified, for a given time length of $\boldsymbol{L_T}$-Sec., in the conventional and the devised approach then the compression ration, $\boldsymbol{R_{COMP}}$, can be calculated as:

$$R_{COMP} = \frac{N_r}{P}.$$

**Computational Complexity** compares the designed system performance with the fixed-rate counter equals in terms of the count of required standard operations like additions, multiplications and divisions [12]. In conventional case, the denoised signal is segmented by employing a rectangular window. It splits the incoming samples sequence in $\boldsymbol{L_T}$-Sec. segments. Each segment is composed of $\boldsymbol{N_r}$ samples. The processing cost of this process is negligible compared to operations like additions and multiplications [12]. Each segment is further split into subbands by using the 3rd level Daubechies wavelet decomposition. It consists of half-band FIR high-pass and low-pass filters with a subsampling factor of two. Let $\boldsymbol{Kg}$ be the order of half-band filters and same filters are employed at all levels of decomposition. It is well known that a $\boldsymbol{Kg}$ order filter performs $\boldsymbol{Kg}$ additions and $\boldsymbol{Kg}$ multiplications [5]. Therefore, the computational complexity of this fixed rate wavelet decomposition process $\boldsymbol{C_{FR-WD}}$ can be mathematically expressed by Eq. (4). This mathematical derivation is also clear from Fig. 2.

$$C_{FR-WD} = \underbrace{3.5 \times Kg.N_r}_{Additions} + \underbrace{3.5 \times Kg.N_r}_{Multiplications}. \tag{4}$$

For the case of designed solution $xf_n$ is firstly subsampled and then $xd_n$ is segmented by employing a rectangular window. Each segment is composed of $N = 0.25 \times N_r$ samples. If $Kg$ is the order of half-band filters and same filters are employed at all levels of decomposition then the computational complexity of this process $C_{P-WD}$ can be mathematically expressed by Eq. (5). If $M = 0.5 \times M_r$ is the count of samples processed by the denoising module then the total computational complexity for the designed front-end processing chain can be expressed by using Eq. (10).

$$C_{P-WD} = \underbrace{0.875 \times Kg.N_r}_{Additions} + \underbrace{0.875 \times Kg.N_r}_{Multiplications} \tag{5}$$

**Classification Accuracy and Specificity** are used to evaluate the overall system precision. The processes may be formally described by means of Eq. (6) and Eq. (7). Where, "True Positives" (TP) and "True Negatives" (TN) are correct classifications. "False Negatives" and "False Positives" (FP) (FN) are wrong classification results [13].

$$Accuracy = \frac{T_P + T_N}{T_P + T_N + F_P + F_N} \times 100\%. \tag{6}$$

$$Specificity = \frac{T_N}{T_N + F_P}. \tag{7}$$

## 3 Results and Discussions

Examples of the considered ECG signal classes are shown in Fig. 2. These incoming signals $x_n$ are denoised by employing the band-pass FIR filter. It improves the expected signal SNR ("Signal to Noise Ratio") and results in an increased classification precision. An example of the filtered version of signal for the (RBBB) class is shown in Fig. 3-a. The de-noised signal $xf_n$ is down-sampled with a factor of $D = 3$. An example of the subsampled versions of signal for the RBBB class is shown in Fig. 3-b.

The decimated signal $xd_n$ is splitted into fixed length segments of 0.9 s durations. Onward each segment is decomposed into subbands via the application of a 3 stages wavelet decomposer. Computational Gain of the designed front-end processing chain over the fixed-rate counterpart is calculated by using Eq. (4) and Eq. (5). It results in 4-fold reduction in terms of count of additions and multiplications of the designed solution compared to the fixed-rate counterpart.

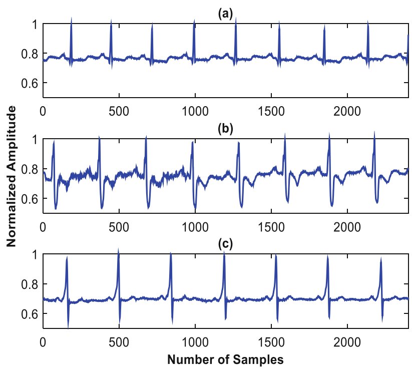


**Fig. 2.** Examples of the ECG signals. (a) (N), (b) (RBBB) and (c) (WPW).

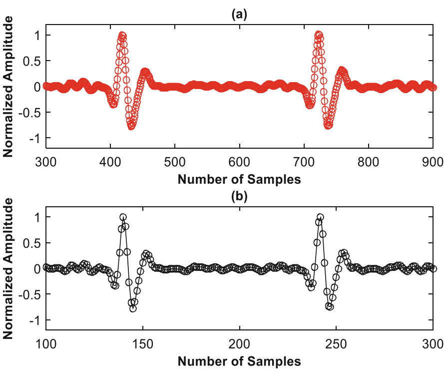


**Fig. 3.** Example of denoised RBBB signal (a) and example of decimated RBBB signal (b).

In next step, four statistical features are extracted from each subband. In this way each intended instance is presented by 16 parameters. The compression gain of the designed framework over the conventional equal is computed by using $R_{COMP} = \frac{N_r}{P}$. It results in 22.5-fold real-time compression gain of the proposed solution over the conventional equal.

Above results show that the devised solution outperforms the conventional equals in terms of processing efficiency and compression gain. However, due to the multirate processing feature it may lose its performance in terms of the precision. Therefore, the overall performance of the system is measured in terms of the accuracy of the classification process. The KNN classifier is employed with $k = 5$ configuration. Training and testing sets are made of 3 distinct classes. Total 450 instances are used. The 10-fold cross validation technique is used for all experiments. Classifier's performance is quantified in terms of the accuracy and the specificity by using Eq. (6) and Eq. (7). The obtained results are summarized in Table 1. It shows that for the studied case, the obtained classification accuracies are high. The highest classification accuracy is obtained for the (WPW) class, 93.2%. The average classification accuracy of the designed framework is 91.87% with an average specificity of 0.947. It concludes that the suggested approach not only attains the outperformance in terms of compression gain and processing efficiency but it also secures an appropriate ECG arrhythmia classification precision.

**Table 1.** Classification performance for 3 class ECG dataset

| ECG class | Classification accuracy (% age) | Specificity | Average accuracy (% age) | Average specificity |
|---|---|---|---|---|
| Normal (N) | 90.3 | 0.935 | 91.87 | 0.947 |
| RBBB | 92.1 | 0.951 | | |
| WPW | 93.2 | 0.956 | | |

## 4 Conclusion

In this paper a novel multirate ECG processing, subbands decomposition and classification framework is designed. The decomposed signal subband features are mined and in next step these are utilized by the mature k-Nearest Neighbor (KNN) based classifier for an effective arrhythmia diagnosis. The multirate feature diminishes the system processing load. It is shown that because of the multirate feature the system has attained the 4 folds diminishing in the count of processing load as compared to the conventional equals. Additionally, the features extraction process has induced 22.5 times compression gain in the system. It also assures a same factor of processing load diminishing at the post classification stage. The overall performance of the system is quantified in terms of the accuracy of the classification process. For the studied case the designed framework has attained the highest classification accuracy of 93.2% and specificity of 0.956. It assures that the devised solution is a potential candidate to be embedded in contemporary automatic and mobile cardiac diseases diagnosis systems.

A possible future direction of work is to adopt a model-based testing methodology for validating the proposed approach [15–18]. Integration and investigation of event-based processing modules [19–22] in this system is another prospect.

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# Comparative Study of Relevant Methods for MRI/X Brain Image Registration

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**Abstract.** Several methods of brain image registration have been proposed in order to overcome the requirement of clinicians. In this paper, we assess the performance of a hybrid method for brain image registration against the most used standard registration tools. Most traditional registration tools use different methods for mono- and multi-modal registration, whereas the hybrid registration method is providing both mono and multi-modal brain registration of PET, MRI and CT images. To determine the appropriate registration method, we used two challenging brain image datasets as well as two evaluation metrics. Results show that the hybrid method outperforms all other standard registration tools and has achieved promising accuracy for MRI/X brain image registration.

**Keywords:** MRI/X brain image registration · Hybrid method · Standard registration tools · Brain diagnosis

## 1 Introduction

Hundreds of millions of people worldwide suffer from neurological disorders, and early detection coupled with appropriate treatment can generally cure these diseases. In this context, Computer Aided Diagnosis (CAD) explains the need to design automatic and semi-automatic tools to effectively process brain medical imaging. This could help clinicians to detect affected organs in order to specify appropriate treatments. However, there are still many challenges (*e.g.* noise, resolution, partial volume effect ...) that need to be investigated. There are several brain medical imaging modalities, and each of them has a different aspect of anatomy and/or functionality. Anatomical medical imaging (*e.g.* Magnetic Resonance Imaging (MRI), Computed Tomography (CT) ...) provides information on the structure, the shape, the edge, and the contents of organs. Functional medical imaging (*e.g.* Positron Emission Tomography (PET) ...) focuses on the function of organs, tissues or cells. In clinical routines, experts generally


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refer to both functional and structural aspects conjointly. In particular, MRI is frequently coupled with CT, MRI atlas and PET. However, a registration step is required in order to ensure effectively the complementarity of structural and functional images. Research on registration process is driven either by the type of attributes (geometric *vs.* iconic methods), the type of transformation (rigid *vs.* non-rigid) or the involved images (monomodal *vs.* multimodal) (Fig. 1). The principle of geometric registration methods consists in extracting geometric primitives from the two images to be registered (*e.g.* points, curves, surfaces ...), whereas iconic registration methods operate directly on the intensities. Furthermore, the rigid registration methods aim to correct the geometric transformations, including translation, rotation, shear, and scaling, whereas the non-rigid registration methods are carried out using localized stretch of the images. In this type of transformation, all kinds of deformation fields can be used (*e.g.* splines, B-spline, elastic model ...) [1]. For the monomodal registration methods, the two images are coming from the same modality (*e.g.* MRI scans, CT scans ...), whilst in the multimodal registration ones, the two images come from two different modalities (*e.g.* MRI and PET, MRI and CT ...) [2]. Generally, one of the key challenges in brain image registration is its veracity. This is because of the limitations in the registration methods, which are dependent on the quality of MRI/X parameters as well as the inaccuracy on the non-linear transformations. In addition to the registration errors, several registrations methods suffer from the extensive computational cost. To circumvent these limits, atlas-based registration coupled with standard softwares (such as SPM, ITK ... ) are commonly used. Indeed, various studies are using this framework in order to investigate Parkinson disease [3], brain tumors using CT/MRI [4] or PET/MRI [5], and Alzheimer disease [6]. Additionally, challenges can arise where mono- and multimodal registration is required sequentially. To this end, we evaluate a hybrid method that may handle mono- and multi-modal registration according to the same technique. In fact, this paper is dedicated to determine the best tool for mono- and multi-modal registration for MRI/X brain images, such that X refers in our case to PET, CT and MRI atlas. We compare three widely brain image registration tools (SPM, ITK-Snap, 3D Slicer) against an accurate hybrid registration method from the state-of-the-art.

The rest of this paper is organized as follows. Section 2 shows the studied registration methods. Then, we present the clinical datasets and the evaluation protocol in Sect. 3. We detail experimental results in Sect. 4. Finally, a conclusion with some directions for future work are discussed in Sect. 5.

## 2 Registration Methods

**ITK-Snap.** Insight Segmentation and Registration Toolkit (ITK-Snap) is a popular tool for segmenting and registering medical images such as MRI, PET and CT [7]. It is an open source software widely used by clinicians and non-computer researchers. ITK-Snap allows manual and automatic medical image registration. This software groups several methods of registration based on the intensity. For

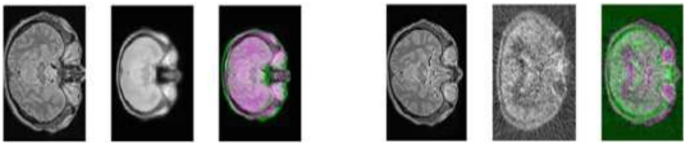
(a) (b)

**Fig. 1.** MRI/X brain image registration: (a) mono-modal MRI/MRI atlas (from left to right: MRI image, MRI atlas and superposed images), (b) multi-modal MRI/PET (from left to right: MRI image, PET image and superposed images).

the automatic registration, the similarity measures included in ITK-Snap are mutual information, cross-correlation, and intensity difference. The transformation model included is affine and rigid transformation. This tool helps the users to locally find optimal rigid and affine transformations dynamically. For the manual registration, it is enough to determine the values of $x$, $y$, and $z$ for the translation, rotation, and scaling. In our case, we used the same settings as [8].

**SPM.** Statistical Parametric Mapping (SPM) is an open source software for analysing functional brain imaging data (*e.g.* fMRI, PET, SPECT ...). It uses several setting options, which are referred to the Powell optimization algorithm. These options are: objective function, separation, tolerance and histogram smoothing. For the objective function, SPM uses either mutual information, normalized mutual information, or entropy correlation coefficient for multimodal registration, and normalised cross-correlation for monomodal registration. Separation, which is the average distance between sampled points, is of 8 mm for fMRI and 12 mm for PET [9]. SPM applies Gaussian smoothing to the $256 \times 256$ joint histogram. For similarity measurement, SPM includes the Nearest Neighbor, trilinear, and B-spline interpolation, and trilinear interpolation proved to be the most adequate for MRI and PET. For monomodal registration, SPM presents other parameters for estimating deformations (*e.g.* bias regularisation). Also, a mutual information-based affine registration with the tissue probability maps is used to obtain approximate alignment, with a smoothness value of 0 mm.

**3D Slicer.** 3D Slicer [10] supports rigid, affine and deformable registration. It includes point-surface and intensity-based registration. In fact, individual intensity-based registration modules depend on the used similarity metric (mutual information and cross-correlation) and flexibility of the transformation settings (rigid, affine, B-spline and dense deformation fields) [11]. The choice of algorithms depends on the organs' anatomy (*e.g.* brain, lungs ...), modality (multimodal *vs.* monomodal), performance (robustness *vs.* speed), and level of interaction. Besides, 3D Slicer uses parametric maps in order to align anatomical volumes. The registration process consists of three steps (Fig. 2). Firstly, it allows to align subject B: T2 according to the MRI mode T1 of the same subject. Secondly, it aligns subject A: T2 according to A: T1. Lastly, the registration is performed between the registered subject B: T1 and the fixed subject A: T1.

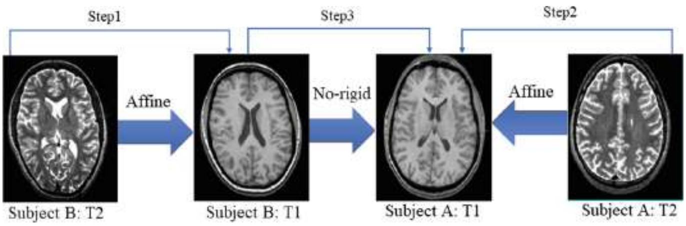


**Fig. 2.** Flowchart of 3D Slicer.

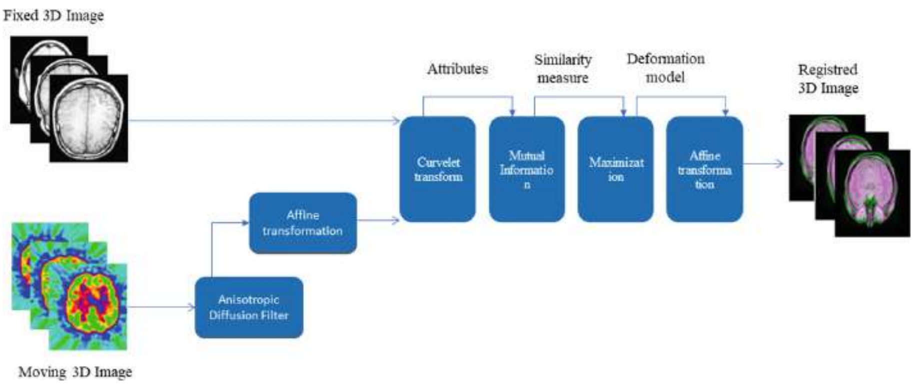


**Fig. 3.** Flowchart of the hybrid method.

**Hybrid Method.** The hybrid method is a unified tool for mono- and multi-modal 3D brain image registration. In fact, we extended the multi-modal 2D brain image registration work of [2]. The method is composed of five steps (Fig. 3) and its main contribution lies in adopting adaptive mutual information based on curvelet coefficients. Firstly, an anisotropic diffusion filter [12] denoises the moving image. Secondly, an affine transformation is applied on the moving image using transformation matrices (translation, rotation, scaling and shear). Thirdly, features from the two images are extracted using curvelet transform [13], and the Gaussian probability density function [14,15] is used to model the distribution of curvelet coefficients. Then, an adaptive mutual information, based on a conditional entropy between the coefficients of curvelet, aligns the images, and mutual information parameters are optimized using the maximum likelihood [16]. Finally, to align the moving image on the reference one, an affine transformation is adapted in order to deal with common distortions.

## 3 Materials

In this section, we present the used 3D medical image datasets and the evaluation protocol that we adopted in order to evaluate the compared registration methods.

**Clinical Datasets.** To compare the performance of the studied methods, two datasets were investigated. The first dataset, from the Retrospective Image Registration Evaluation (RIRE) project [17], consists of eight 3D triplets of PET, MRI and CT images of brain. The MRI voxel size is of 1.25, 1.28 and 4 mm in the $x$, $y$ and $z$ directions, respectively. The PET voxel size is (2.59 mm, 8 mm, 8 mm) in *(x, y, z)*. MR images have been obtained using a Siemens SP 1.5 T scanner, and the PET ones with a Siemens/CTI ECAT 933/0816 scanner. The CT voxel size is equal to (0.65 mm, 0.65 mm, 4.0 mm) in *(x, y, z)*. CT images have been acquired using a Siemens Somatom Plus scanner. The second dataset is provided by the Center for Addiction and Mental Health of Canada (CAMH). It includes a collection of nine 3D images. For fixed MRI images, voxel dimensions along the $x$, $y$, and $z$ axes are 0.86, 0.86, and 3 mm, respectively. These images are captured by a Signa 1.5-T scanner from General Electric Medical System. PET images are captured by a Scanditronix PET scanning system, GE 2048-15B, with $x$, $y$ and $z$ voxel dimensions equal to 2 mm, 2 mm and 6.5 mm, respectively.

**Evaluation Metrics.** To quantify the accuracy of the studied methods, we measured Normalized Cross-Correlation Coefficient (NCCC) (1) and Normalized Mutual Information (NMI) (2) scores. NCCC evaluates the degree of similarity between two medical images. In fact, cross correlation is less sensitive to linear changes in amplitude and illumination in the images to be compared. A high value of NCCC shows the high accuracy of the registration. Furthermore, NMI, which is a measure of the quality of the registration, is defined in terms of the entropy $H$ of the image. It measures the proximity between the fixed source image $I_f$ and the moving one $I_m$. The more the value of normalized mutual information is, the more the accuracy of the registration process is.

$$NCCC = \frac{\sum_X^{x=1} \sum_Y^{y=1} \left(I_m(x,y) - \overline{I_m}\right)\left(I_f(x,y) - \overline{I_f}\right)}{\sqrt{\sum_X^{x=1} \sum_Y^{y=1} \left(I_m(x,y) - \overline{I_m}\right)^2 \left(I_f(x,y) - \overline{I_f}\right)^2}}, \tag{1}$$

$$NMI = \frac{2(H(I_f) + H(I_m))}{H(I_f) + H(I_m) + H(I_f|I_m) + H(I_m|I_f)}, \tag{2}$$

where, $H(\ )$ and $H\ (\ |\ )$ denote marginal and conditional entropies, respectively.

## 4 Results

We compare qualitatively and quantitatively the studied hybrid method against the other aforementioned softwares for MRI/MRI, MRI/CT, and MRI/PET images.

**Qualitative Evaluation.** Figures 4 and 5 show some samples of 3D slices before and after mono- and multi-modal registrations. For the multimodal case, PET and CT refer to the moving image and the MRI image is the fixed one. Obtained results prove the performance of the Hybrid Method (HM) comparatively to SPM, ITK-Snap and 3D Slicer (Fig. 4). Monomodal registration is similar to multimodal registration, in except for the modality of the moving image (Template MRI image), which is the same of the source image (Fig. 5). We conclude that the registered images by the hybrid method show a slight improvement in the accuracy of image registration and sharpness, since that contours in these images are better represented than those of registered images using SPM, ITK-Snap and 3D Slicer. Indeed, the representative cases of the superposition of the source image and the registered one based on the hybrid method allow good boundary estimation. The visual evaluations of the outputs show that the hybrid method allows a reliable registration of MRI/PET, MRI/CT or MRI/MRI scans. This can be explained by many reasons. In fact, the use of an anisotropic diffusion filtering ensures the maximization of PET image homogeneity and the minimization of the diffusion at the edges. Furthermore, the aim behind the use of a multi-scale and multidirectional geometric transform, which is the curvelet transform, is the optimal sparse representation of smooth objects with discontinuities along curves. Then, adaptive mutual information coupled with curvelet coefficients ensures the insensitivity to the permutations of intensity while handling simultaneously the positive and negative intensity correlations.

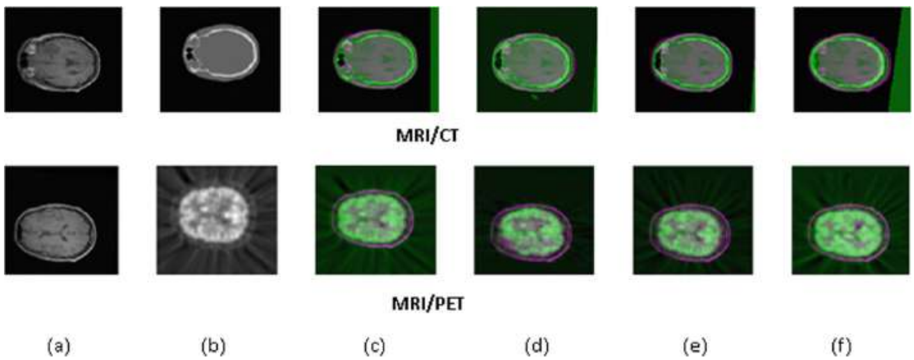


**Fig. 4.** Examples of MRI/X multimodal registration: (a) MRI image, (b) X image, superposed images using (c) HM, (d) SPM (e) ITK-Snap, and (f) 3D Slicer.

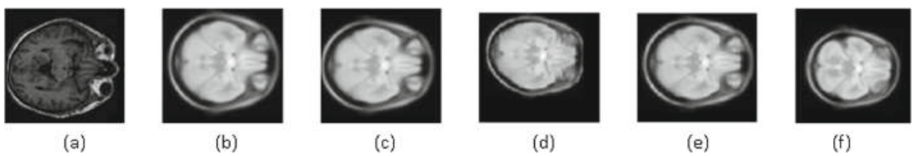


**Fig. 5.** Example of MRI/MRI monomodal registration: (a) MRI image, (b) MRI atlas image, registered images using (c) HM, (d) SPM, (e) ITK-Snap, and (f) 3D Slicer.

**Quantitative Evaluation.** The average NCCC and NMI values resulting from the analysis of different mono- and multi-modal registration methods of MRI brain images from the CAHM dataset are summarized in Table 1, whilst Table 2 illustrates MRI(T1)/PET registration results using the RIRE dataset. It is clear that both NMI and NCCC values given by the HM for the mono- and multi-modal registrations are better than those given by the other three widely used tools. The superiority of HM is confirmed by the boxplots of the four compared methods for registering MRI/CT and MRI(PD)/PET scans (Fig. 6). It should be pointed out that the nature of the images to be aligned can be very diverse and it affects considerably the choice of the registration method to be adopted. The hybrid method allows to align effectively images from the same modality as well as from different modalities. The nature of the modalities considered, as well as the type of the imaged organ, also influences the choice of the method. Likewise, the dimensionality of the input images could also be taken into consideration. Although no available registration method is perfect, research is being done to improve the results, while reducing the rate of registration error. This could increase the diagnosis confidence by improving the diagnosis accuracy.

**Table 1.** Average NMI and NCCC values resulting from the studied mono and multi-modal registration methods using the CAHM dataset (best values are in bold).

| | | NMI | | | | NCCC | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Image pair | HM | SPM | ITK | 3D Slicer | HM | SPM | ITK | 3D Slicer |
| Monomodal | 1 | **0.0344** | 0.0087 | 0.0089 | 0.0630 | **0.2666** | 0.2226 | 0.0050 | 0.2623 |
| | 2 | **0.0085** | 0.0047 | 0.0032 | 0.0072 | **0.2010** | 0.1718 | 0.0215 | 0.1995 |
| | 3 | **0.0561** | 0.0075 | 0.0064 | 0.0495 | **0.2609** | 0.0259 | 0.0054 | 0.2520 |
| | 4 | **0.0887** | 0.0093 | 0.0081 | 0.0802 | **0.2381** | 0.0103 | 0.0078 | 0.2358 |
| | 5 | **0.0930** | 0.0075 | 0.0063 | 0.0912 | **0.2567** | 0.0505 | 0.0126 | 0.2468 |
| | 6 | **0.1333** | 0.0526 | 0.0526 | 0.1140 | **0.2518** | 0.0430 | 0.2318 | 0.2566 |
| | 7 | **0.1102** | 0.0351 | 0.0281 | 0.1021 | **0.2135** | 0.1270 | 0.0512 | 0.2048 |
| | 8 | **0.1011** | 0.0513 | 0.0426 | 0.0977 | **0.2017** | 0.0334 | 0.1882 | 0.1975 |
| | 9 | **0.0284** | 0.0476 | 0.0440 | 0.0469 | **0.2543** | 0.1345 | 0.1567 | 0.2491 |
| Multimodal | 1 | **0.0766** | 0.0578 | 0.0598 | 0.0690 | **0.2408** | 0.2329 | 0.2395 | 0.2343 |
| | 2 | **0.0331** | 0.0161 | 0.0165 | 0.0122 | **0.2682** | 0.1839 | 0.1858 | 0.1561 |
| | 3 | **0.0972** | 0.0728 | 0.0741 | 0.0641 | **0.2486** | 0.2373 | 0.2301 | 0.2362 |
| | 4 | **0.0603** | 0.0356 | 0.0344 | 0.0323 | **0.2580** | 0.2115 | 0.1884 | 0.1777 |
| | 5 | **0.0823** | 0.0794 | 0.0774 | 0.0783 | **0.2351** | 0.2264 | 0.2287 | 0.2279 |
| | 6 | **0.0963** | 0.0831 | 0.0813 | 0.0602 | **0.2483** | 0.2405 | 0.2462 | 0.2444 |
| | 7 | **0.0719** | 0.0623 | 0.0619 | 0.0457 | **0.2556** | 0.1627 | 0.2310 | 0.2131 |
| | 8 | **0.0845** | 0.0674 | 0.0678 | 0.0678 | **0.2381** | 0.1376 | 0.2115 | 0.2099 |
| | 9 | **0.0643** | 0.0439 | 0.0511 | 0.0589 | **0.2467** | 0.1873 | 0.2098 | 0.2125 |

**Table 2.** Average NMI and NCCC values resulting from the different multimodal registration methods using the RIRE dataset (best values are in bold).

| | NMI | | | | NCCC | | | |
|---|---|---|---|---|---|---|---|---|
| Image pair | HM | SPM | ITK | 3D Slicer | HM | SPM | ITK | 3D Slicer |
| 1 | **0.0830** | 0.0798 | 0.0740 | 0.0790 | **0.2473** | 0.2255 | 0.2363 | 0.2457 |
| 2 | **0.0780** | 0.0723 | 0.0671 | 0.0723 | **0.2651** | 0.2451 | 0.2478 | 0.2537 |
| 3 | **0.0498** | 0.0387 | 0.0352 | 0.0405 | **0.2726** | 0.2343 | 0.2275 | 0.2336 |
| 4 | **0.0391** | 0.0288 | 0.0266 | 0.0340 | **0.2139** | 0.1799 | 0.1554 | 0.2066 |
| 5 | **0.0643** | 0.0459 | 0.0406 | 0.0591 | **0.2401** | 0.2246 | 0.1965 | 0.2251 |
| 6 | **0.0765** | 0.0576 | 0.0520 | 0.0657 | **0.2542** | 0.2394 | 0.2378 | 0.2474 |
| 7 | **0.0605** | 0.0553 | 0.0510 | 0.0515 | **0.2726** | 0.2419 | 0.2539 | 0.2522 |
| 8 | **0.0763** | 0.0698 | 0.0631 | 0.0607 | **0.2642** | 0.2446 | 0.2487 | 0.2542 |

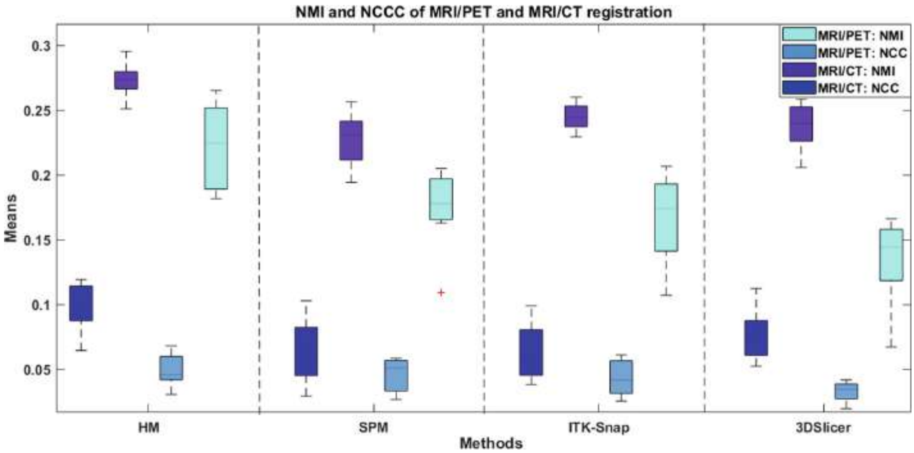


**Fig. 6.** Comparing boxplot distributions of the four studied methods for the registration of MRI(PD)/PET and MRI/CT brain images from the RIRE dataset.

## 5 Conclusion

In this work, a comparative study of a hybrid registration method with standard registration tools is investigated for 3D brain images. The hybrid method uses mutual information based on conditional entropy for the detection of the similarity criteria, while ensuring mono- as well as multi-modal registrations. However, the standard tools use different methods to align different brain image modalities. Qualitative and quantitative evaluations show the effectiveness of the hybrid method against all other studied methods. For the brain case, rigid registration is sufficient, but for other organs, non-rigid registration is required. For that, we plan to test the hybrid method on other organs using diverse medical imaging tools while comparing it with non-rigid registration tools.

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# Machine Learning Classification Models with SPD/ED Dataset: Comparative Study of Abstract Versus Full Article Approach

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**Abstract.** In response to the researchers need in the bio-medical domain, we opted for automating the bibliographic research stage. In this context, several classification models of supervised machine learning are used. Namely the SVM, Random Forest, Decision Tree, KNN, and Gradient Boosting. In this paper, we conduct a comparative study between experimental results of full article classification and abstract classification approaches. Furthermore, we evaluate our results by using evaluation metrics such as accuracy, precision, recall and F1-score. We observe that the abstract approach outperforms the full article approach in terms of learning time and efficiency.

**Keywords:** Text classification · Data mining · Supervised machine learning · Medical informatics · Public health

## 1 Introduction

In the vast field of artificial intelligence, machine learning is called upon to play a central role allowing machines to learn automatically in the context of scientific research. In fact, the field of scientific research seems to be a challenging task and can generate difficulties for researchers. In this paper, we are interested in the epidemiological research domain. Here is a list of some of today's challenges; 1) Research in medicine requires an efficient working methodology to better attain pertinent results, confirm/affirm or complete a hypothesis or theory, evaluate a procedure or a program, minimize bias, etc., 2) Medical researchers face challenges in epidemiological research, such as the choice of population, sample size, time of study, and target knowledge base; the selection of reference subjects; the required budget, data collection, 3) Developing coherent epidemiological research requires the integration of knowledge and skill, 4) Based on the results of [2], one of the major challenges of this specified


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domain is the literature review task which should be exhaustive. In this paper, we focus on the last aforementioned challenge. To overcome this problem, machine learning techniques and algorithms are recommended. In our work, we are concerned with several machine learning methods namely the Support Vector Machine (SVM), K Nearest Neighbor (KNN), Gradient Boosting (GB), Random Forest (RF), Decision Tree (DT), Multi-Nominal Naive Bayes (MNB) and Logistic Regression (LR).

The originality of our work lies in the creation of a new public database SPD/ED in the biomedical domain based on title, abstract, keywords and full scientific papers. Our database is a collection of several scientific papers classified into four different categories according to the taxonomy of the epidemiological studies (Analytic, descriptive, Meta-Analysis and Others) [5]. Based on the aforementioned machine learning methods, we will conduct a comparative study between the text classification task based on the abstract versus the full article.

The paper is organized as follows. Section 2 explains basic concepts of machine learning methods. Related work is discussed in Sect. 3. In Sect. 4, we present our method. Section 5 discusses the experimental results. Section 6 concludes the paper and outlines areas for future research.

## 2 Machine Learning

In our work, we are interested on text classification, defined as the process of associating a category (or class) with free text, based on the information it contains, is an important element of information retrieval systems. In our work, we deal with the text classification challenge and accuracy problem. In fact, the main challenge consists in, for each new entry, being able to determine to which category this entry belongs. Associating a class with free text is a costly and difficult task, therefore the automation of this task has become a challenge for the scientific community. To help the scientific community the task of Text classification is assisted by the machine learning.

### 2.1 Different Types of Approaches

There are several Machine learning methods: supervised, unsupervised, reinforcement and semi-supervised learning. In our work, we are interested on the supervised learning.

### 2.2 Machine Learning Algorithms

The objective of machine learning is to recognize among data structures that are difficult to detect manually. From these structures, we seek to classify new textual data. In our work, we focus on the classification of scientific papers in the epidemiological domain based on the taxonomy of the epidemiological studies.

#### 2.2.1 Decision Tree (DT)

Decision trees are classification rules which base their decisions on a series of tests associated with a set of attributes. These tests are organized in a tree structure. The internal nodes are called decision nodes. Each decision node is labeled by a test which can be applied to any description of an individual in the population.

### 2.2.2 Support Vector Machine (SVM)

Support Vector Machines is a phenomenon f (possibly non-deterministic) which, from a certain set of inputs x, produces an output $y = f(x)$. This approach, often translated by the name of Support Vector Machine (SVM), is a class of learning algorithms initially defined for discrimination and prediction of a binary qualitative variable. The main objective is to find f from the only observation of a certain number of input-output pairs $\{(xi,\ yi)\colon i = 1, \ldots, n\}$. Among its advantages, SVM overcomes various common problems related to the recognition of shapes.

### 2.2.3 K-Nearest Neighbors (KNN)

The principle of this model consists in choosing the k data closest to the point studied in order to predict its value. The objective is to make a classification without making a hypothesis on the function $y = f(x1, x2, \ldots, xn)$ which links the dependent variable y to the independent variables $x1, x2, \ldots, xn$. Otherwise, the idea of the KNN algorithm is for a new observation $(u1,\ u2, \ldots, up)$ to predict the k observations that are most similar to it in the training data [1].

### 2.2.4 Multi-nominal Naïve Bayes (MNNB)

The Multi-Nominal Naïve Bayes classifier is derived from Bayesian decision theory. It is a fundamental statistical approach in pattern recognition. Bayesian decision theory chooses the best decision among the possible decisions based on these laws and the costs associated with each decision. The objective consists in finding a decision rule which minimizes an average cost and in defining which decision (action) to take according to the observed entity.

### 2.2.5 Random Forest (RF)

The algorithm of "random forests" was proposed by Leo Breiman and Adèle Cutler in 2001 [3]. It performs parallel learning on multiple decision trees randomly constructed and trained on subsets of data different. The ideal number of trees, which can go up to several hundred or more, is an important parameter: it is very variable and depends on the problem.

### 2.2.6 Gradient Boosting (GB)

This boosting technique is mainly used with decision trees (it is then called Gradient Tree Boosting). Again, the main idea is to aggregate several classifiers together but to create them iteratively. These "mini-classifiers" are generally simple and parameterized functions, most often decision trees, each parameter of which is the split criterion of the branches.

## 3 Related Work

In reference [5], the authors presented the various classic and new techniques for classifying texts: the preprocessing of documents such as tokenization, the removal of stop words, stemming; Lemmatizing, machine learning algorithms for document modeling; representation of document characteristics, optimal data representation; learning based on machine learning classifiers; measuring the performance of the classification model based on evaluation methods and performance metrics.

The authors of reference [5], presented five classifiers (SVM, NB, KNN, Decision Tree and Decision Table) with three different versions of the database. In addition, accuracy and scalability are calculated to evaluate and examine the advantages and disadvantages of them for Arabic TC based on the efficient tools of machine learning (Weka and RapidMiner).

In reference [4], the authors summarized the eminent multi-class classifiers, based on the literature, in order to apply them to evaluate on a new benchmark dataset of Vietnamese News (VNNews-01). In the data collect process, they are referred to more than thirty Vietnamese online newspaper websites and grouped into twenty-five categories. They added that their work might promote the text mining research in Vietnam.

Some authors present a comparative study of three machine learning algorithm to do the task of classifying human facial expression. Then, they analyzed the main performance. In the experimental study process, they introduced 23 variables calculated from the distance of facial features as the input in the classification phase. As output, they defined seven categories, such as: angry, disgust, fear, happy, neutral, sad, and surprise. As experimental results, they recorded 75.15% of K-Nearest Neighbor (KNN)'s accuracy, 80% for Support Vector Machine (SVM), and 76.97% for Random Forest algorithm. As for the result using the largest amount of data, the accuracy is 98.85% for KNN, 90% for SVM, and 98.85% for Random Forest algorithm [6].

## 4 Method

### 4.1 Data Collection

In our work, we focused on supervised learning. To do so, we collected a set of labeled scientific articles from different scientific journals including Science direct, PubMed, Google scholar, etc. In addition, scientific articles were classified in 4 different predefined classes related to the taxonomy of epidemiological study, including Descriptive, Analytic, Meta-Analysis and Experimental. The several categories' definitions are presented in Table 1.

Data collection was performed on the basis of two different approaches. The first approach is only interested in the Abstract part. We notice that, in the field of epidemiology, the Abstract part is composed of different parts in particular Aim/Introduction/Purpose, Methods, Results and discussion and conclusion. The first approach reveals a first database made up of 300 abstracts per category. The second approach is to collect the full article without omitting any section from Abstract to the references. This exercise led us to the creation of a second extended database of 300 articles by category. Figures 1 and 2 exemplify the distribution of scientific papers according to their categories.

**Table 1.** Label encoding

| Category code | Category name | Definition |
|---|---|---|
| 0 | Analytic study | Raise etiological hypotheses by comparing the prevalence of the event in exposed and unexposed subjects |
| 1 | Descriptive study | Describe phenomena and their geographic distribution and temporal |
| 2 | Meta-Analysis study | Assess the effect of a treatment used on comparable populations, by combining the results of multiple studies |
| 3 | Experimental study | Intervene on the exhibition status of subjects. It can affect the factor (s) of exposure, the time of exposure and the people exposed |

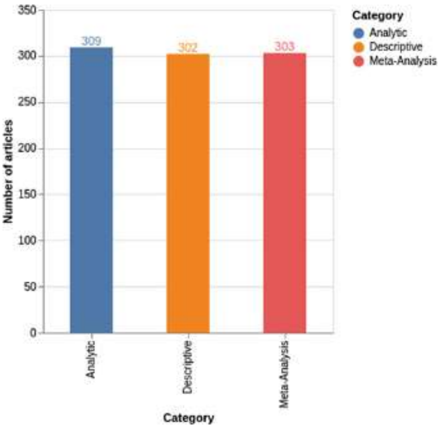


**Fig. 1.** The distribution of articles across the different values of labels/article.

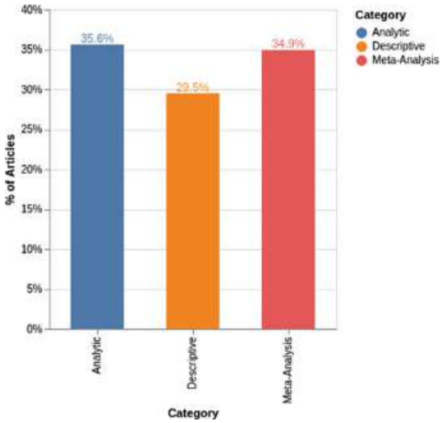


**Fig. 2.** Histogram representation of the articles/label Percentage

It is worth noting, that this is a critical step since this task is normally performed manually. The state of the art of existing databases shows that there is no standard corpus containing scientific articles classified according to the taxonomy of epidemiological studies. Scientific papers are labeled according to different predefined classes according to the taxonomy of the epidemiological study. For that reason, in the data collect process, we were aware that the quality of data plays a vital role in the training data process and the calculation of the accuracy score of any machine learning classification algorithm. Based on the carefully selected data, the machine learning algorithms can learn the patterns and correlations in the data.

### 4.2 Data Preprocessing

In order to transform raw data into an understandable format, we aim to apply data preprocessing techniques to build machine learning classifier. In fact, the data should be cleaned and preprocessed to eliminate characteristics of less important data and improve accuracy. For this purpose, we used machine learning techniques such as lowercasing which defines a common approach to reduce all the text to lower case for simplicity, Tokenization which assumes splitting text into tokens, Punctuation Removal which is a form of pre-processing to filter out useless data and Stop words Removal.

### 4.3 Data Representation

The TF * IDF (for Term Frequency * Inverse Document Frequency) is the result of a calculation, in the algorithm of search engines, allowing to obtain a weight, an evaluation of the relevance of a document compared to a term, taking into account two factors: the frequency of this word in the document (TF) and the number of documents containing this word (IDF) in the corpus studied. The TF * IDF is expressed as follows:

$$w_{i,j} = tf_{i,j} \times log\left(\frac{N}{df_i}\right)$$

Where $tf_{i,j}$ = number of occurrences of $i$ in $j$, $d_i$ = number of documents containing of $i$, $N$ = total number of documents.

### 4.4 Method

In our work, we compared 6 classifiers of supervised learning that learn and predict a categorical response that includes 4 categories as mentioned before. We adopted performance measures to assess the performance of classifiers, in particular accuracy, precision, recall and f1-score. We studied the performance measures of each classifier compared to all scientific papers. The performance measurement values reflect the careful selection of data from our database from the various scientific journals. We compared classifiers based on their respective best performance.

### 4.5 Performance Metrics

In this subsection, we will focus on indicators that measure the quality of the model. To measure the performance of this classifier, we must distinguish 4 types of elements classified for the desired class namely: True Positive, False Positive, True Negative and False Negative. In the following, we present the performance metrics adopted to assess the performance of the different machine learning models used. Indeed, our assessment is based on 4 different measures including: Accuracy, Precision, Recall, F1-Score.

## 5 Results

This section summarizes the experimental results obtained using our Dataset SPD/ED in two version, the extended and the closed one. In fact, we used several machine learning classifiers, aforementioned detailed. In each approach, the dataset is divided into train and test dataset with the ratio of 25% of test data and 75% of training data. Both train and test data need to be preprocessed and converted into feature vectors.

As depicted in Table 2, we present a comparative table of two approaches proposed at the level of this paper.

**Table 2.** Comparative table of machine learning algorithms based on our database in the case of 300 Full papers and 300 abstracts.

| Machine learning methods | 300 full papers | | | | 300 abstracts | | | |
|---|---|---|---|---|---|---|---|---|
| | Accuracy | Precision | Recall | F1-score | Accuracy | Precision | Recall | F1-score |
| SVM | **80%** | 75% | 81% | 78% | **81%** | 74% | 72% | 73% |
| KNN | **62%** | 53% | 58% | 55% | **65%** | 49% | 56% | 52% |
| RF | **81%** | 85% | 72% | 78% | **83%** | 81% | 70% | 75% |
| MN_NB | **74%** | 82% | 58% | 68% | **79%** | 83% | 58% | 69% |
| DT | **86%** | 79% | 86% | 82% | **75%** | 65% | 74% | 69% |
| GB | **78%** | 81% | 78% | 79% | **81%** | 75% | 69% | 71% |

From Table 2, we can see that each algorithm shows high performance. In another side, we can see, from Table 2, that using the abstract (Aims, Methods, Results and Conclusion) only from the whole paper, is more fruitful and efficient in terms of accuracy. Then, we conclude that SVM, RF and GB are more accurate than the others used algorithms.

Based on the experimental results, we first concluded that the best scores obtained are justified by the relevant choice of scientific papers in the learning phase. Second, we can see, according to Table 2, that the training data process with the Abstract approach is more efficient and fruitful in terms of accuracy than the Full paper approach. We recorded that SVM, KNN, RF and MN Naïve Bayes present motivating performances.

We explored both methods: Machine learning and Deep learning. In contrast to image classification, we observed in our specific application of text mining that the time-consuming process of deep learning does not outperform machine learning. At the contrary, in some cases, machine learning produces significantly better results. We believe that, in our experience, deep learning does not provide efficient results given the size of our database.

## 6 Conclusion

In this paper, we presented a comparative study of two different approaches of text classification using supervised machine learning classifiers. We started by identifying different methods of machine learning for text classification. Based on the literature review, we presented a survey on the machine learning techniques proposed for text classification. Through extensive experiments, we evaluated 6 methods based on our proposed dataset in the epidemiological domain. To the best of our knowledge, this is the first comparative study on scientific papers classification in the epidemiological domain. We proceeded with a careful selection of the different scientific papers, was made, based on a list of predefined classes according to the taxonomy of the epidemiological studies including: descriptive, analytical experimental and meta-analysis. Based on our experimental results, we emphasize that the learning done on the Abstract part (Introduction, Methods, Results, and Conclusion) is much more efficient than working with full paper because the divergence of the subject in question.

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# Evaluation of Stationary Wavelet Transforms in Reconstruction of Pure High Frequency Oscillations (HFOs)

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**Abstract.** High frequency oscillations (HFO) from, MEG (magnetoencephalography) and intracerebral EEG are considered as effective tools to identify cognitive status and several cortical disorders especially in epilepsy diagnosis.

The aim of our study is to evaluate stationary wavelet transform (SWT) technique performance in efficient reconstruction of pure epileptic high frequency oscillations, reputed as biomarkers of epileptogenic zones: generators of inter ictal epileptic discharges, and offhand seizures.

We applied SWT on simulated and real database to detect non-contaminated HFO by spiky element. For simulated data, we computed the GOF of reconstruction that reaches for all studied constraint (relative amplitude, frequency, SNR and overlap) a promising results. For real data we used time frequency domain to evaluate SWT robustness of HFO reconstruction. We proved that SWT is an efficient filtering technique for separation HFO from spiky events. Our results would have an important impact on the definition of epileptogenic zones.

**Keywords:** IEEG signal · Epilepsy · HFOs · SWT · GOF · SNR

## 1 Introduction

Over the past 15 years, researchers have shown usefulness of intra-cerebral activity above 70 Hz: High frequency oscillations (HFO) as efficient biomarkers for epileptogenicity. HFO has been considered as a clue of seizure build up and it appears especially, during ictal period. In fact HFO are exhibited as two sub band: ripples (80200) and fast ripples beyond 200 Hz [1].


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HFOs can be detected visually by neurologist expert [2] or automatically: using automatic detectors developed on a preprocessing chain [3, 4].

To ensure the detection of HFOs, it is necessary to filter the used signal in HFO bands, however spiky component can disturb the detection stage due to induced false oscillations obtained by filter response [5]. Hence, it is necessary to choose accurate filtering technique within this framework.

Bénar et al. proved the efficiency of stationary wavelet transform in detection and separation between spikes and gamma oscillations.

Hence, we propose to study stationary wavelet transform performance in reconstruction of pure HFOs.

First, we tested SWT performance on filtered simulated data (in HFO frequency range) where we evaluated it for different constraints (SNR, overlap rate, relative amplitude and frequency range).

Second, our focus was to evaluate SWT robustness of HFO reconstruction on filtered real IEEG signal (in HFO frequency range) using time frequency analysis. These results would assist neurologist during diagnosis of pharmaco resistant patient by defining epileptogenic tissue that should be delineated through a surgical intervention.

In the first section, we depict our simulated and real data, the filtering technique and evaluation methods used. In the second section, we exhibit our obtained results and finally we conclude and discuss our results.

## 2 Materials and Methods

### 2.1 Materials

All signal-processing steps of our paper are executed using Matlab software (Mathworks, Natick, MA) with EEGLAB toolbox.

**Simulated Data:** Obtained by a combination of a spike, and HFO shapes as real IEEG signal, sampled at 1000 Hz. Through different tests, we created different sets of signal (composed of spikes and HFO) by varying different parameters: relative amplitudes, frequency of oscillations, signal to noise ratio (SNR) and overlapping rate: we obtained 4 sets of simulated data composed of spiky and HFO events. We increased the spiky amplitude by 2, 4, 6, 8 and 10 times compared to oscillatory one. We varied also oscillation's frequency in this range [80 150 100 200 250] Hz (ripples and fast ripples). Overlap between spike and HFO oscillations is changed with equal steps via the size of oscillations window: no overlap (spike and oscillation are completely separated) until we reached 100% overlap when spiky and oscillatory events are superimposed. The overlap step is equal to 25%. Finally, we ranged SNR ratio (Eq. 1) from −5 dB to 20 dB.

$$\mathrm{SNR} = 10 * \log(\mathrm{S}/\mathrm{N}) \tag{1}$$

Where S is the simulated signal and N is the studied added noise.

**Real Data:** (IEEG) recordings for a pharmaco-resistant epileptic subject, where acquisition and pretreatment steps were assigned to clinical neurophysiology department of La Timone Hospital, Marseille [6] and validated by an expert neurologist. Our data is recorded on a Deltamed system, sampled at 1000 Hz with a low-pass filter. This particular IEEG signal is selected since it exhibits important epileptic HFOs patterns and regular spikes.

### 2.2 Methods

The Stationary Wavelet Transform SWT technique is a diversity of Dynamic Wavelet Transform with an advantage of overcoming decimation of DWT; which leads to a better maintain of signal characteristics. It performs even better than Continuous Wavelet Transform CWT by exceeding frequency-overlapping band.

In fact, SWT was used in various fields of application such as de-noising and detection [8], also, very useful in physiological signal analysis [7].

In [9] SWT was studied and implemented to reconstruct pre-ictal gamma oscillations in order to predict seizure build up. Hence, we proposed to study and evaluate SWT method performance in reconstruction of ripples and fast ripples: HFO. SWT decomposed a signal to be filtered into approximations and details coefficients, then, and through a thresholding steps (using masks), it allows to detect only desired parts by inverse of SWT method (iswt) [10]. Our thresholding step consists of creating a rectangle mask with a width equal to raw window studied and a length equal to 2 scales of decomposition (approximation and detail coefficients) [6]. SWT is a projection of scale $\theta_{j,k}$ function dilated and translated to obtain $cA_j(k)$ as approximations coefficients and $cD_j(k)$ as detail ones.

During implementation steps of SWT, we choose 6 levels of decomposition for a better detection of HFO [6]. We adopted the symlet wavelet family, since they are almost symmetrical to oscillation; moreover they are featured by their orthogonally which facilitate the reconstruction step.

**Evaluation by Goodness of Fit** (GOF) is used in different areas to evaluate performance of filtering technique [6, 11, 12]. After applying SWT we computed GOF between reconstructed simulated signals (reconstructed HFO) $s_r(t)$ and original simulated signals (original simulated HFO) s(t) by the following formula:

$$\mathrm{GOF} = 1 - \left(\left(\mathrm{sum}(\mathrm{s}(\mathrm{t}) - \mathrm{s_r}(\mathrm{t}))^2\right)/\mathrm{sum}(\mathrm{s}(\mathrm{t}))^2\right) \tag{2}$$

To evaluate SWT filtering method robustness in recovering pure HFO, we calculated similarity rate of reconstructed HFO within original simulated HFO signals for different frequency range, relative amplitude, overlap rate and (SNR).

**Time Frequency Representation:** Obtained by a time-frequency transform that provides 2 dimensional domain of an original one dimensional signal. This card allows via visible inspection or thresholding step to define specific shape both in time and frequency plan in our case, we will define pure HFO from spiky events [13].

## 3 Results

### 3.1 Simulated Data

We depict in Fig. 1 three types of simulated data, where upper line is a temporal representation of a ripple, a spike and a spiky event with a ripple one. The lower line represent frequency plan of the studied events. Combining HFO and spiky event produces a complex shape in which it is difficult to distinguish basic elements.

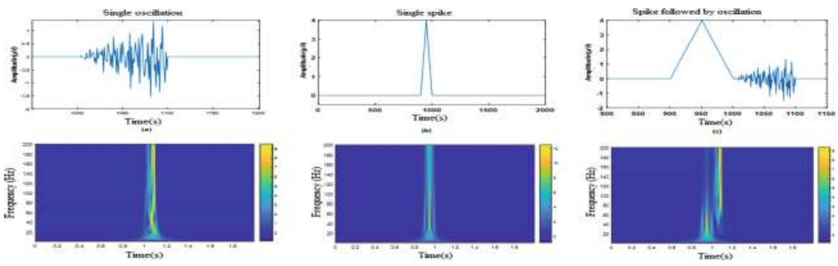


**Fig. 1.** Time representation of (a) single oscillation, (b) single spike, (c) spike followed by HFO, proceeded successively by their Time frequency plan.

In Fig. 2, we illustrated reconstruction of HFO by SWT technique for two frequency configurations; we studied different frequency effect on HFO reconstruction. SWT was able to reconstruct HFO with a minimum of spiky elements.

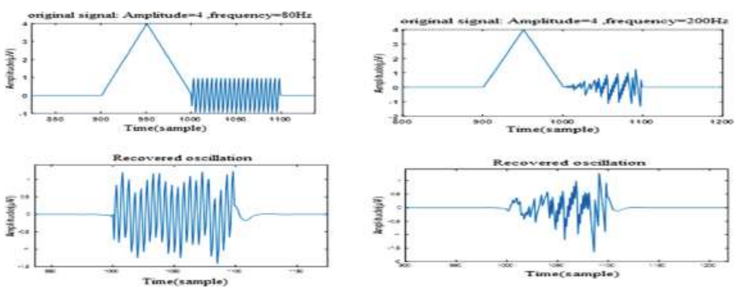


**Fig. 2.** Two sets of reconstruction of HFO (80 Hz and 200 Hz) by SWT, first line is original signal, second line is recovered HFO.

In Fig. 3(a), we gathered GOF values for HFO reconstruction after varying different relative amplitude between spiky and HFO events. We notice that for all relative amplitude, reconstruction result of HFO is beyond 78% for an amplitude of spiky event 8 times higher than HFO, and it reaches 97% for a relative amplitude equal to 4.

Hence, we can annotate that SWT have a good performance in reconstruction of HFO even for a low relative amplitude between spiky and HFO events.

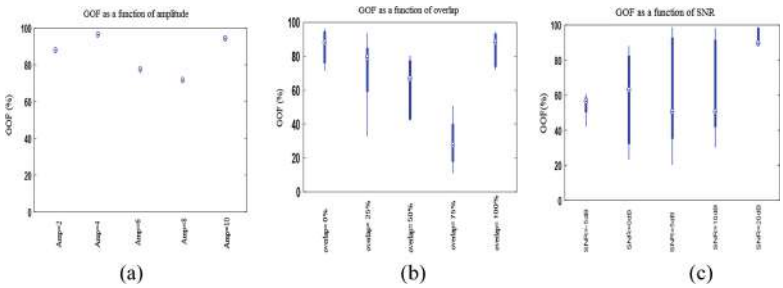


**Fig. 3.** GOF values for (a) different relative amplitudes of spiky and HFO events, (b) different temporal overlap and (c) different SNR rates.

We represent in Fig. 3(b) result of SWT reconstruction GOF for time overlaps constraint between spiky and HFO. We found that all configurations of overlap the GOF is beyond 80% for a low rate of overlap and total overlap, however the GOF rate declines for a rate of overlap >50% and <75%. We presented GOF as a box, where central mark is median, and 25th and 75th percentiles are edges of each box.

In Fig. 3(b), we displayed GOF result of HFO reconstruction as a function of SNR.

The best rate of GOF are obtained for SNR > 10 dB, which exceeds 85%, however GOF results are lower for low SNR with a median GOF around 58% and 75th percentiles above 82%.

## 3.2 Real Data

In Fig. 4, we depict time series of our real data (channel 26) and its representation in time frequency domain (upper line). Our choice (channel 26) was justified by high occurrence of HFO comparing to other channels (important activities: spiky events and different rhythms of oscillations and HFO in full overlap). We filtered our real data in

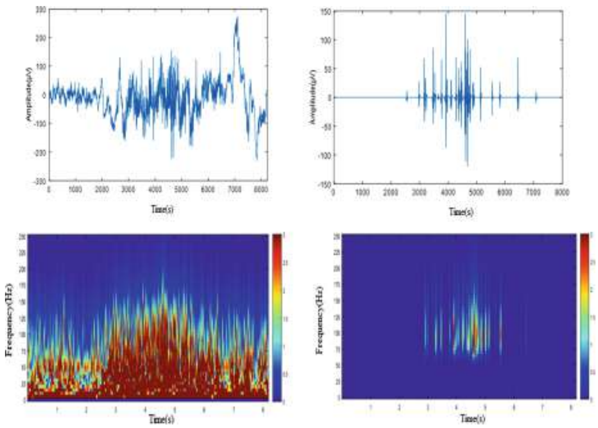

**Fig. 4.** Upper line: real data (channel 26), and pure recovered HFO by SWT, lower line time-frequency representation of raw, and pure HFO.

HFO frequency range than we applied SWT, and we depict pure recovered. In lower line we illustrate raw signal and recovered HFO time frequency domain.

After applying SWT, only ripples and fast ripples (HFO) are sustained, oscillatory activities with a frequency range beyond 80 Hz, which is clear from time frequency illustration. Hence, HFOs are efficiently reconstructed, by visual inspection of time frequency domain. SWT is a powerful method for separating such a range of oscillations frequency from spikes.

## 4 Conclusion

In our study, we tested performance of SWT filtering method, in reconstruction of pure HFO (HFO without spiky events) on simulated data and real signal. For simulated signal (inspired from IEEG recording), we evaluated robustness of SWT in HFOs reconstruction for several parameters that are proved very powerful in varying quality of obtained results. We studied effect of relative amplitude between HFO and spiky events, impact of frequency range (ripples and fast one), overlapping rate and finally signal-to-noise ratio. From our obtained results and for all studied constraint, SWT reconstruction of HFO reveal a good GOF rate. Hence, such study could be as a reference of SWT performance in reconstruction of HFO among 4 constraints (amplitude, frequency, SNR, overlap).

For real data, we evaluated performance of SWT reconstruction of HFO using time frequency representation and neurologist expert inspection.

SWT gives good results in reconstruction of non-contaminated HFO by spiky element even in bad environment (low SNR, different range of frequency, high overlap and low relative amplitude). These results predispose SWT for reconstruction and detection of all range of oscillatory frequency. Our obtained results are very promising in further study of HFO and its networks connectivity since we are dealing with pure HFO and hence non-contaminated cortical generators. Our perspectives are defining pure HFO networks connectivity in order to define epileptogenic zones. This result would have an important impact on surgical intervention of pharmaco- resistant patient to delineate epileptogenic tissue and get free seizure.

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# Ensuring the Correctness and Well Modeling of Intelligent Healthcare Management Systems

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**Abstract.** Recent research focus more and more on IoT systems and their applications in order to make people life easier and controllable. The main aim is to expand IoT applications and services into various domains while ensuring communication and automated exchange between them. Recent research handles many issues related to IoT especially implementation, modeling, and deployment. However, many challenges need more deep and thorough analysis especially in terms of flexible modeling, extensible implementation, with respect to the privacy issue. This work focuses principally on modeling IoT systems dedicated to smart healthcare case. We attempt to address the emergency service by initiating a modeling mechanism for Healthcare Management System (HMS) by using UML diagrams, and propose an appropriate access control in order to reinforce it. Then, we ensure the correctness of the developed HMS by relying on the verification and validation based on a formal analysis that showed significant results by using Alloy tool.

**Keywords:** Healthcare Management Systems · IoT · UML · RBAC · Formal validation · Alloy

## 1 Introduction

Nowadays, unfortunately people are busy and neglect their little health issues such as low pulse rate, high blood pressure, etc. [6]. Among the most challenging objectives of our contemporary society is enhancing healthcare. The provision of quality care to patients while minimizing healthcare costs is a primary goal, while traditional patient evaluation, care, management and supervision practices are often performed manually by nurses [1]. Further, the emergency service is very sensitive for what the patient needs to care in real-time during the treatment period depending the case. Therefor, in order to support and improve healthcare processes we need a flexible system that make the health care services more robust [1,16] by covering more special cases and respecting safety standards and users/patients privacy.

As evidence, one of the most important priorities of our society is to improve the performance of biomedical systems and healthcare infrastructures [1,11]. From a research perspective, Internet of Things (IoT) [9,10] innovations seek to build


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intelligent systems that support and improve healthcare, by using smart sensors, which allow for automatic monitoring, tracking patients and collecting data from various sources in real-time. Nevertheless, IoT plays an important role in supplying patients and clinicians with convenience in the area of healthcare. This consists of a system which communicates via a network that links internal and external facilities, applications and devices that might support patients and doctors monitor, track and archive critical medical data. Some of the products include wearable health bands, smart meters, and smart video cameras, fitness shoes and smart watches. In this same direction, smartphones applications may contribute in sending medical records and in real time alerts to medical and emergency services [6,15]. Such interconnected systems create a vast amount of data and information that should be managed effectively. That is already a hard and challenging task to achieve.

In the last few years, many substantial changes in the domain of IoT healthcare are happening. The way human beings and other devices connect and communicate is evolving and becoming better day after day. The ever-growing communication and information technologies [6] allow the control of healthcare outcomes and the decrease of healthcare costs. Consumers, patients and health experts need to think about some creative and more efficient approaches to enjoy the benefits of the revolutionizing IoT in healthcare. With the aid of the ability of IoT, they are now able to gather raw real-time data from very high numbers of patients via smart devices linked to an interconnected network during a continuous period of time. It will take a long time to completely realize the capabilities of these modern technologies. People will see medical experts achieving critical tasks in a much more reliable manner. These experts will not only produce reliable results but they will also save a lot of time, which should be of maximum gain. IoT's capabilities are really infinite and ever-growing [6].

The basic idea of the proposed solution is to provide patients with reliable and efficient health services by creating a networked knowledge infrastructure so that experts and physicians can make use of this data and make decisions quickly and efficiently. The suggested system will be equipped with apps by which a physician may examine patients anytime from anywhere. It will be also possible to work on emergency scenarios and give a warning to the doctor with the current status of the patient, and complete medical records. We model the whole system by relying on the standard modeling language UML including class, sequence, and use cases diagrams. Further to ensure the privacy of users (practitioners and patients) we develop a role based access control (RBAC) for the proposed health system. To fulfill the healthcare policies and the well correctness of the reinforcement as well as the functionality of the system, the proposed approach relies on Alloy analyzer in order to check automatically the requirements. Alloy [8] can express specifications of a system's structure and behavior as an abstract model to evolve and expand. Alloy language powered by Alloy Analyzer tool can be used to edit, build, and test its specifications. The analyzer simulates the specification and shows the system's flaws by checking the correctness and find the counterexamples that help to maintain the system. As well, it has the capabilities to present solutions in graphical format with customizing option. Depending on all these benefits, Alloy has been used for the analysis of many systems including security and software architectures. The proposed solution models first the health care system as well as the reinforcement mechanism using UML and express the related requirements in Alloy. It takes as input the system requirements as assertions and the reinforced model including UML diagrams and RBAC model. The results showed the effective correctness of the modeled system and its related reinforcement mechanism.

The next Sect. 2 describes the related work. Then, we present the modeling and the validation of the system. Finally, Sect. 5 concludes the paper and suggests the possible future research.

## 2 Related Work

In this section, we study the latest IoT contributions, its application in information services, and especially those targeting health care systems. We survey also the contributions dealing with IoT systems modeling, verification and validation.

– Ouchani [14] develops a formal framework to analyze the functional correctness of IoT systems. The proposed framework covers the main components of IoT systems and the approach is automatic. However, the framework suffers from the limitations inherited from PRISM and the security properties are not specified.
– Drira [2] discusses the challenges of modeling IoT in large scale systems called system-of-systems by focusing on interactions and real-time reconfigurations. This contribution presents an overview of architectural concepts without dealing with practical experiments.
– Rahman *et al.* [18] discuss the complexity of distributing services in many IoT devices as well as the challenges facing the system requirements for each level: devices, services, and applications. The proposed model assures a quality attributes such as update, interoperability, security, functional appropriateness, availability and adaptability. However, the verification process suffers from many limitations at the evaluation step.
– Gupta *et al.* [6] design an IoT-based health monitoring framework to reduce the neglect of healthcare. Their solution uses the second generation Intel Galileo board, an Arduino IDE that is explored to program the brain, and Xampp database. This solution provides support emergency medical services by collecting, integrating, and inter-operating of IoT data flexibly. However, they are limited in controlling the access and ensuring privacy.
– Madakam *et al.* [12] review IoT concepts that aim to unify everything into a common infrastructure using smart sensors. First, they focus on basic requirements, geneses, definitions, aliases and characteristics of IoT. Further, they present a various technologies and their usages in innumerable IoT applications into all the domains including medical, manufacturing, transportation, etc. Finally, they acknowledge the need to a standard definition and protocols as well as a universal architecture of IoT that allows for various technologies the ability to inter-operate.
– Gigli *et al.* [5] attempt services categorization provided by IoT systems, which aims to help building a service provider. They consider ubiquitous services which are collaborative aware. However, they require to overcome protocol distinctions among technologies and unify every aspect of the network.

- Mainak *et al.* [13] designs an agent based model which predict the response time of emergency service by taking into consideration the characteristics of road segments and driving behaviour of emergency vehicle drivers. First, they collecting real time driving data by Fire emergency service of Allahabad city using GPS logger HOLUX M1000C. Then, they analyze collected data in GIS along with road network, population density and land use data. Based on the analysis results, they model a fire emergency vehicle (FEV) service. For validation, they compare the theoretical response time with the measured one by simulating scenarios that have 80% matching segments.
- Hussein *et al.* [7] propose a coordination emergency responses framework using agent-based modeling. The main components of this model are Emergency Response Services, Coordination Unit, MCI, Command and Control Center, and Agent Based Simulation. In case of incident, the MCI sends an aid request to the command and control center which transfers all information needed to emergency response services. Next, all resource information are gathered and updated as necessary by this unit. Finally, the resulting plan from the coordination unit will be sent to the agent based simulation, which used to simulate emergency response tasks in real environments, and identify the best coordination mechanism plan to achieve the best response time.
- Catarinucci *et al.* [1] propose a “Smart Hospital System” (SHS) for automatic monitoring and tracking of patients, personnel, and biomedical devices. It composes of a “Hybrid Sensing Network” (HSN) that collects both environmental conditions and patients’ physiological parameters as well as the IoT Smart Gateway that controls the overall SHS behavior. The user interfaces builtin RESTful services which allow user to communicate with the HSN through the 2-way Proxy.
- Molano *et al.* [17] propose an architecture of IoT applied to the industry. First, they present a metamodel that generates industrial cases by extending cyber physical systems to cover covers sensors and actuators to monitor manufacturing. However, safety of data and system accuracy, standardization of technology and interoperability of systems within actual deployments are not considered.
- Cristian *et al.* [4] review the artificial intelligence-IoT fusion with a focus on four important fields. They presents AI basics and the general concepts of computer vision and Fuzzy Logic, and their link with IoT. Besides, they present natural language processing to facilitate the humain-machine interaction.
- Espada [3] proposes a model for constructing and interpreting digital objects in IoT systems which can eliminate the management of pre-configuration and requirements. The model covers the integration and communication of digital objects, applications, devices and users.

Based on the discussed literature, few of them rely on the satisfiability analysis and the stand modeling language to ensure the robustness of the developed solution.

## 3 HMS Modeling

This section describes the structural and behavioral diagrams of **HMS** proposed system through UML use case, class, and sequence diagrams. Figure 1 shows the main actors and the possible use cases for **HMS**. The doctor can prescribe the status of a patient already registered by the IT Staff, and also can consult his medical reports. Each patient have a medical record, that can be filled or updated by a nurse, a doctor, or a smart object. These cases are only allowed for signed-in and authorized actors. A nurse and smart objects can fill or update the medical record whereas the doctor can consult, fill, update, and prescribe medicines to a patient.

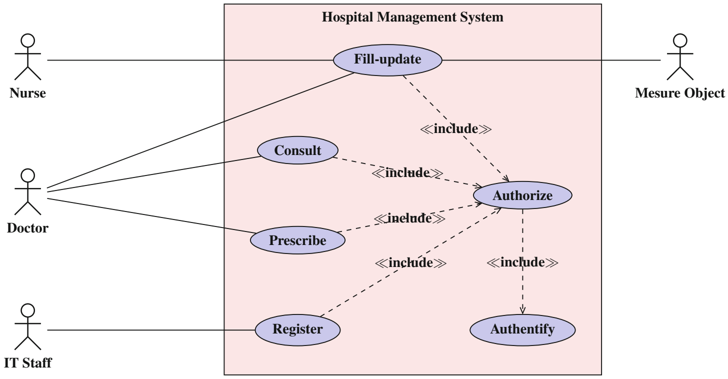


**Fig. 1.** Use case diagram for HMS.

Figure 2 shows the main classes that represent the structure of principle users and resources. Only the staff with the IoT can fill or update the patient's medical record if they have the authority to do that, also each update of the medical record will be saved automatically in the medical history. We consider also to a patient to have a holder regarding his treatments.

## 4 HMS Validation

In terms of system specification, Alloy is a modeling language including a formal syntax and semantics. A specified model in Alloy can be in ASCII format as well with a visual representation. Generally, Alloy targets the formal specification of object oriented data models that can be used generally in data modeling, that also can be displayed graphically. Also for systems analysis, Alloy is a verification tool that automatically analyze the properties (requirements) of alloy models. After checking the properties, Alloy might generate counterexamples in case of the property violation. Alloy consists of predicates, facts, relations and signatures. Signatures represent the different entities of the system. Relations specify the relations between them. Predicates and facts define constraints, which apply on relations and signatures.

Each Alloy model begins with the module declaration. The first step is to declare the signatures using the keyword sig. Then, we define the relations (fields) which associate atoms. To define a subset, we should use the keywords extends or in, also the multiplicity keywords such as one, lone, set, some, etc. Facts correspond to the constraints which must always hold. Finally, we define the predicate using the keyword pred and run it.

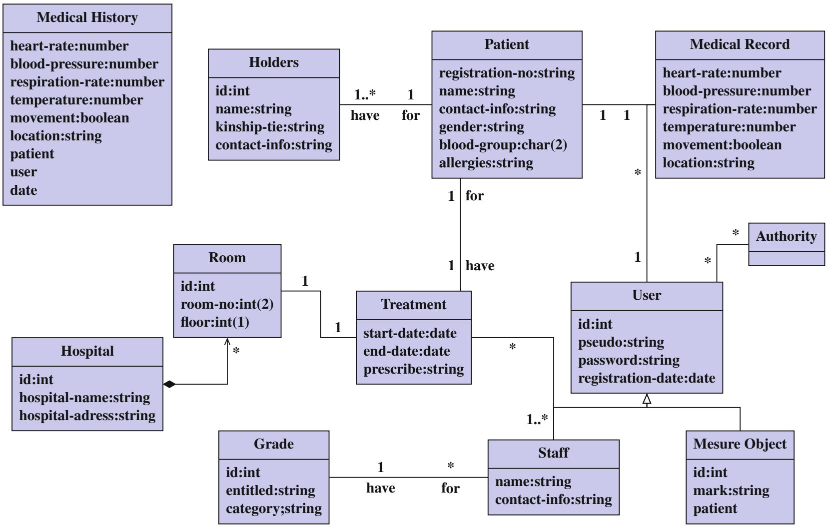


**Fig. 2.** Class diagram for HMS.

For the validation of **HMS**, we describe its classes and relations in Alloy specification respecting its syntax and logic. Listing 1.1 shows a fragment of the transformation of **HMS** into the input language of Alloy where sigs refer to classes, extends to associations, and the multiplicity to the class diagram relations.

Listing 1.1: HMS description in Alloy input language.

```
module hms  /*Model of hospital  management system.*/

abstract sig User {}// Refer to user class

sig Staff extends User {// Refer to staff class
        g : one Grade}
sig MesureObject extends User{} // Refer to mesureObject class
sig Patient {// Refer to patient class
mr : MedicalRecord}
sig MedicalHistory { // Refer to medicalHistory class
        p : one Patient,
        u : one User}
sig Holders {// Refer to holders class
        p : one Patient}
sig Treatment {// Refer to treatment class
        p : one Patient,
        r : one Room,
        s : some Staff}
```

For the effectiveness of the proposed framework, we show the correctness of the proposed model through checking and simulation. We check the assertions related to HMS as described in Fig. 3. The first assertion is to check if only a single user has a medical record. The second looks for the medical history of users whereas the third confirms that the medical data are updated by an authorized user.

```
// Checking each MH refer to one patient
assert eachMHreferOnePatient { all mhs: MedicalHistory
        | one pt: Patient  | mhs.p = pt }
check eachMHreferOnePatient

// Checking each MH updated by one user
assert eachMHupdatedOneUser { all mhs: MedicalHistory
        | one ur: User  | mhs.u = ur }
check eachMHupdatedOneUser

// Checking single use of MR
assert singleUseMR { all ps: Patient | one p: Patient
| ps.mr = p.mr }
check singleUseMR
```

**Fig. 3.** Checking HMS Assertions.

## 5 Conclusion

This contribution proposes a concrete model for healthcare system, especially for emergency service in order to facilitate the integration and communication of IoT measures, devices and management systems. First, we proposed UML modeling for the structural and behavioral description of the specific domain of emergency. Further, we proposed Alloy for ensuring the correctness of the model by expressing it safely into its input language. With respect to the obtained results we ensure the correctness of the proposed model. Regarding the obtained results, we target to extend the work in different directions. First, we generalize a meta model from where we can instantiate the model of different services rather than medical and health care. In addition, we have to automate the generation of Alloy code and prove its soundness. Also, we intend to provide, the network architecture including the web services for the different models. Then, we show the impact between them and how we can express and ensure the privacy when deployed. Our final target is to generate a mega system using micro-services architecture, with extensible secure services that can be deployed for different environments.

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# Short Contributions: Wellbeing Technology

# An Embedded ANN Raspberry PI for Inertial Sensor Based Human Activity Recognition

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**Abstract.** Human Activity Recognition (HAR) is one of the critical subjects of research in health and human machine interaction fields in recent years. Algorithms such as Support Vector Machine (SVM), K-Nearest Neighbors (K-NN), Decision Tree (DT) and many other algorithms were previously implemented to serve this common goal but most of the traditional Machine learning proposed solutions were not satisfying in term of accuracy and real time testing process. For that, a human activities analysis and recognition system with an embedded trained ANN model on Raspberry PI for an online testing process is proposed in this work. This paper includes a comparative study between the Artificial Neural Network (ANN) and the Recurrent Neural Network (RNN), using signals produced by the accelerometer and gyroscope, embedded within the BlueNRG-Tile sensor. After evaluate algorithms performance in terms of accuracy and precision which reached an accuracy of 82% for ANN and 99% for RNN, obtained ANN model was implemented in a Raspberry PI for real-time predictions. Results show that the system provides a real-time human activity recognition with an accuracy of 86%.

**Keywords:** Machine learning · Deep learning · HAR · Embedded ANN · LSTM-RNN · Raspberry PI · Python

## 1 Introduction

Human activity recognition (HAR) refers to the automatic detection of various physical activities performed by people in their daily lives [1]. Activity recognition can be achieved by exploiting information retrieved from sensors such as

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accelerometer, gyroscope etc., while the activity is being performed with the help of Artificial Intelligence methods. In recent years, several machine learning and deep learning algorithms for human activity recognition have been proposed. Sukor et al. [2] used several methods of machine learning such as Support Vector Machine (SVM), Decision Tree (DT), and Multiple Layer Perception-Neural Network (MLP-NN) to classify activities such as slow sitting, standing, upstairs, downstairs and lying using the accelerometer sensor embedded in a smartphone. The obtained results show that the use of Principal Component Analysis (PCA) to reduce the dimensionality of features obtains higher recognition rate with the rate of 96.85% for the DT algorithm and 100% for the MLP-NN algorithm which may have over fitting problems. G. McCalmont et al. [3] also tested the activity recognition performance. Three classifiers were used, including Artificial Neural Network (ANN), K-Nearest Neighbor (KNN) and Random Forest (RF) to classify five exercises which are slow walking, normal walking, fast walking, upstairs and down stairs using accelerometer, gyroscope and magnetometer. They found that ANN models with many layers achieve an accuracy of 80% while RF and KNN achieve an accuracy slightly above 70%. Song-Mi Lee et al. presented a RF algorithm and achieve an accuracy of 89.1% [4]. Furthermore, three human activity data, walking, running, and staying still, are gathered using smartphone accelerometer sensor and classified with Convolutional Neural Network (CNN) and had better performance 92.71% [4]. Furthermore Abdulmajid Murad et al. [5] use a 3D accelerometer, 3D gyroscope and 3D magnetometer to classify six activities. Four algorithms Extreme Learning Machine (ELM), SVM, CNN and RNN are used to classify these activities. The best accuracy was achieved with the RNN algorithms 96.7%. It could be considered that the ANN is one of the best machine learning algorithm used for HAR and the RNN is reported to overperform other deep learning algorithms in term of accuracy and precision to recognize human activities. In addition, most of research in the field, validate their results with simulations, without comparing theses simulations with results provided by real-time embedded and hardware based implementations. So a lack of standalone, sensor based HAR systems, with embedded machine learning and real-time response is remarked. This research aims is to compare simulation results with results provided by a real-time implementation and to judge performance gived by embedded ANN to recognize human activities. The rest of this paper is arranged as follows: The second section introduces the ANN architecture and process. In addition, an overview of the LSTM (Long Short Term Memory) Recurrent Neural Network is presented in the third section. The next section presents the data acquisition structure for HAR with the database properties. Furthermore, an evaluation of ANN and LSTM-RNN using Receiver Operating Characteristic (ROC) are presented. Moreover, to validate our simulations results, the developed ANN model is implemented in a Raspberry PI as a real-time standalone HAR system.

## 2 Artificial Neural Networks/Feed Forward Neural Networks

Artificial Neural Networks, (ANNs), and their variants, are a class of Machine Learning (ML) techniques that have been proven, powerful throughout many applications such as machine translation [6], medical diagnosis [7] and many other fields [8]. ANNs were inspired by the neuroscience. Thus, the building block of an ANN is called a neuron. A basic neural network is shown in Fig. 1. It consists of an input layer, one or more hidden layers, and an output layer. Each layer consists of one or more neuron. Inputs are fed into the neurons that compute some output values based on the weights and biases associated with them. These outputs are summed and multiplied feed activation function to give to final output [9]. The activation function is a core logic of the neural networks. It defines the output of the neuron given an input or a set of inputs. There are several types of activation function like the "sigmoid function", the Hyperbolic Tangent function "Tanh", the Rectified Linear Unit function "ReLU" and the "softmax" activation function [10]. To boost model accuracy and precision, optimizers are added to the neural network. An optimizer update the weight parameters to minimize the loss function. There are several types of optimizers like "Adam" which is stands for adaptive moment estimation, "Adagrad", RmsProp and many other optimizers.

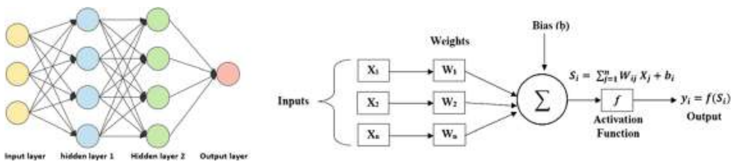


**Fig. 1.** Artificial Neural Network achitecture and process [11]

These steps are followed in order to train a neural network [9]:

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**Algorithm 1:** Artificial Neural Network process

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**1. Initialize Network.** Creates a new neural network ready for training. It accepts three parameters, the number of inputs, the number of neurons to have in the hidden layer and the number of outputs.
**2. Randomly initialize weights** $w_i$**..** Each neuron has a set of weights that need to be maintained. One weight for each input connection and an additional weight for the bias.
**3. Implement forward propagation to compute the output(s).** Calculate and storage of intermediate variables (including outputs) for the neural network within the models in the order from input layer to output layer.
**4. Implement the cost function.** This is typically expressed as a difference or distance between the predicted value and the actual value.
**5. Forward propagate input to a network output and calculate the derivative of an neuron output.** All of the outputs from one layer become inputs to the neurons on the next layer.

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## 3 Long Short Term Memory-RNN/Back Propagation Neural Networks

Recurrent Neural Networks are the only networks with internal memory, which makes them robust and powerful. In a RNN, Weights are applied to both the current input and the looping back output and are adjusted through gradient descent or back propagation [12]. The RNN work on this recursive formula (1) where $X_t$ is the input at time step t, $S_t$ is the state at time step t and $F_w$ is the recursive function.

$$S_t = F_w * (S_{t-1}, X_t) \tag{1}$$

$$S_t = F_w(S_{t-1}, X_t) \tag{2}$$

$$S_t = \tanh(W_s * S_{t-1}, W_x * X_t) \tag{3}$$

$$Y_t = W_y * S_t \tag{4}$$

The recursive function is a tanh function (3), we multiply the input state with the weights of X mentioned as $W_x$ and the previous state with $W_s$ and then past it through a tanh activation to get the new state (3). To get the output vector, we multiply the new state $S_t$ with $W_y$ (4). RNN learn use back propagation through time. Therefore, we calculate the loss using the output, go back to each state, and update weights by multiplying gradients. The updating weights would be negligible and our network will not get any better. This problem is called vanishing gradients problem. To solve it and to improve the accuracy, we add a more interactions to RNN and this is the idea behind Long Short Term Memory (LSTM) [13]. The LSTM cell is capable of learning long-term dependencies. RNNs usually have a short memory and are extended by LSTM units to extend the memory of the network. It provides the capabilities to absorb more information from even longer sequences of data. This helps to boost the precision of the prediction by taking into account more data. The LSTM cell maintains three kinds of gates and one cell state: the input gate, the forget gate and the output gate. The architecture of an LSTM cell is shown in Fig. 2, where the input gate chooses what new information needs to be stored in the cell state. This is shown in Eq. 5 and 7, where $i_t$ is the input gate layer output and $C_t$ is the cell state update. The forget gate decides what existing information in cell state needs to be thrown away, this is shown in Eq. 8, where $C_t$ is again the update of the cell state [12]. Finally, the output gate filters the output and determines the final cell output. This can be seen through Eqs. 9 and 10, where $o_t$ is the output-gate layer output and $h_t$ is the resulting hidden state for the given input. $\check{C}_t$ is called as intermediate cell state, used to calculate the $C_t$, which is the cell state using Eq. 6. The input gate and the intermediate cell state are added with the old cell state and the forget gate, and then this cell state is passed through tanh activation to be multiplied with the output gate [14]. The following steps are used to train a LSTM-RNN [14]:

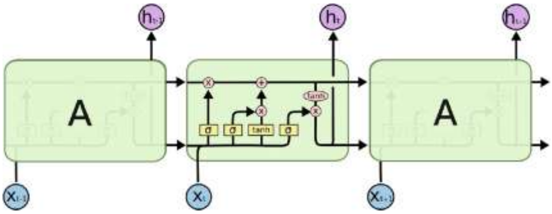


**Fig. 2.** Architecture of an LSTM cell

**Algorithm 2:** LSTM-RNN process

**1. Calculate the input gate by passing the previous state and the input through sigmoid activation.**

$$Input\ Gate : i_t = \sigma(W_i[h_{t-1}, X_t]) \tag{5}$$

**2. Calculate the intermediate cell state by passing our input and the previous state through tanh activation.**

$$Intermidate\ Cell\ State : \check{C}_t = \tanh(W_c[h_{t-1}, X_t]) \tag{6}$$

**3. Perform element wise multiplication and calculate the forget gate and multiply it with the old state $C_0$.**

$$Cell\ State : C_t = (i_t * \check{C}_t) + (f_t * \check{C}_t) \tag{7}$$

$$Forget\ Gate : f_t = \sigma(W_f[h_{t-1}, X_t]) \tag{8}$$

**4. Add these to obtain a new cell state, which is $C_1$, and calculate the output gate and we multiply it with the cell state passed through the tanh activation.**

$$Output\ Gate : o_t = \sigma(W_o[h_{t-1}, X_t]) \tag{9}$$

$$New\ State : h_t = o_t * \tanh(C_t) \tag{10}$$

# 4 Experimental Results

## 4.1 Activity Database Collection for HAR

The data acquisition system has a standard structure as shown in Fig. 3. The main component of the data acquisition phase is the sensors (BlueNRG-Tile), which measure the various attributes such as acceleration and velocity. The other components are the ST-BLE (BlueNRG-Tile) application, communication network, and a server to save data. The ST-BLE Sensor application is used for collecting and preprocessing the raw sensor signal [15]. Activity recognition component, which is built on the training and testing stages, relies mostly on machine learning and deep learning models. A large dataset of collected features for training the model is required for the training stage [16]. The data was collected from the Blue-NRG-Tile to measure the Acceleration from tri-axial accelerometer sensor and the Velocity from the tri-axial gyroscope. The dataset contains 3 human activities: sitting, walking and running. the dataset was recorded by 5 persons (2 boys and 3 girls) for 2 min each activity. Data recorded is along three dimensions of the X, Y and Z axis at 15 Hz frequency.

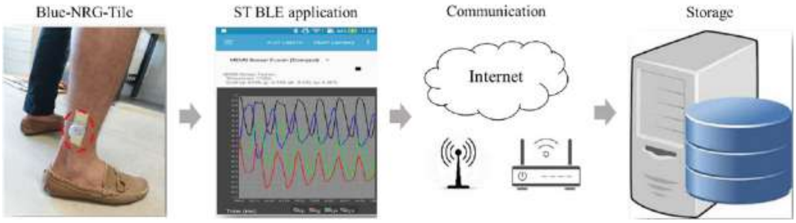


**Fig. 3.** Data acquisition structure for HAR system

Accelerometer and gyroscope of the BlueNRG-Tile placed on the right foot, are used to capture data. The dataset has a total of 219600 data samples and it was divided into 80% for training, 10% for the testing and 10% for the validation part.

### 4.2 ANN Evaluation

The ANN model is built using the Keras library. The model has one hidden layer with $N_{inputs+1}$ units which are used to extract features from the sequence of input data. The output layer provides the final predicted output. It is congured to utilize a 'Sigmoid' activation and the 'Adam' optimizer, used to boost accuracy. The model is compiled to run 50 epochs with a batch size of 1024 using 'Mean Squared Error' as its loss function and the accuracy as its performance metrics. Figure 4 shows the training session's progress over iterations and a confusion matrix to show how the model predicted versus true predictions. After training the model for 50 epochs, an accuracy above 82% with a loss of almost 10% are obtained. The confusion matrix shows that an overlap in the prediction of walking that is confused with running (22.18%). The addition of the gyroscope has the advantage of increasing the model accuracy (from 70% to 82%), decreasing the loss rate (from 15% to 10%) and subsequently increase the precision of prediction by class. The main difference between this model and the model trained with only accelerometer sensor data is the necessary number of iterations to achieve the highest accuracy or the lowest loss. The last model

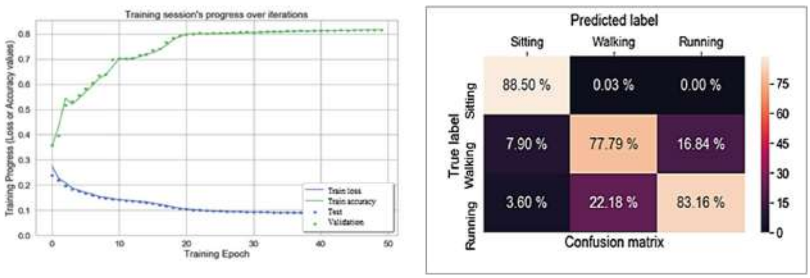


**Fig. 4.** ANN evaluation using accelerometer and gyroscope

requires 20 iterations to achieve an accuracy above 82%, whereas, this model needs only 7 iterations to achieve this value of accuracy with the minimum of loss rate (10%) which indicate the necessity of the gyroscope for inertial sensor based HAR system.

### 4.3 LSTM-RNN Evaluation

The LSTM-RNN model is built using the Keras library and Tensorflow as its back-end. The model first has two hidden LSTM layers with ($N_{inputs+1}$) units each, which are used to extract features from the sequence of input data with the "ReLU" activation function for each neuron. The output layer was configured to utilize a 'Softmax activation and the 'Adam' optimizer was used to boost accuracy. The model was compiled to run 50 epochs with a batch size of 1024 using 'Mean Squared Error' as its loss function and the accuracy as its performance metrics. From Fig. 5, the accuracy reached about 99% for the first 10 iterations and the loss rate went down to about 10% with the first 50 iterations. The confusion matrix shows a slight overlap between walking and running activities (1.84%). The use of LSTM-RNN and the tri-axial accelerometer, the tri-axial gyroscope allows having good classification between walking and running activities and especially for sitting class. Human activities are recognized with high accuracy (about 99%) using a tri-axial accelerometer and gyroscope located at the right foot by using LSTM-RNN classifier. The LSTM-RNN using an accelerometer and gyroscope can be a reliable model to be implemented for real time human activity recognition, but the optimization metrics, such as the number of sensors used, the energy consumption, cost, the number of layers, units used and the complexity of the deep learning (LSTM-RNN) compared to the machine learning algorithm (ANN) needs to be taken into consideration [17]. The next section presents an implementation of ANN to validate our obtained simulations. To more understand the efficacy of these algorithms, our next focus research will be on the implementation of the LSTM-RNN for real-time recognition.

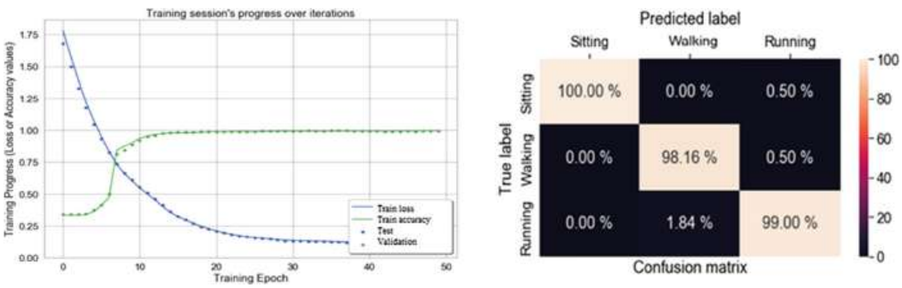


**Fig. 5.** LSTM-RNN evaluation using accelerometer and gyroscope

## 5 Real-Time HAR Implementation in Raspberry PI

After collecting data from the BlueNRG-Tile and building the ANN model using an accelerometer and a gyroscope, this section presents an implementation of the developed algorithm in a Raspberry PI using MPU6050 to capture data for real time predictions as shown in Fig. 6. The prototype is tested to a boy of 16 years old for 15 s. As shown in the Fig. 6, The MPU6050 is placed on the right foot attached to the raspberry PI with jumper.


**Fig. 6.** Connecting the Raspberry PI with the MPU6050

**Table 1.** Confusion matrix for the real-time implementation

| Actual | Predicted | | |
|---|---|---|---|
| | Sitting | Walking | Running |
| Sitting | 93.34% | 6.66% | 0% |
| Walking | 0% | 86.66% | 13.34% |
| Running | 0% | 20% | 80% |

Table 1 presents the confusion matrix for the real-time implementation for 15 s each activity. To express the efficacy of the algorithm, the performance metrics in term of accuracy and precision needs to discuss. The confusion matrix validates our simulation results. To calculate the accuracy, True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN) are required. After testing the prototype for 15 s, an accuracy of 86% is achieved with an average precision approximately 84%. Real-time simulation with the Raspberry PI shows good results in term of prediction and differentiation between sitting, walking and running activities. Obtained results from simulations and results provided from the Raspberry, are very close, which rounds our prototype reliable and robust model. Moreover, to evaluate the performance of the considered approaches, we compare our models to other research works. We find that our trained models are more robust in term of accuracy compared to McCalmont, G. et al. [3] which achieve an accuracy above 80% for ANN and 70% for the KNN. Moreover, we compare our trained LSTM-RNN model which reached of an accuracy performance 99%, to Mi Lee, S. et al. [4] and Abdulmajid Murad et al. [5] which use a Convolutional Neural Network (CNN) algorithm and (Sequential ELM, SVM, CNN and RNN) respectively, the best accuracy was achieved with the RNN-LSTM algorithms (99%) The focus of next paper will be on a the implementation of LSTM-RNN in the Raspberry PI with a comparative study between ANN and LSTM-RNN for real-time HAR.

## 6 Conclusion

In this paper, a deep learning algorithm named Recurrent Neural Network (RNN) with LSTM memory units and keras was tested using accelerometer and gyroscope to classify and analyze human activities such as sitting, walking and running. This produced an overall accuracy of 99%. Furthermore, we have exported the ANN model using accelerometer and gyroscope to be implemented in a Raspberry PI. In addition, we have tested the model with data collected from the MPU6050 and we have successfully shown that the model provides good results in term of real-time prediction and classification with 86% of accuracy. For the future work direction, an IoT smart device of human activity recognition based on embedded deep learning will be developed. In addition, the deep learning algorithm in the medical fields to implement a real-time fall detection system and anomaly detection system for elderly monitoring, and disease prevention will be investigated.

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# Human Activities Recognition in Android Smartphone Using WSVM-HMM Classifier

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**Abstract.** Being able to recognize human activities is essential for several applications such as health monitoring, fall detection, context-aware mobile applications. In this work, we perform the recognition of the human activity based on the combined Weighted SVM and HMM by taking advantage of the relative strengths of these two classification paradigms. One significant advantage in WSVMs is that, they deal the problem of imbalanced data but his drawback is that, they are inherently static classifiers - they do not implicitly model temporal evolution of data. HMMs have the advantage of being able to handle dynamic data with certain assumptions about stationary and independence. The experiment results on real datasets show that the proposed method possess the better robustness and distinction.

**Keywords:** Activity recognition · Classification · Weighted SVM · HMM

## 1 Introduction

The advancement of technologies has facilitated the monitoring of human activities through the embedded sensors in a smartphone. Recently, smart phones, equipped with a rich set of sensors, are explored as alternative platforms for human activity recognition (HAR) [1, 2]. HAR technology aims at recognizing the behavior and activities of users through a series of observations, which has wide application [3, 4] in different areas, such as healthcare and military monitoring.

With smartphones becoming an integral part of daily human life [5], they are being preferred as the most usable appliances that could recognize human activities due to its powerful in terms of mobility, user-friendly interface, network capability, strong CPU, memory, and battery. They contain a large number of hardware sensors such as accelerometer, gyroscope, temperature, humidity, light sensor, and GPS receiver.

The human sensor based activity recognition is a combination of sensor networks hand-in-hand with the data mining and machine learning techniques [6]. The smartphones provide enormous amount of sensor data for one to understand the daily activity patterns of an individual.

The basic procedure for mobile activity recognition involves i) collection of labelled data, i.e., associated with a specific class or activity from users that perform sample activities to be recognized ii) classification model generation by using collected


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data to train and test classification algorithms iii) a model deployment stage where the learnt model is transferred to the mobile device for identifying new contiguous portions of sensor data streams that cover various activities of interest. Sensor data can be processed in real-time or logged for offline analysis and evaluation. The model generation is usually performed offline on a server system and later deployed to the phone to recognize the activity performed.

Recently, several authors [7, 8] have proposed many applications related to activity recognition on multiple body positions. Most of the work, like Ahmad [9], Tran [10], Awan [11], Shoaib [12], and Abidine [13], consider a single classifier approach to study activity recognition using smartphones. For the classification, SVMs are popular [8, 14]. It is also the case for HMMs [15] which they commonly used for time-series activity recognition. However, there is very limited number of publications in the literature that investigate the application of the WSVM classifier for smartphone data, and no one is found about applying the latter one on smartphone data or even on HAR system's datasets. Building a system with high precision to accurately identify these activities is a challenging task.

In this work, we adopted a new method for physical activity recognition using mobile phones that uses labels outputting WSVM in HMM. WSVM investigated the effect of overweighting the minority class on SVM modeling between the performed activities. HMM is a natural solution to address the activity complexity by — capturing and smoothing information during the transition between two activities (e.g. Walking and Standing). We also used the feature extraction approach that transforms the original high dimensional data to a lower dimensional feature space. The transformation can be linear or nonlinear. In this project, we employed the linear Principal Component Analysis (PCA) [16] to extract the feature vectors.

# 2 The Proposed HAR System by Combining WSVM-HMM Based PCA

## 2.1 Overview

Figure 1 shows the architecture of the proposed activity recognition system. Among the available labelled data, training and test subsets are chosen using the cross-validation mechanism. The constructed PCA space is then used for training and testing the Weighted SVM classifier. In the second step of the process is a pre-classification by 'WSVM', this phase is carried out by the 'cross-validation' will generate an estimate of the label vector.

The principal component features concatenated with the WSVM estimated label vector are employed as a new training data to train HMM classifier. The final classification is performed with the 'Viterbi' algorithm, by the use of a HMM model.

An estimated label vector is generated by the 'Viterbi' algorithm and the system will output the recognized activity (i.e., walking, running, and others).

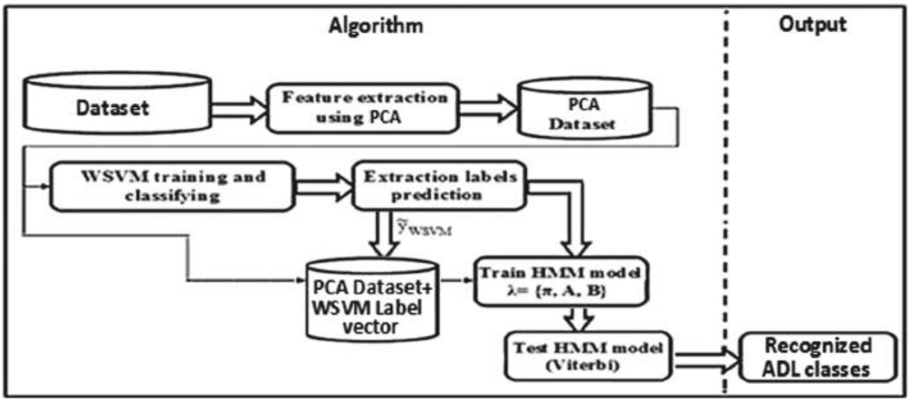


**Fig. 1.** Hybrid WSVM-HMM system based PCA approach.

### 2.2 Principal Component Analysis (PCA)

PCA [16] is an orthogonal projection-based technique such that the variance of the projected data is maximized. In our case, a large number of features are extracted by prepossessing the raw signals generated from different sensors. It is a widely used technique for dimensionality reduction, feature extraction, and data visualization through the construction of uncorrelated principal components that are a linear combination of the original variables. The PCA components can be counted by performing the eigenvector decomposition of the covariance matrix $S$:

$$S = \sum_{j=1}^{m} \left( (\vec{x})_j - \mu \right) \left( (\vec{x})_j - \mu \right)^T, \quad \mu = \frac{1}{m} \sum_{j=m}^{m} (\vec{x})_j \, . \tag{1}$$

This problem leads to solve the eigenvalue equation with $\lambda$ *is the eigenvalue of S and V is the eigenvector corresponding to the* $\lambda$:

$$\lambda V = SV, ||V|| = 1. \tag{2}$$

Where V = [$v_1$, $v_2$, …, $v_i$], (i = 1, …, n) is the n × n matrix containing n eigenvectors and λ is an n × n diagonal matrix of eigenvalues of the covariance matrix. In Eq. (2), each n dimensional eigenvector $v_i$ corresponds to the ith eigenvalue $\lambda_i$.

### 2.3 Weighted Support Vector Machines (WSVM)

Osuna et al. [17] proposed an extension of the SVM modeling, Weighted SVM algorithm to overcome the imbalance problem by introducing two different penalty parameter $C_-$ and $C_+$ in the primal Lagrangian (Eq. 3) for the minority ($y_i = -1$) and majority classes ($y_i = +1$), as follow

$$\min_{s,b,\zeta} \frac{1}{2} w \bullet w + C_+ \sum_{i|y_i=1}^{m_+} \zeta_i + C_- \sum_{i|y_i=-1}^{m_-} \zeta_i$$
$$\text{subject to } y_i(s \bullet \Phi(y_i) + b) \geq 1 - \zeta_i,\ \zeta_i \geq 0,\ i = 1, \ldots, m\ . \tag{3}$$

$m_+$ *(resp.* $m_-$*)* the number of positive (resp. negative) instances in the initial database *(* $m_- + m_+ = m$*).* Solving the formulation dual of WSVM [17] gives a decision function for classifying a test point $y \in R^p$

$$f(x) = \text{sgn}\left(\sum_{i=m}^{m_{sv}} \alpha_i y_i K(x, x_i) + b\right)\ . \tag{4}$$

We used the Gaussian kernel as follows: $K(x, y) = \exp\left(-\|x - y\|^2 / 2\sigma^2\right)$. Some authors [17–19] have proposed adjusting different cost parameters to solve the imbalanced problem. To extend Weighted SVM to the multi-class scenario in order to deal with $N$ classes (daily activities), we have shown in [20] that the cost of misclassifying a point from the small class should be heavier than the cost for errors on the large class. They used different misclassification $C_i$ per class, use this conclusion can get a satisfactory result. By taking $C_- = C_i$ and $C_+ = C$, with $m_+$ and $m_i$ be the number of samples of majority classes and number of samples in the $i^{\text{th}}$ class, the main ratio cost value $\boldsymbol{C_i}$ for each activity can be obtained by:

$$C_i = \text{round}(C \times [m_+ / m_i]),\ i = 1, \ldots, N. \tag{5}$$

### 2.4 Hidden Markov Model (HMM)

HMM [21] comprises two parts: Markov chain and stochastic process. Markov chain, whose output is a sequence of state, can be described by the initial probability distribution for the states (π) and the state transition matrix (A), while stochastic process whose output is a sequence of observed values, is described by the observation probability matrix (B). Thus, a HMM can be described as:

$$A = \mathrm{a_{ij}} = P(y_t = j | y_{t-1} = i) \text{ and } \sum_{j=1}^{N} a_{ij} = 1 \tag{6}$$

$$B = \left[b_j(O_t)\right] \tag{7}$$

$$b_j(O_t) = P(q_{k+1} = O_t /\ q_t = i) \tag{8}$$

$$\pi = [\pi_1, \pi_2 \ldots, \pi_N] \tag{9}$$

$$\pi_i = P(q_0 = i). \tag{10}$$

With: $i, j \in \{1,2, \ldots, N\}$
$O_t$: Vector of observations

A standard HMM is a generative probabilistic model, which generates hidden states $y_t$ from observable data $x_t$ at each discrete time instant. In our case the hidden variable is the activities that the subject was performing at a given time step and the observable variable is the vector of sensor readings. HMM model mainly works on two basic principles as follows: the observable variable at time $t$, namely $x_t$, depends *only* on the hidden variable $y_t$. The hidden variable at time $t$, namely $y_t$, depends *only* on the previous hidden variable $y_{t-1}$.

Learning the parameters of these parameters corresponds to maximizing the joint probability p(x, y) between the sensor data and activities in the training data. The joint probability therefore factorizes as follows:

$$P(\mathrm{x}, \mathrm{y}) = \prod_{t=1}^{T} p(y_t | y_{t-1}) p(x_t | y_t) \ . \tag{11}$$

The main aim of this model is to determine the best hidden state sequence from the observed output sequence that maximizes $p$(x, y).

# 3 Experimental Results and Analysis

## 3.1 Datasets

We validate our method on three public datasets whose information is summarized in Table 1. The first dataset used is from [22]: the Human Activity Dataset (HAR). The second dataset (HAPT) [23] with Postural Transitions is similar to previous dataset, further, it includes postural transitions in addition of the previous version of the dataset Records. The third dataset is from [24], titled Wireless Sensor Data Mining (WISDM). All datasets have been recorded by means of Android smartphone. For the annotation of the activities, the video-recorded is used to label the data manually. The HAR and

**Table 1.** Summary of datasets used in the evaluation

| Houses | HAR | HAPT | WISDM |
|---|---|---|---|
| Nb of subjects | 30 | 30 | 29 |
| Annotation | Video | Video | Graphical user interface |
| $F_{Sampling}$ (Hz) | 50 | 50 | 20 |
| Features | 561 | 561 | 6 |
| Smartphone | Samsung Galaxy SII | Samsung Galaxy SII | Cell Phone |
| Position | Waist | Waist | Front leg pocket |
| Sensors | Accelerometer and gyroscope | Accelerometer and gyroscope | Accelerometer |
| Activities | 6 | 12 | 6 |

HAPT datasets provide a large extracted features extracted by prepossessing the raw signals generated from sensors.

### 3.2 Results

These algorithms are tested under MATLAB environment and the WSVM algorithm is tested with implementation LibSVM [25] using Gaussian kernel is used for all the datasets. Each training dataset is normalized before classification within a range of $[-1, 1]$. We optimized the SVM hyper-parameters $(\sigma, C)$ for all training sets in the range [0.1, 0.2, 0.5, 1] and {0.1, 1, 5, 10, 100}, respectively, to maximize the error rate of five fold- cross validation technique. The optimal parameters $\sigma_{opt} = 0.9$, 0.9, and 0.8 are found to be optimal the training dataset of HAR, HAPT, and WISDM, respectively. We show in the Table 2 that the fusion of principal component features with WSVM-HMM makes the model more robust, achieving better performance. One also notices for HAR dataset that the multi-class WSVM method improves the classification results over MC-SVM, MC-HF-SVM and HMM classifiers used alone. On the other hand, the results also show that WSVM outperforms HMM for recognizing activities for all datasets except for the HAPT dataset.

In terms of reducing the datasets, the feature reduction identifies the most relevant features for the learning process. We notice that PCA features can improve the discrimination between different activities than the original features. For WISDM the performances of activity recognition are low than HAR and HAPT datasets with 561 features. This is explained by the number of features (6) for WISDM is not sufficient when using PCA algorithm. Another reason to the lowest accuracy in WISDM dataset is attributed to the use only the accelerometer sensor comparatively to the HAR and HAPT that use the both accelerometer and gyroscope sensors.

**Table 2.** The micro-averaged measures: Recall, Precision, F-measure and Accuracy for all approaches in (%). Bold values are the results for our approach for each dataset.

| Datasets | Approach | Recall | Precision | F-measure | Accuracy |
|---|---|---|---|---|---|
| HAR | MC-SVM [8] | 89.6 | 89.9 | 89.7 | 89.3 |
| | MC-HF-SVM [8] | 89.3 | 89.2 | 89.2 | 89.0 |
| | WSVM | 92.4 | 91.6 | 91.9 | 93.9 |
| | HMM | 89.2 | 90.2 | 89.7 | 93.7 |
| | **Proposed** | **94.0** | **96.7** | **95.3** | **94.9** |
| HAPT | WSVM | 96.0 | 92.4 | 94.1 | 86.1 |
| | HMM | 98.3 | 97.1 | 97.7 | 96.5 |
| | **Proposed** | **97.3** | **99.0** | **98.1** | **96.8** |
| WISDM | J48 [26] | 81.7 | – | – | 85.1 |
| | LogisticRegression [26] | 68.4 | – | – | 78.1 |
| | MultilayerPerceptron [26] | 80.4 | – | – | 91.7 |
| | WSVM | 83.4 | 76.5 | 79.8 | 81.4 |
| | HMM | 79.4 | 80.0 | 79.7 | 84.9 |
| | **Proposed** | **91.9** | **79.8** | **85.4** | **92.3** |

**Table 3.** Confusion matrix of activities for the proposed method on the HAR dataset.

| Activities | Walking | W. Upstairs | W. Downstairs | Sitting | Standing | Laying |
|---|---|---|---|---|---|---|
| Walking | **97.1** | 2.1 | 0.7 | 0.0 | 0.0 | 0.1 |
| Walking. Upstairs | 1.2 | **96.2** | 2.4 | 0.1 | 0.1 | 0.0 |
| Walking. Downstairs | 0.7 | 2.2 | **97.1** | 0.0 | 0.0 | 0.0 |
| Sitting | 0.6 | 0.0 | 0.1 | **83.5** | 12.2 | 3.6 |
| Standing | 0.1 | 0.2 | 0.2 | 7.4 | **91.4** | 0.7 |
| Laying | 0.0 | 0.0 | 0.3 | 0.8 | 0.3 | **98.6** |

To get a detailed knowledge of the performances on each class corresponding to current activity for the HAR dataset with six different activities. We calculate the confusion matrix of the proposed method in Table 3. From these tables, we see that the best performances were obtained for the proposed method for all classes, in particular for the static activities (Sitting and Standing).

In the Table 3, 96.2% of 'W. Upstairs' activity instances are correctly recognized, while 2.4% goes into 'W. Downstairs' and 1.2% are confused with 'Walking' activity. The similar classes such as 'Walking', 'W. Upstairs', and 'W. Downstairs' show similar trend of sharing errors among each other. The reason is the similar status of smartphone when the user does these dynamic activities. We notice that the static activities share errors among each other. 12.2% of 'Standing' activity instances are confused with 'Sitting' activity and 7.4% of 'Sitting' activity instances are confused with 'Standing' activity. Intuitively, this can be explained by the fact that the patterns in the acceleration data between these activities are somewhat similar.

## 4 Conclusion and Future Work

Experimental results of the hybrid model presented demonstrate how it can be effectively employed for activity recognition of static and dynamic activities. It obtains a significant performance. Specifically, we show how the hybrid system obtained by using the WSVM label output a new feature added to the reduced data for training and testing HMM outperforms other well known supervised pattern recognition approaches. We consider that WSVM approach has great potential to deal the imbalance class in this human activity recognition problem. However, it must be noticed that hybridizing these schemes implies a more complex system. Fortunately, the training phase in a deployed activity recognizer is usually done offline, so we do not consider such growth of complexity a real problem in our domain.

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# Mobile Assistive Application for Blind People in Indoor Navigation

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**Abstract.** Navigation is an important human task that needs the human sense of vision. In this context, recent technologies developments provide technical assistance to support the visually impaired in their daily tasks and improve their quality of life. In this paper, we present a mobile assistive application called "GuiderMoi" that retrieves information about directions using color targets and identifies the next orientation for the visually impaired. In order to avoid the failure in detection and the inaccurate tracking caused by the mobile camera, the proposed method based on the CamShift algorithm aims to introduce better location and identification of color targets. Tests were conduct in natural indoor scene. The results depending on the distance and the angle of view, defined the accurate values to have a highest rate of target recognition. This work has perspectives for this such as implicating the augmented reality and the intelligent navigation based on machine learning and real-time processing.

**Keywords:** Assistive application · Color targets · Camshift algorithm · Android application

## 1 Introduction

Vision is a vital human sense that plays a crucial role in the human perception of the environment. However, for the visually impaired, this information is not generally available through external intervention. In fact, to ensure safe and independent mobility, people are usually dependent on external information, planned experience, and existing technology to navigate in indoor environments or in unfamiliar outdoor. In this context, many researchers address the issue of how to enable these individuals to overcome the inability to navigate the environment independently and to understand the visual scene defined by a set of components and characteristics. In this work, we are considering to design a system that provides assistance for the visually impaired to better navigate in both indoor and outdoor environment.


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## 2 State of the Art

Recent technological developments provide technical assistance that helps to support visually impaired people in their daily tasks and improves their quality of life. In this context, sensory substitution systems [1–4] are devices that allow information normally acquired by a defective sensory organ and restored to another perceptive modality. For the visually impaired, it consists of transmitting visual information via the auditory or somatosensory system

First, the visuo-tactile substitution devices convert a visual image into tactile information. There are many devices such as the TVSS [5], TDU [6]. These tools are efficient in the recognition of simple forms, the possibility of reading and localization [7].

Moreover, the visuo-auditory substitution devices are based on the transformation of visual image into auditory information. Thanks to auditory system, visually impaired people use sounds for navigation that inform them about the environment and protect them from obstacles. There are many devices such as the Voice [7], PSVA [8], the Vibe [9], and See Colour [10].

These visual substitution systems are using the translation of visual information into another auditory sensory in order to assist visual impaired people. However, existing system needs hard equipment and sometimes the visual impaired should handle it in a backpack.

In addition, new technologies such as mobile phones or smartphones provide technical assistance to support the visually impaired in their daily tasks and aim to improve their quality of life. These devices are equipped with touch screens that ensure better user experience. In fact, they are more adaptable to the visually impaired people using a guiding system for way finding. So that, using a smartphone and its integrated camera, the system is able to detect objects such as the panels [11].

Another technology was presented in literature, which is the Near Field Communication (NFC). NFC is one of the newest technologies in the communication area. It has a rapid progress in mobile devices and an increase number of smartphones equipped with NFC readers. This technology combines identification and interconnection and enables secure communication between electronic devices [12]. In fact, the user has simply to touch the NFC tagged object in order to obtain detailed information.

Besides, there are other visual substitution applications based on voice and haptic replication. The user receives information when entering or sliding the finger on the screen using a screen reader that converts text to speech and ensure reading and navigating through the contents [13].

In addition, haptic is a technology that provides tactile feedback. For tactile-based interfaces [14], haptic can make the user feel and visualize the shape of an element without looking at the screen. It can also provide comments when the finger reaches the limit of an element or button.

The experiments results in literature [15] illustrate the ability of blind and visually impaired people to use assistive mobile application in order to locate the guide signs with an auditory feedback.

# 3 Proposed Method

In order to assist blind and visually impaired people in indoor navigation and facilitate the way finding, we propose a navigation system using mobile application that detects and reads colour targets retrieved through the integrated camera. The developed android application named "GuiderMoi" is mainly used to assist the blind person in indoor environment and buildings.

## 3.1 General Architecture

The general architecture of the proposed system based on mobile application is shown in Fig. 1.

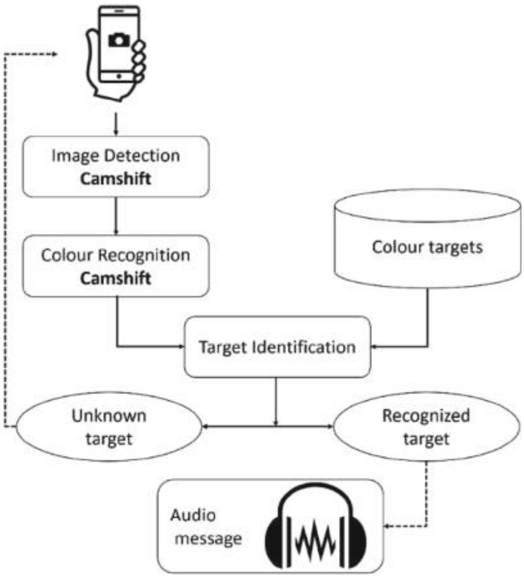


**Fig. 1.** General architecture

The colour targets are detected using the Camshift algorithm [16]. Once the colours are determined, a comparison is made with targets in database. If the target is unrecognized, we repeat the operation from the beginning. Otherwise, we continue processing to determine the direction. Finally, once the direction is determined, a vocal notification is launched to notify the user about his next direction.

### 3.2 Continually Adaptive MeanShift (Camshift) for Target Color Detection

Color targets are a tracking symbols designed to solve the problem of environmental labelling [17]. They are distinctive and difficult to confuse with a typical background clutter and are detectable by a robust algorithm that can work very quickly on a smartphone. Based on the idea of [18], we added the fourth color to detect the last direction.

In our proposed system, the colour targets are represented as four squares giving a particular orientation (Fig. 2):

- Red: turn left
- Black: turn right
- Blue: moving forward
- Green: back off

**Fig. 2.** Color targets (Color figure online)

Then, whenever the target is detected, the system provides a vocal directional orientation (for example “turn left”) to guide the visually impaired to its desired destination from its current location.

In the step of color detection of the target, we use color recognition algorithms mainly Camshift.

Furthermore, Camshift (Continually Adaptive MeanShift) is an important algorithm for object tracking based on the color histogram [16]. The algorithm is based on finding the probability distribution map in a search window and iteratively updates the position and size of the window to convergence.

### 3.3 Camshift Algorithm

The Camshift algorithm uses the meanshift algorithm [16] in a loop varying the size of the window until convergence.

The window in the mean shift is applied with a given size. After convergence, the procedure is re-iterated with a new window, centred on the position found by the mean shift, but with a size depending on the zero order moment of the spatial distribution of the pixels probability previously calculated by the mean shift [16].

The different stages of Cam-shift are as follows:

- Initialize the window $W$: position and size.
- As long as $W$ is moved with a certain threshold and the maximum number of iterations is not reached:

- Apply the mean shift; keep the center $(x_c, y_c)$ and the zeo-order moment $M_{oo}$
- The window W will be centered on $(x_c, y_c)$ with the width $w = 2\sqrt{\frac{M_{00}}{256}}$ and the height $h = 1.2\,w$

Cam-shift is mainly used in the image segmentation. In fact, after convergence of the mean shift, the height of the window is chosen 20% greater than its width, but this choice is arbitrary and can be changed according to the application.

# 4 Results and Discussion

In this section, we present the test conditions and the results of target detection and recognition depending on the distance, the angle of view and the luminosity. In addition, we worked on measuring variables (distance, angle, illumination) because of the sensitivity of mobile application in natural indoor environment conditions.

## 4.1 Target Detection

The tests are performed in real time in indoor scene. We used the mobile application (GuiderMoi) with variation on the distance, the angle of view and the illumination values (Fig. 3).

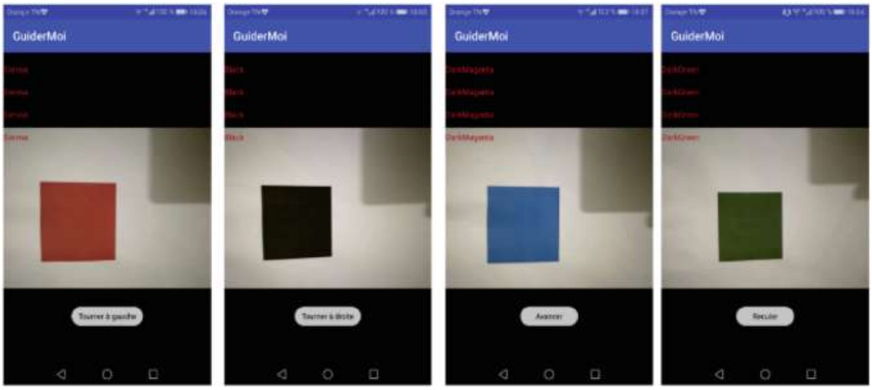


**Fig. 3.** The mobile application (GuiderMoi) detecting targets

**Distances**

First, we choose a reference angle of 90° and we change the distance between the target and the smartphone's camera calculated in centimetres.

Then, for each selected distance, we detect the target and we repeat the test ten times. Then we calculate the number of successful tests.

In addition, the tests are carried out first in the case of daylight in the case of fluorescent light and finally in the case of incandescent light.

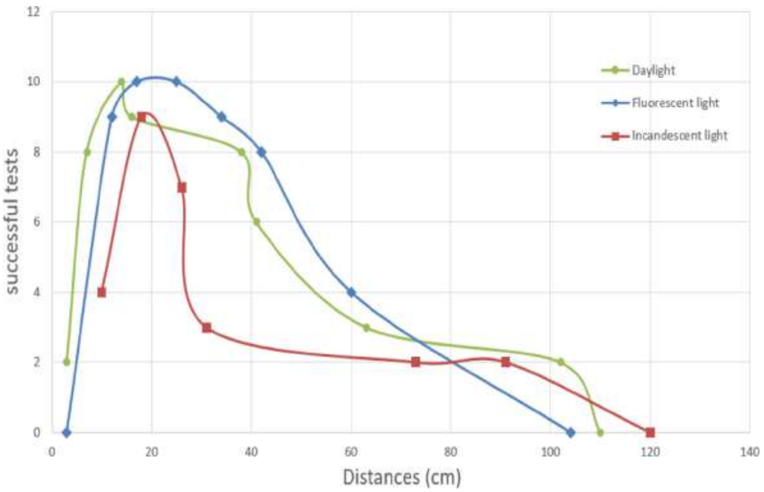


**Fig. 4.** Variation of successful tests by distance in the case of daylight, fluorescent light and incandescent light (Color figure online)

Furthermore, Fig. 4 shows that the target is well detected in the case of daylight but we notice that the detection range increases in the case of fluorescent light and decreases in the case of incandescent light.

**Angle of vision**

In this test, we choose a reference distance of 25 cm and we change the angle between the target and the smartphone camera calculated in degrees.

For each selected angle, we use the application (GuiderMoi) to detect the target and we repeat the test ten times. Then we calculate the number of successful tests. Additionally, the tests are carried out first in the case of daylight, in the case of fluorescent light and finally in the case of incandescent light (Fig. 5).

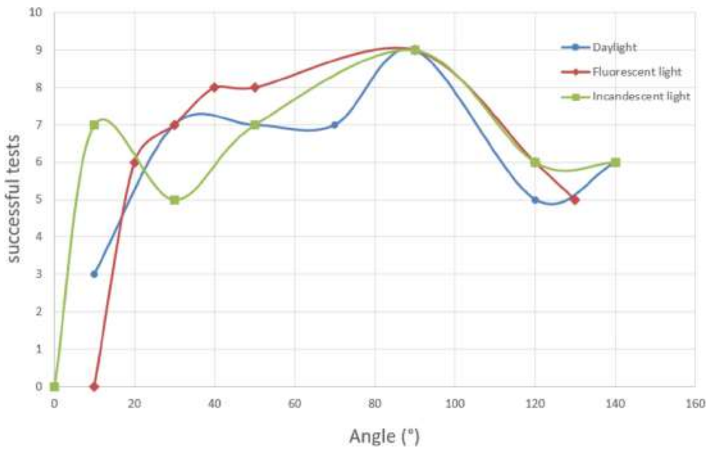


**Fig. 5.** Variation of successful tests by viewing angle case of daylight, fluorescent light and incandescent light (Color figure online)

We notice in Fig. 5 that the detection ranges with respect to daylight increases in the case of fluorescent light and decreases in the case of incandescent light.

### 4.2 Discussion

First, we tested the mobile application (GuiderMoi) under different conditions mainly distance, angle of view and illumination. We noticed that the colour of the targets was well chosen and their detection is robust especially for the red and the black targets. Then, in the case of illumination, the detection is better in the case of the fluorescent light since it is white and has no influence on the colours.

Moreover, for the distance between the target and the user, the detection is between 15 and 30 cm and the optimal distances are 25 cm. In addition, for the viewing angle, the best position is 90°.

Furthermore, for time processing, the mobile application (GuiderMoi) has the advantage of being in real time. Unfortunately, we have a loss of detection at distance greater than 1 m. In fact, the target becomes smaller and more difficult to identify. At a short distance, we get the reflection of the smartphone on the target that gives false colour detection. Besides, the user has to be exactly in front of the target in order to have a robust detection. We have a total loss of detection at the limits of the target that is to say at an angle of 0° and 180°. The navigation tests were successful in the case of fluorescent light, the user in front of the target with a distance equal to 25 cm.

There are some limitations to our approach. The first is that we are only using the Hue component of the HSV color space. This means that unless the object we are trying to track is not a single shade, then the results will likely be suboptimal.

To remedy this, we can simply extend the code to compute a 2D histogram using both the Hue and Saturation components. However, OpenCV currently does not support 3D histograms in the back projection calculation and Cam-Shift tracking.

The second limitation is tuning the number of bins in the color histogram. This will depend on many aspects, including the application conditions. We need to tune this parameter for our application.

Finally, if we are looking for a more robust tracking solution that can take into account texture and localized features, we should look into keypoints detection, local invariant descriptors (ex. DoG and SIFT), and matching between the sets of keypoints and their corresponding features.

## 5 Conclusion

In this paper, we propose a navigation system based on mobile application "GuiderMoi" to provide assistance for visually impaired in indoor environment. In fact, the mobile application provides information about directions and helps the visually impaired to navigate effectively and independently based on colour targets detection and identification. In future research, it would be interesting to study how we can improve mobile applications using augmented reality and intelligent navigation based on deep learning.

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# Older People's Needs and Opportunities for Assistive Technologies

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**Abstract.** Older adults experience a disconnect between their needs and adoption of technologies that have potential to assist and to support more independent living. This paper reviewed research that links people's needs with opportunities for assistive technologies. It searched 13 databases identifying 923 papers with 34 papers finally included for detailed analysis. The research papers identified needs in the fields of health, leisure, living, safety, communication, family relationship and social involvement. Amongst these, support for activities of daily living category was of most interest. In specific sub-categories, the next most reported need was assistive technology to support walking and mobility followed by smart cooking/kitchen technology and assistive technology for social contacts with family member/other people. The research aimed to inform a program of research into improving the adoption of technologies where they can ameliorate identified needs of older people.

**Keywords:** Older people · Needs · Assistive technologies · Systematic review

## 1 Introduction

Global life expectancy rose from 64.2 years in 1990 to 72.6 years in 2019 [1]. There is increasing interest in and availability of support for people choosing to remain in their own homes and delay or avoid moving to institutional care, with an increasing need to improve access to services at home in health management, rehabilitation nursing and entertainment [2]. This research aimed to identify the state of matching needs with technologies focusing on support in the home environment to support independence in everyday activities. Important technology features include ease of use, security, safety, reliability and use independency as important factors in adoption of assistive technology [3]. There is a need for greater awareness of what smart home and assistive technologies are needed to guide technology developers as well as to increase the understanding of potential users of what is available and how it might benefit them.

"Assistive technology" is an umbrella term referring to a range of specialized technology used by people to support activities of daily living and specific tasks [4]. It is about the use of an array of electronic devices incorporated into everyday objects in order to monitoring the user's status and provide assistance as needed, including feedback, guidance, alerts or warnings [5]. Assistive technology has evolved with and emerged from information technology, passing from detecting and reporting problems, to assisting


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with prevention of ill-health and adverse events [6]. Smart home technologies refer to technology for clinical and wellness monitoring of people in their homes and/or promotes independence and quality of life [7]. The smart home and assistive technologies mentioned in this literature review covers use in both indoors and outdoors.

This paper aims to address three issues. First, to review the needs of older people for assistive technologies and smart home technologies by identifying relevant research. The methods involved searching bibliographic databases, to screen according to inclusion and exclusion criteria. Second, the paper aims to map needs with available smart home and assistive technologies according to the findings from identified papers. Third, to identify the knowledge gap of needs from older people and the gap of awareness of technologies available.

## 2 Method - Search Strategy and Eligibility of Study Selection

A search was undertaken of 13 bibliographic databases which included: A). Academic Search Ultimate; B). AHFS Consumer Medication Information; C). Anthropology Plus; D). Applied Science & Technology Source Ultimate; E). Business Source Ultimate; F). CINAHL with Full Text; G). Health Business Elite; H). Health Source - Consumer Edition; I). Health Source: Nursing/Academic Edition; J). Humanities Source Ultimate; K). Mental Measurements Yearbook with Tests in Print; L). Psychology and Behavioral Sciences Collection; and M). Sociology Source Ultimate.

Key words for the search were "Older people", "Elderly", "Old aged people", "Assistive technologies" and "Smart Home Technologies". There were some synonyms because there is a range of terms that authors may use as keywords. No doubt there will be other relevant research into this topic that has escaped our search which is a limitation of this review.

Before the study, we formulated the eligibility criteria which included: A). the result must focus on older people, while other groups can be involved such as younger people with disabilities, but the result towards other groups must be separately demonstrated in the conclusion of the research; B). The research should be based on empirical evidence, observed and calculated from data, questionnaire or interview, not be discussion papers without a data collection; C). The research should discuss older people's needs that are significantly beneficial to quality of life, including independent living skills, satisfaction of living, mental status, social involvement, selection of aged care mode, relationship with relatives, etc.; D). The factors discussed in the research positively link to and enhance with greater opportunities of assistive technologies which help older people with quality of life but not in other fields; E). The result should be published within 5 years; F); and the paper should be published in English. According to the assistive technologies mentioned and related to older people's quality of life, to researcher's introduction, to what researchers observed in sociology experiment, we classified older people's needs. The following result showed older people's needs in each type.

## 3 Results

By searching in 13 bibliographic databases we yielded 923 results. We excluded 386 papers due to duplication leaving 537 studies for screening. Based on the exclusion and inclusion criteria, we identified 34 papers for detailed analysis.

Though different researchers classified older people's needs in various ways, this paper, which looks into their broad types of needs, required a comprehensive way of classification. Our classifications were informed by Lee and Lim, who divided older people's need into health, leisure, living/safety and family relationship [8]. They included both indoor and outdoor activities, both physical and mental health, both independent living and interaction with others, both self-well-being conditions and objective environment improvement. We found this approach useful to distinguish different kinds of needs towards technologies, it made fewer overlaps and mixes when mapping to older people's needs. Based on their method, we refined categories, as a result, this review classified older people's needs towards smart home and assistive technologies into health, leisure, living, safety, communication, family relationship and social involvement – 6 categories in total. The clear summary of categories, sub-categories with frequencies and identified papers is shown in Table 1.

Among the 6 categories of needs of older people related to smart home and assistive technologies, "Living" category was the highest priority, which represented 40% of the total concerns, followed by "Safety" (16%), "Health" (15%), "Family Relationship and Social Involvement" (11%), "Leisure" (10%) and "Communication" (8%). Looking into subcategories of specific needs, walking and mobility assistance was the most needed, which was mentioned 16 times by identified researchers, represented 6.7% of the entire spectrum of older people's needs, followed by social contacts with family member/other people and smart cooking/kitchen technology, which both were mentioned 12 times by identified researchers, represented 5.1% of the entire spectrum of older people's needs.

Relevant systematic reviews in the last 5 years used the keywords "Elderly", "Older people", "Smart Home Technologies" and "Assistive Technologies", our search found 26 relevant systematic reviews published. These were about older people's attitude to [9] or adoption of [10] technologies, as well as technology for specific disease [11–14], for social [15] and communication [16], for nursing or caregivers [17], for monitoring [18–20] and mental well-beings [21] - none of them were comprehensively about the whole spectrum of assistive technologies, at the same time, none of them comprehensively based on older people's broad spectrum of needs. here is a need for a review based on older people's needs that might be addressed by smart home and assistive technologies.

**Table 1.** The frequency of users' needs towards technologies

| Category | Sub-category | References for articles mentioned | Frequency |
|---|---|---|---|
| Health | Sight/Vision Assistance Technology | [7, 9, 18, 21, 22, 26–28, 37] | 9 |
| | Long-term Pain Management | [12, 35] | 2 |
| | Rehabilitation Management | [16] | 1 |
| | Mood Recording/Management Technology | [6, 19, 24, 27, 30] | 5 |
| | Medication Reminder/Treatment | [6, 11, 17–19, 22, 27, 28] | 8 |
| | General Health Monitoring Technology | [6, 9, 21, 28, 31] | 5 |
| | Cognitive Ability Assistance Technology | [21, 26–28, 30] | 5 |
| | Nurse Call System | [6] | 1 |
| Leisure | General Recreational/Entertainment Technology | [7, 32] | 2 |
| | Tailored Games | [6, 7, 10, 16, 18–20, 34] | 8 |
| | Sports Assistive Technology | [7, 25, 28] | 3 |
| | Musical Instrument Playing Assistance | [6, 7, 16, 19, 34] | 5 |
| | Television and radio | [6, 9, 37] | 3 |
| | Travel Assistance | [30] | 1 |
| | Education Technology | [6, 32] | 2 |
| Living | Automatic Control Technology for Home Appliance | [6, 9, 11, 15, 17, 18, 22, 28, 31, 38] | 10 |
| | Gardening/Farming Assistance | [7, 27] | 2 |
| | Smart Cooking/Kitchen Technology | [7, 11, 13, 16–18, 21, 22, 24, 27–29] | 12 |
| | Toilet Use Assistance | [13, 17, 21, 22, 24, 27–29, 31] | 9 |
| | Cleaning and Laundry Assistance | [11, 17, 18, 21, 22, 24, 27–29, 35] | 10 |
| | Reaching and Grasping Technology | [9, 15, 16, 18, 21, 22, 24, 27, 29, 38] | 10 |
| | Showering Assistance | [13, 16, 18, 21, 22, 24, 27–29, 38] | 10 |
| | Dressing Assistance | [17, 18, 21, 22, 24, 27–29] | 8 |
| | Walking and Mobility Assistance | [9, 16–22, 24–27, 29, 31, 35, 38] | 16 |
| | Eating Reminder and Assistance | [17, 21, 24, 27, 28] | 5 |
| | Item Locating System | [11, 17, 28] | 3 |

(*continued*)

**Table 1.** (*continued*)

| Category | Sub-category | References for articles mentioned | Frequency |
|---|---|---|---|
| Safety | Overall Sense of Safety | [3, 6, 25, 32, 33] | 5 |
| | Falling Prevention | [17, 18, 23, 28, 31, 35, 38] | 7 |
| | Reminder for Declined Memory | [11, 15, 17, 22, 26, 34] | 6 |
| | Home/Location Finding Technology | [17, 21, 23, 28, 34, 35] | 6 |
| | Technology of Emergency Response/Warning about Potential Hazards | [13, 22–24, 30, 31, 34, 35] | 8 |
| | Gas Leakage Detector | [6, 13] | 2 |
| | Transportation Assistance | [9, 21, 22] | 3 |
| Family Relationship and Social Involvement | Finance Managing Assistance | [7, 17] | 2 |
| | Appointment/Issue Reminding Technology | [9, 17, 18, 28, 34] | 5 |
| | Shopping Assistance/Delivery | [17, 18, 22, 28, 30] | 5 |
| | Video Call System | [6] | 1 |
| | Assistance of Social Contacts with Family Member/Other People | [6, 10, 14, 17, 21, 26, 27, 29, 30, 32, 36, 37] | 12 |
| | Relative Recognizing Technology | [17] | 1 |
| Communication | Personal Communication Technology | [7, 9, 14, 18, 30, 34, 36] | 7 |
| | Smart Phone and Computer | [7, 9, 11, 23, 26, 34] | 6 |
| | Companionship Technology/Robots | [8, 14, 16, 18, 19, 36, 38] | 7 |
| Total | | | 238 |

## 4 Discussion

There are three potential ways to link older people with assistive technologies or smart home technologies. The first one is to develop or innovate technologies as the initial activity and then promote the technology to older people and finally evaluate the result of impact. However, technologies that are acquired in ways that are not congruent with seniors' personal needs and circumstances run a higher risk of proving to be ineffective or inappropriate resulting in poor levels of adoption [22]. The second way is to focus on older people's attitude and adoption upon assistive technologies - to optimize user acceptance towards products by identifying and eliminating the barriers of adoption.

This includes research that looked at user attitude and acceptance and examined social factors which appropriately supports the relationship between users and service providers [23]. The third way is to listen to older people's needs and develop, optimize the technologies in specific orientation. Because some older adults experience a misfit between technology and needs, they must see the value of a device to use it [24]. The research reported on in this paper follows the third way, which looks into older people's detailed and specific needs at the beginning. the paper reviews the existed smart home and assistive technologies that cope with the needs, moreover, the direction of technologies' innovation.

To investigate older people's needs, much of the extant research reports on projects that chose the direct way, either by observing the phenomena or by analyzing data and transcript: 11 research reports tested the needs by enrolling older people into a clinical trial, project and intervention/control group to be observed and tested for the performance in real scenario; 20 research reports acquired the answer by questionnaire, survey, face-to-face or telephone interview, and derive the information from the data.

The existing literature reports on research that identified older people's needs of sight/vision assistance technology, long-term pain and rehabilitation management, mood recording/management technology, medication reminder/treatment, nurse call system, general health monitoring and cognitive ability assistance technology. We found the focus was mostly on the need for sight/vision assistance technology (represented 25% in this category), medication reminder/treatment (represented 22% in this category) and general health monitoring technology (represented 14% in this category). At this point, the highly recommended technologies were low vision assistive devices [25], health monitoring robots [26] and e-readers [27].

As for the needs for leisure, research results indicated that older people had the need for general recreational/entertainment technology, tailored games, sports assistive technology, musical instrument playing assistance, television and radio, travel assistance and education technology. We found that tailored games attracted 33% of research focus, which was the most needed by older people in this category. It was followed by 21% research results seeking for the technology for playing musical instrument. Game system, movie/music player [8], and entertainment console [28] were the most preferred.

The very significant category, living, represented of almost half of older people's needs towards smart home and assistive technologies. To be specific, walking and mobility assistance were the most focused (represented 25% in this category), followed by smart cooking/kitchen technology (represented 13% in this category). Older people had a rather broad range of needs in everyday living, including automatic control technology for home appliance, gardening/farming assistance, smart cooking/kitchen technology, toilet use assistance, cleaning and laundry assistance, reaching and grasping technology, shower assistance, dressing assistance, walking and mobility assistance, eating reminder and assistance and item locating system. Researchers found physical activity stimulation, home automation [27], smart power outlet, universal remote control [29] to be appropriate for older people.

Safety is a critical aspect for older people's both indoor and outdoor activities. according to identified papers, older people were concerned about overall sense of safety, falling prevention, reminder for declined memory, home/location finding technology, technology of emergency response/warning about potential hazards, gas leakage detector and transportation assistance. There was no doubt that technology of emergency response/warning about potential hazards was the most focused one (represented 22% in this category), followed by falling prevention (represented 19% in this category). Alarm system [30] was the most significant technology, together with gas/smoke sensor [29] and emergency call devices [31].

Communication, family relationship and social involvement played an important role in older people's mental health. Nine types of needs were identified, including finance managing assistance, appointment/issue reminding technology, shopping assistance/delivery, video call system, assistance of social contacts with family member/other people, relative recognizing technology, personal communication technology, companionship technology/robots, smart phone and computer. Among them, assistance of social contacts with family member and companionship technology/robots were pointed out by 45% of the researchers concentrating on this field. Video call system and social robots [32, 33] were the most recommended technologies.

Researchers looked into older people's target [25] and expectations [30, 34, 35] towards assistive technology, or just set the feature of a specific type assistive technologies [36] but did not include comprehensive view of assistive technologies. Some of the previous research focused on motivations [37, 38], barriers [39] and effectiveness [26] of smart home and assistive technologies – they focused more on adoption [8, 40, 41] than needs. Looking at the range of assistive technologies mentioned in the research, some research was broad enough but not specified, which just mentioned the whole range of assistive technology [42–45] or technology used in a very broad field [24, 46–50]. This is not useful enough to guide technology developers to map their detailed products to older people. On the other hand, some research provided very narrow view of assistive technologies [3, 28, 32, 33, 51–53], with only one or two specific technologies introduced.

There appears to be a need for an effective way to analyze and predict older people's needs that can be matched with the assistive technologies that are available.

## 5 Conclusion

There is existing literature into older people's needs in the field of health, leisure, living, safety, communication, family relationship and social involvement. Among them, living category was of most interest. To be more specific, assistive technology for walking and mobility were of the most interest by researchers. The information was gained mostly by interview, telephone talk, home visit or observation in a project. Though these methods were direct, liable, accurate, they were less efficient by directly interacting with older people, who might not be able to express their needs well because of inadequate awareness of technology or chronic disease that hinders the ability of communication. Another way to link older people's needs with technologies was to apply a technology push to older people and check the effectiveness and adoption, which may then cause misfit between older adults' needs and available technology. A better way may be needed to explore the opportunities for smart homes and assistive technologies neither by directly interviewing older people nor by technology push. One suggestion is that researchers can look into databases related to older people's health and quality of life – by analyzing the significant associating factors related to older people's independent living, smart home and assistive technologies contributing these factors, which can be referred as the future needed ones. The other solution might be seeking older people's needs in aged care service provision. To sum up, better method of exploring older people's needs and market demand of assistive technologies are required, broader types of older people's needs are to be discovered, at the same time, more types of assistive technologies are to be suggested by further research.

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# Towards a Formal Context-Aware Workflow Model for Ambient Environment

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**Abstract.** Ambient systems owns some particular characteristics that makes their context awareness a sincere problem; they are composed of heterogeneous distributed devices, some of these devices may appear and disappear during operations. In addition, users interacting in these systems are themselves dynamic. Therefore, context-aware workflow management allows workflows to adapt dynamically according to the environment changes. Context information are complex and diverse which makes the modeling the key issue. This paper presents an approach to model context-aware workflows. First, we describe the workflow using Ag-LOTOS. Then, based on this description, we build the contextual planning system *CPSw* that allows the presentation of the context at each activity state.

**Keywords:** Modeling of physical and conceptual information in smart environments · Context awareness · Ambient intelligence · Formal description · Workflow

## 1 Introduction

In order to meet the needs of everyday life, systems are becoming more and more complex, which leads to seek to give more atomicity and initiative to the different software modules. To respond to this technological evolution, ambient intelligence [1] is a new paradigm of distributed systems where the environment is aware of the user's needs and find a way to fulfill that need to improve the quality of people's life.

Due to the extreme mobility of users, ubiquitous software [2] run in a highly dynamic and varying environment. Therefore, context awareness [3] and context adaptation [4] are some important aspects for pervasive software that have to be aware of the context's changes, and dynamically adjust their execution [4]. Context-aware workflow [5] is an interesting field that allows workflows to adapt dynamically to the context changes in ubiquitous environment.

To achieve this goal, no many results have been accomplished in workflow's context modelling. [6] proposes a context-aware workflow management system


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(WFMS) for navigation applications in ubiquitous computing. In [7], a dynamic context-aware access control for pervasive computing in enterprise environment is proposed. However, [8,9] allow users to model their daily activities in the form of workflow adaptable to context information. [10] proposes an approach to build a flexible model to adapt business process based on context. In [11], both the conceptual model and the workflow model are defined based on OWL.

Considering that the ambient systems manage our daily life such as smart hospital, smart home, robots, etc., errors are critical regarding human life. Many WFMS tools [12,13] exist and allow the modelling and verification of workflows. However, mathematical approaches are proved to be more effective [14]. [15] describes the workflow patterns in the formal specification language LOTOS [16]. In addition, [17] proposes an approach to specify and verify the service composition using LOTOS.

In this paper, we describe at first the workflow using Ag-LOTOS [18], a formal specification model based on LOTOS. Ag-LOTOS is a formal technique based on process algebra that allows to formally describe the workflow and to verify properties on the model. Then, the contextual planning system of the workflow (CPSw) [19] is built based on the semantics of Ag-LOTOS constrained by contextual information. Unlike the previous work, our approach allows a formal description of the context as *pre*- and *post*-condition in each state of all the possible traces and adjust the changes dynamically. The proposed model can be used in the verification process to check some contextual properties.

## 2 The Context-Aware Workflow Model

### 2.1 Ag-LOTOS for Workflows

Business Process Management (BPM) has been defined by van der Alast as "a way to support business processes using methods, technique and software to model, execute, control and analyze operational processes involving humans, organizations, applications, documents or any other source of information" [20]. However, a workflow can be defined as "business process automation during which documents, information or tasks are passed from one participant to another according to a set of process rules" [20]. A workflow pattern [21] represents the abstraction of most frequent activities sequence, and are composed when specifying new workflows.

In this section, we aim to use Ag-LOTOS [18] to improve workflow specification by including contextual information to each state of the workflow model, and by modeling the ambient characteristics such as communication and mobility that cause the dynamic changes of the context.

Similar to LOTOS [16], Ag-LOTOS concurrency allows the modeling of parallel activities. The Ag-LOTOS subsystem support allows the composition of workflow elements. Since Ag LOTOS is derived from LOTOS, we follow the procedure of mapping of the workflow patterns to LOTOS notation applied in [14] and citecite6 to give the suitable definition of each operator in the workflow context. To specify activities in details, we can simply model them with Ag-LOTOS sub-processes (hierarchy of processes). Note that Ag-LOTOS processes are used to model activities in the workflow. However, the process in the workflow context indicates a set of activities.

Ag-LOTOS expressions are written by composing actions through the LOTOS operators.

The syntax is defined as follows [18]:

$$P ::= E$$

$$E ::= exit|stop$$

$$a; E|E \odot E \quad (a \in \partial)$$

$$|hide\, L\, in\, E$$

$$\mathcal{H} ::= move(l) \quad (\mathcal{H} \subset \partial, l \in \ominus)$$

$$|x!(v)|x?(v) \quad (x \in \mathcal{U}, v \in \mathcal{M})$$

$$\odot ::= \{|[L]|, |||, \gg, [\,], \|, [>\}$$

Where $\partial$ is a finite set of observable actions, L is a subset of $\partial$ and $\mathcal{H} \subset \partial$ is the set of ambient intelligence primitives, which represent the mobility and the communication. $\ominus$ is the finite set of spatial localities of the pervasive environment, $\mathcal{U}$ is a finite or infinite set of users, with which the user can communicate, and $\mathcal{M}$ is the set of messages that can be sent or received.

An essential component of a process definition is its behavior expression E. A behavior expression is built by applying an operator, e.g., $\gg$, to other behavior expressions. A behavior expression may also include instantiations of other processes.

**Termination.** In Ag-LOTOS, the termination is represented via the operator *stop* witch indicates the inaction while the *exit* operator expresses the successful termination.

**Fail.** In $A = fail$, *fail* represents the fact that the execution of an activity $A$ fails because of the dynamic context of the workflow.

**Prefix.** The operator ';' is used to prefix a behavior expression with an action to produce a new one. Note that actions are the elementary units executed by activities.

**Hiding.** *hide* is used to express the discriminator pattern (similar to LOTOS). An external gate is used to invoke the subprocess that enables the activity. This gate is hidden inside the discriminator to avoid any external synchronization (see [14,15] for further details).

Respectively, the set $\odot$ represents the standard LOTOS operators.

**Sequence.** The sequential composition operator $\gg$ is used to represent the sequence pattern.

**Cycle.** A loop in a process allows the repetitive execution of activities, $P ::= E \gg$P.

**Choice.** $A\,[\,]\,B$, activity $A$ or $B$ will be chosen.

**Disabling.** During the activity execution, it is possible to indicate its failure with the disabling operator $[>$. $A\,[> B$ means activity $A$ may be disabled by activity $B$ which interrupts the main flow and uses *stop* instead of *exit*.

**Parallelism (general case).** $A\,|[L]|\,B$ means if the process (activity $A$) is ready to execute some action at one of the synchronization gates, it is forced, in the absence of alternative actions, to wait until the process (activity $B$) offers the same action.

**Full Synchronization.** $A \parallel B$ means that if $L = \partial$, the two composed activities are forced to execute in complete synchronicity.

**Pure Interleaving.** If $L = \emptyset$, the absence of synchronization leads to the absence of interaction points among processes, this is achieved through the interleaving operator '$|||$'.

### 2.2 Contextual Planning System of the Workflow

In order to illustrate the concept of the formal design of workflows with the contextual information, the contextual planning system is built from an Ag-LOTOS specification using the rules in Table 1.

**Table 1.** The semantic rules.

| | | |
|---|---|---|
| Action: | $\dfrac{ws \xrightarrow{a} ws' \quad a \in Act}{(ws, l) \xrightarrow{a} (ws', l)}$ | |
| Mobility: | $\dfrac{ws \xrightarrow{move(l')} ws' \quad (l \neq l')}{(ws, l) \xrightarrow{move(l')} (ws', l')}$ | |
| Communication: | $(a)\dfrac{ws \xrightarrow{x!(u)} ws' \quad (u \in \mathcal{U})}{(ws, l) \xrightarrow{x!(u)} (ws', l)}$ | $(b)\dfrac{ws \xrightarrow{x?(u)} ws' \quad (u \in \mathcal{U})}{(ws, l) \xrightarrow{x?(u)} (ws', l)}$ |

The Contextual Planning System of the Workflow (CPSw) based on CPS [22] takes into account two types of information: workflow planning state $ws$ and locality $l$. Table 1 shows the operational semantic rules that define the possible planning state changes for the workflow. From an initial planning state $(ws_0, l)$, we apply these rules to produce the CPSw. The contextual planning system CPSw is a labeled Kripke structure $(S, s_0, Tr, L)$ where $S$ is the set of contextual planning workflow states, $s_0 = (ws_0, l) \in S$ is the initial planning state of the workflow, $Tr \subseteq S \times \partial \cup \{T\} \times S$ is the set of transitions which are denoted $s \xrightarrow{a} s'$, and $L : S \rightarrow \ominus$ is the location labeling function.

## 3 Case Study

In this paper, we target on context-aware workflow models for ubiquitous company. Let there be an enterprise with several helpdesk employees associated with smart badges that provide the system with spatial information at each moment.

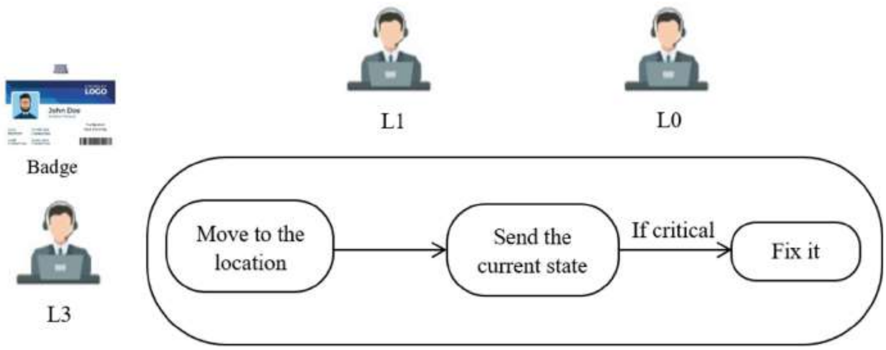


**Fig. 1.** The scenario that illustrate the case study.

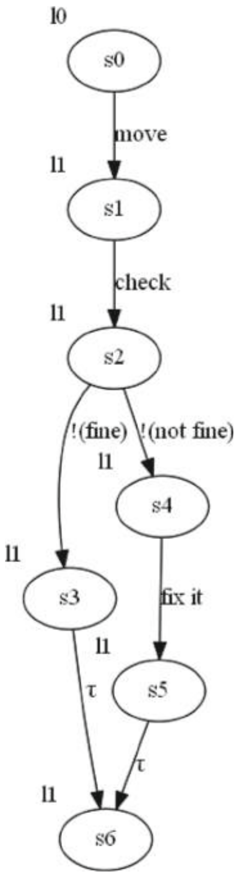


**Fig. 2.** The CPSw corresponding tot the case study.

The scenario illustrated in Fig. 1 is highly context dependent, especially in the following way:

If the system detects a problem on the switch in datacenter location, he sends a request to the closest helpdesk. This one has to move to the location of the switch and send the current state by email to the management system:

**State 1** `fine`, indicate that there is no critical problem.
**State 2** `not_fine`, in case of critical one which need to be fixed.

The corresponding CPSw to the scenario is illustrated in Fig. 2. It is built from the initial Ag-LOTOS description:

```
move(l1); check;
   (x!(fine); exit [] x!(not_fine); fix_it(l1); exit
```

## 4 Conclusion

Workflow systems are currently used by many organizations including health care, automation and finance. Context awareness is the ability for workflows to react to the changing situations. In this paper, we introduced a context-aware workflow model, the CPSw, that presents all the possible evolutions of workflow's activities constrained by the contextual information. CPSw is constructed formally based on Ag-LOTOS description giving the set of activities.

We learned that using Ag-LOTOS to describe workflow activities is a promising approach. Mainly, because it allows a formal description of the current context in each state as *pre*- and *post*-conditions, and dynamically adjusts the modifications. Furthermore, it allows the verification and validation of the model.

The proposed model can be used in the verification process to verify certain contextual properties. For future works, we aim to consider different types of context information such as the time.

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# The PULSE Project: A Case of Use of Big Data Uses Toward a Cohomprensive Health Vision of City Well Being

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**Abstract.** Despite the silent effects sometimes hidden to the major audience, air pollution is becoming one of the most impactful threat to global health. Cities are the places where deaths due to air pollution are concentrated most.

In order to correctly address intervention and prevention thus is essential to assest the risk and the impacts of air pollution spatially and temporally inside the urban spaces. PULSE aims to design and build a large-scale data management system enabling real time analytics of health, behaviour and environmental data on air quality. The objective is to reduce the environmental and behavioral risk of chronic disease incidence to allow timely and evidence-driven management of epidemiological episodes linked in particular to two pathologies; asthma and type 2 diabetes in adult populations. developing a policy-making across the domains of health, environment, transport, planning in the PULSE test bed cities.

**Keywords:** Air pollution · Health · Data platform · Participation

## 1 Introduction

Air pollution has become silently and hiddendly one of the most impactful menace to global health.

The European Environmental agency [1] estimates that premature deaths attributable to exposure to air pollution of fine matter particles reach are about 412 000 in over 41 EU countries. The exposure to NO2 and O3 concentrations on the same countries in 2016 has been around 71000 and 15000 respectively.


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The health threat of air pollution remain located mostly in cities. But the effects does not only limitate on wellbeing, but are also econonomical. The most vulnerable to the risks are lower income socio-economic groups that nowadays are also the most exposed to environmental hazards.

Air pollution indeed does not represent only a sanitary issue: it's burden reflects also in increasing medical costs.

Air pollution thus, is a problem can be only addressed with a strategic vision can only be addressed with long term targeted policies, majorly in urban environments.

In the year 2015 ITU and the United Nations Economic Commission for Europe (UNECE) gave the definition of smart and sustainable city as "an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects". This definition led also in 2016, in the United for Smart Sustainable Cities initiative (U4SSC). This open global platform responded to United Nations Sustainable Development Goal 11: "Make cities and human settlements inclusive, safe, resilient and sustainable.", offering an enabling environment to spread knowledge and innovation globally [2]. Also the health sector has been contaminated by this vision: the increase of social networking, cloud-based platforms, and smartphone apps that support data collection has enhance opportunities to collect data outside of the traditional clinical environment. Such informative explosion allowed patients to collect and share data among each other, their families and clinicians.

Patient-generated health data (PGHD) is defined as health-related data generated and recorded by or from patients outside of the clinical areas. This data could be an important resource available for patient, clinicians and decision makers to be used by to address a current or emerging health issue, and most of it is globally wide, also if they are integrated by information coming from diffuse sensory/IoT devices and Manually input voluntary data reported by the patients, caregivers, or generic citizen participation bring to shared decision-making. The definitions above helps to understand the context of PULSE project. PULSE aims to design and build a large-scale data management system enabling real time analytics of flows of personal data.

The objective is to reduce the environmental and behavioral risk of chronic disease incidence to allow timely and evidence-driven management of epidemiological episodes linked in particular to two pathologies; asthma and type 2 diabetes in adult populations. Developing a policy-making across the domains of health, environment, transport, planning in the PULSE test bed cities.

The project is currently active in eight pilot cities, Barcelona, Birmingham, New York, Paris, Singapore, Pavia, Keelung and Taiwan, following a participatory approach where citizen provide data through personal devices and the PulsAIR app, that are integrated with information from heterogeneous sources: open city data, health systems, urban sensors and satellites. PULSE foster long-term sustainability goal of establishing an integrated data ecosystem based on continuous large-scale collection of all stated heterogeneous data available within the smart city environment.

# 2 The PULSE Project

PULSE project is goaled on build a set of extensible models and technologies to predict, mitigate and manage health problems in cities and promote population health.

Currently PULSE is working in eight global cities. It harvest a multivariate data platform feed by open city data, data from health systems, urban and remote sensors and personal devices to minimize environmental and behavioral risk of chronic disease incidence and prevalence and enable evidence-driven and timely management of public health events and processes. The clinical is on asthma and Type 2 Diabetes in adult populations: the project has been pioneer in the development of dynamic spatio-temporal health impact assessments through exposure-risk simulation model with the support of WebGis for geolocated population-based data.

PULSE gives finally a more wide vision of wellbeing were it is intended also in the relationship with environmental conditions.

## 2.1 Data Collection Principles

Acquisition, systematization and correlation of large volumes of heterogeneous health, social, personal and environmental data is among the core and primary activities in the PULSE project.

The overall goal of the deployments involves deriving additional values from the acquired data, through: developing more comprehensive benchmarking and understanding of the impact of social and environmental factors on health and wellbeing in urban communities, thereby broadening the scope of public health.

On this sake PULSE has developed tools for end-users (primarily citizens and patients, public health institutions and city services) that leverage open, crowd-sourced and remote sensing data, through integration, enrichment and improved accuracy/reliability of risk models, to guide actions and deliver interventions aiming to mitigate asthma and T2D risk and improve healthy habits and quality of life.

Figure 1 shows the conceptual schema of the relationships among dataflows.

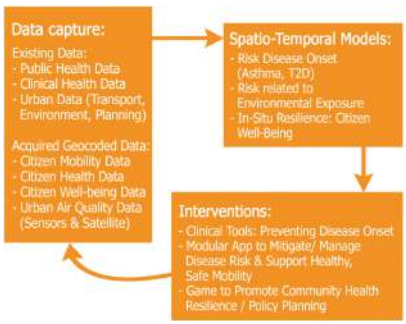


**Fig. 1.** PULSE data flow conceptual structure. The figure shows the collected data clustered on the basis of macro pourpouses

### 2.2 Clinical Focus

PULSE project focuses on the link between air pollution and the respiratory disease of Asthma, and between physical inactivity and the metabolic disease of Type 2 Diabetes. The risk assessment for this two pathologies comprises the evaluation respectively of:

- *for type 2 diabetes:* behavioural risks associated (i.e. reduced exercise/physical activity at home or in public places). This is associated with higher risk of T2D onset in a dose-response relationship. The assessment use unobtrusive sensing/data collection and volunteered data to collect baseline measures of health and wellbeing, and tracking and model mobility at home and across the city (including time, frequency and route of mode of transit and/or movement).
- *for asthma:* Environmental/exposure risks (i.e. exposure to air pollution, especially with regard to near roadway air pollution). Poor air quality is associated with higher risk of Asthma onset and exacerbation.

Risks of diseases onset are evaluated thorough risk assessment models, that in PULSE are biometric simulation models that predict the risk of the onset of the ashtma and diabetes in relationship to air quality.

The models has been developed by chosen ones from a literature review of the prediction models of type 2 diabetes (T2D) onset and asthma adult-onse. Some of them were selected to be implemented and recalibrated on the datasets available on PULSE repository and adding new variables [12].

### 2.3 Data Architecture

PULSE architecture is composed by 5 main structures [15]: PULSEAir, App Server, AIR Quality distributed sensor system, GisDB, WebGIS and Personal DB.

- *PULSE App:* is the personal App provided to the participants in charge of collecting sensors data and interacting with the users to propose interventions and gamification. PulsAIR is available both for iOS and Android and can be connected to FitBit, Garmin and Asus health tracker devices.
- *AIR Quality distributed sensor system:* the PULSE air quality sensor's system is composed of multiple type of sensors and sensor's datasets: it combines mobile sensors and mobile network of sensors in order monitor the variable trends in emission within urban areas with an high resolution and to appropriately address the temporal and spatial scales where usually pollutants are spread. Two types of sensors has been used across pilots that are the AQ10x of DunavNet (20+, deployed in all pilots) and PurpleAir PA-II sensor.
- *App Server*: This structure internally connects PULSE components.
- *Personal DB*: This repository contains personal detail, connectivity, activity logs, pilot sites structured data, etc.…
- *GISDB*: This repository is in charge of collecting non-personal sources of data: satellite, open repositories and fixed sensors.
- *WebGIS*: This data engine is in charge of aggregating and exploiting all the collected data to build front-end visualizations through maps.

## 3 Well Being Model and Urban Wellbeing

The WHO definition of health includes reference to wellbeing: health is "a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity" [4]. Wellbeing is a dynamic construct comprised of several dimensions. In a cohomprensive view of wellness can be defined 3 main domain of wellness: the psycological health, the physical health and the subjective wellbeing. Subjective wellbeing (SWB) is often measured via validated psychometric scales, and individual and community surveys. Subjective wellbeing is linked to Health-Related Quality of Life (HRQoL) but is not synonymous with it. The factors identified as the most important for subjective wellbeing vary across space, time and cultural context (Fig. 2).

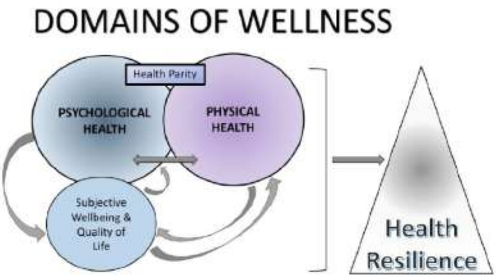


**Fig. 2.** Model of the domains of wellness

Wellness entails contemporary also the simultaneous fulfillment of the three types of needs. Personal needs (e.g., health, self-determination, meaning, spirituality, and opportunities for growth), are intimately tied to the satisfaction of collective needs such as adequate health care, environmental protection, welfare policies, and a measure of economic equality; for citizens require public resources to pursue private aspirations and maintain their health. Wellness also concerns relational needs. Two sets of needs are primordial in pursuing healthy relationships among individuals and groups: respect for diversity and collaboration and democratic participation.

Most approaches to community wellbeing (or its associated terms) follow a components approach: the majority of them have, at their core, an emphasis on individual wellbeing. PULSE has focused on defining and developing a new concept of Urban Wellbeing tied to the broader concept of Urban Health Resilience. This recognizes the connections between the physical characteristics of the urban environment (including assets and deficits) and human health (including both physical and psychological health). The PULSE concept of Urban Wellbeing refers to the interaction between the positive and negative experiences within cities (whether objective or subjective), and the individual and community practices of mobility and placemaking. This novel interpretation of Wellbeing focuses on the dynamic interplay between individual psychological characteristics and strengths, neighborhoods in which people live and work, and the capacity of individuals to respond to environmental and interpersonal stressors [6]. Within our population urban health model, the physical and social environments are understood as key drivers of Wellbeing. This prioritizes an integrated, or relational, approach to urban places and health equity, including population differences in Wellbeing. Central to this relational approach is the idea that place matters – that our health and wellbeing are shaped by the characteristics of the settings where we live and work, and these environments are in turn shaped by our health-related actions and behaviours. Several recent studies have highlighted this important dynamic. Using data from the English Longitudinal Study of Aging, Hamer and Shankar [7] found that individuals who hold more negative perceptions of their neighbourhood report less positive Wellbeing, and experience a greater decline in Wellbeing over time.

Of course, place itself can have a profound impact on our Wellbeing.

## 3.1 Urban Resilience and Wellbeing

In PULSE, we contextualize wellbeing within a model of urban resilience:

Urban resilience refers to the ability of an urban system - and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales – to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity. In this definition, urban resilience is dynamic and offers multiple pathways to resilience (e.g., persistence, transition, and transformation). It recognizes the importance of temporal scale, and advocates general adaptability rather than specific adaptedness. The urban system is conceptualized as complex and adaptive, and it is composed of socio-ecological and socio-technical networks that extend across multiple spatial scales. Resilience is framed as an explicitly desirable state and, therefore, should be negotiated among those who enact it empirically.

Resilient urban neighborhoods can be broadly defined as those that have lower than expected premature mortality (measured via the Urban Health Indicators).

In PULSE, we define Urban Wellbeing as an integral component of Urban Resilience. Urban Wellbeing, in this context, refers to the individual traits and capacities to prepare for, respond to, and recover from the personal and interpersonal challenges encountered in cities. These challenges could include experiences of bias and exclusion, on the one hand, and exposure to under-resourced or polluted environments, on the other. Each of these challenges is associated with physiological and psychological stress at the individual and community level. Stress is, of course, antithetical to Wellbeing. Translating this concepts into data constructs two main instruments are available into PULSE architecture: the risk assessment models, previously described and the urban maps.

## 3.2 Urban Maps

The physical environment, socio-economic and cultural conditions, urban planning, available public or private services and leisure facilities are some of the factors that can have an effect on a person's health. Hence, an interest in the study of geographical patterns of health-related phenomena has increased in recent years. Within this context, maps have been demonstrated to be a useful tool for showing the spatial distribution of many types of data used in public health in a visual and concise manner [13, 14]. For example, it permits the study of general geographical patterns in health data and identifying specific high-risk locations. An example of these maps in PULSE are the personal exposure maps. Personal exposure is a concept from the epidemiological science to quantify the amount of pollution that each individual is exposed to, as a consequence of the living environment, habits etc.

Personal exposure has been obtained matching the data from the dense network of low-cost sensors and the informations on habits coming from the PulsAIR app. Following the sampling rate of the sensors the data has been calculated.

Figure 3 shows a map for the personal exposure to PM10 with an hourly frequency.

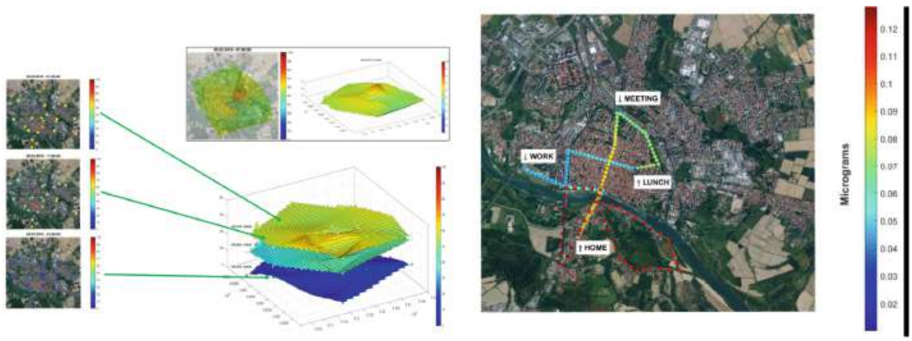


**Fig. 3.** Personal exposure map to PM10

Furthermore using the GPS tracks from the PulsAIR app, FitBit and the personal exposure, an estimate of inhaled pollutant has been obtain in association to three classes of movement by the speed of body translation; standing, walking and running, considering the breaths per minute and the air volume per breath [15].

Personal exposure result has been also traced into exposure paths as in Fig. 3: a time-lapse of 1 min correspond to a dot movement line.

## 4 Conclusions

The multivariate data driven approach of PULSE gives an example of a new conception of health and wellness, not only focused on individual health status, but also on the relationship between individual and environment. Such vision can be also directed toward the definition of “planetary health” provided by “The Lancet Contdown” [16]. The data driven approach pursuited in PULSE has surely given a great opportunity to implement such a vision, that maybe would not so immediatiate without possibility to integrate different sources of data.

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More information on: www.project-pulse.eu.

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# ForeSight - An AI-driven Smart Living Platform, Approach to Add Access Control to openHAB

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**Abstract.** We created an approach for a smart living platform called ForeSight which consists of different modules: a service engineering module, a Web of Things (WoT)-based Internet of Things (IoT) module and an artificial intelligence (AI) component. This paper describes how openHAB, a smart home middleware, is extended to fulfill platform requirements related to a successful interaction with the IoT module of ForeSight, more precisely, to add identity and access management (IAM) to openHAB and comply with European privacy laws.

**Keywords:** Architecture · Artificial intelligence · openHAB · Platform · Privacy · Smart home · Smart living

## 1 Motivation

In recent years, the smart home market has proven its relevance [1,2]. If all 43 million households in Germany were equipped with smart home technology by 2030 with an average value of 3,000 EUR, this would result in a market potential of 129 billion EUR [3]. For other European countries, the situation seems to be similar [4]. Beyond smart homes, the term "smart living" ranges over various areas that are separated today concerning energy management, health and home automation [5]. The smart home is a core element in a connected world, as well as smart city and smart grid [6]. This will lead to more comfort, better assistance and increased safety and security as well as improved resource efficiency and reduced overall costs. The base for such advanced opportunities is the intense usage of AI.

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The ForeSight project follows the approach of an open platform which integrates AI-based solutions, interoperability, context-awareness and established building automation technologies into a flexible multi-domain and multi-component system ranging across different manufacturers and industries [6]. Furthermore, ForeSight will provide the flexibility to add new services and offers corresponding tools for service providers. In Europe, privacy and security issues play an important role [7]. Data needs to be handled carefully. To ensure this, ForeSight will create an adequate IAM mechanism and be as restrictive as possible to ensure privacy concerns, i.e. we will try to keep data stored locally, whenever it is possible.

## 2 State of the Art

These days, systems for energy management, classic smart home use cases like lighting as well as health applications exist. To optimize residents' benefits it is useful to combine these three domains and make them controllable by one single platform, which allows domain and vendor independence. In other areas like manufacturing industry reference architecture models have been established to visualize needs to improve interoperability in general. We adapted these models like RAMI 4.0 [8] to the smart living domain (see Fig. 1). Accordingly, we strive to enable an interoperability level on the business model layer.

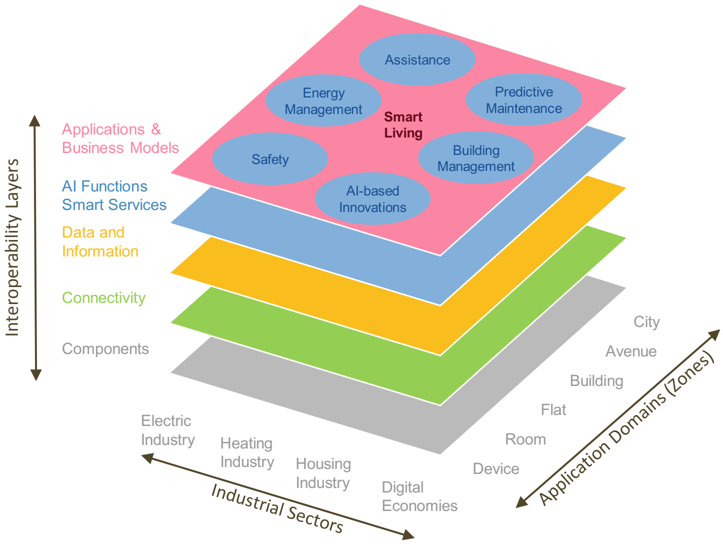


**Fig. 1.** Proposed reference architectural model of smart living.

After describing necessities of interoperability, privacy and security, we need to introduce the concepts of IAM to ensure a solid base for reaching our goals.

There are four topics when it comes to IAM, which need to be considered. In a first step, the user who wants to access the system needs to identify himself (Identification). This claim needs to be verified (Authentication) by the system. Subsequently, it is necessary to grant appropriate rights to the user (Authorisation). For many systems and domains, it is mandatory to log different system events for ensuring auditing, monitoring or tracing (Accountability) [9].

To carry out a target group-oriented authorization, four basic concepts are considered. The first is identity-based access control (IBAC), which provides an access control list for each object, which in turn contains all subjects that are allowed to access the corresponding object [10]. The second concept, role-based access control (RBAC), provides different read and write permissions (generally: transactions) for different user groups [11]. Attribute-based access control (ABAC) defines a similar approach to RBAC, except that users are granted rights based on certain attributes of subjects and objects and environmental conditions [12]. The last type, capability-based access control (CapBAC) turns the rights management the other way around and grants rights based on the token that the user hands over at login [13]. This token then contains an indication of the possibilities a user has on the platform.

openHAB is a smart home middleware, so it is possible to control different systems in one single graphical user interface (GUI) or app. The software uses specific components to offer an abstraction layer for all of its subsystems. To connect to a third-party system like Homematic [14], it is necessary to create a binding. After activating the binding it is possible to search for accessible objects, here for the Homematic bridge and all the Homematic devices, e.g. a switch. The signal of the device and the triggered action from openHAB to the Homematic device is transported through so-called channels. To create a GUI a sitemap is needed. In the sitemap file there is a possibility to name items. An item is a concrete instance of a thing and a channel can be mapped to an item. For automating event-driven tasks there is the concept of rules, a script-like openHAB feature. There are several other smart living middleware systems or promising approaches besides openHAB, for example, universAAL, HomeKit and Connected Home over IP.

## 3 Challenges

To fulfill the idea of our smart living reference architectural model (see Fig. 1) it is necessary to offer a platform architecture which is able to handle upcoming requests as flexible as possible. The corresponding IAM needs to be considered in all systems. This is challenging because existing middleware systems need to be used to connect to different smart home systems to achieve an adequate market penetration. Moreover, as mentioned before, security interferes with comfort, so new concepts need to be evaluated in regard to user acceptance.

openHAB does not yet provide access rights for different user groups and thus does not offer authentication for end-users, besides developer-addressed possibilities. Therefore, openHAB needs to be extended. In addition, there are three variants that allow access from outside on the basis of an encrypted connection. The most secure option is to set up virtual private networks (VPN) to access your system via the router. The second option is to use the specially designed myopenHAB cloud, which can be accessed like various other cloud platforms via a tunnel connection. The third option is to set up a reverse proxy before openHAB, which in turn uses authentication and security certificates to ensure that the smart living system is protected from unauthorized external access. Such remote access strategies are important for several use cases like predictive maintenance scenarios in smart buildings.

## 4 Approach

ForeSight offers a flexible mechanism to handle requests, i.e. it is possible that requests are handled in the local network or, if necessary, will be forwarded to cloud services to increase performance. The core of ForeSight's architecture approach is the thinking object (TO) - a device or group of devices which offers a specific service to the user or other TOs (see Fig. 2). There are three main modules, which are interacting to fulfill the system needs, here a service engineering module for service providers, e.g. a company of the housing industry, and an AI module to handle requests for computationally intensive operations, e.g. visually based object identification, and an IoT module to connect to different smart home middleware systems, e.g. openHAB, which will be able to connect to many different vendor-specific systems. Summing up, ForeSight is connecting to openHAB to ensure interoperability on a syntactic level. Besides, ForeSight will enable the usage of different smart home middleware systems like universAAL as well.

It will be necessary and helpful for TOs if attributes like context sensitiveness, interoperability, semantic information, data management capabilities, rights management, security and privacy are available. In addition, it is helpful to create a digital twin of the corresponding building and another digital twin of the user to predict their specific behavior. As mentioned before it needs to be considered to handle requests exclusively in the local network. Therefore, we create strategies to adapt cloud-based approaches to edge computing as well, especially methods like preprocessing and device performance enhancements. To verify our concepts different use cases, e.g. smart door and smart kitchen, will be implemented. To prove that our approaches are independent of one technology we are using a minimum of two different technology stacks for each use case, e.g. a common router-based stack (internet router and a smart home middleware), and a smart meter gateway based technology stack (see Fig. 2). First, the use cases will be implemented in laboratories and afterwards in real-world environments like Future Living Berlin [15].

To describe our approach more precisely we want to follow a request through our ForeSight platform. The service provider is a company in the housing industry. When a new tenant rents a flat, a picture and fingerprints of the tenant are captured and this data is stored in a database and transferred to the IoT and

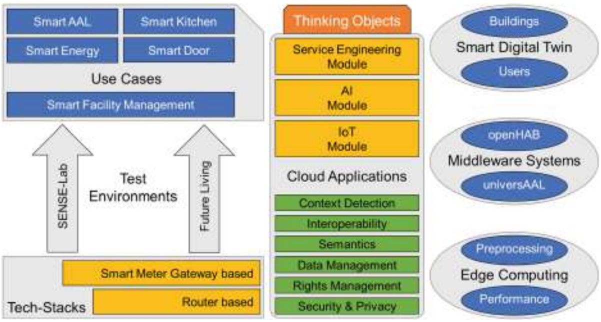


**Fig. 2.** Simplified architecture of the ForeSight Cloud Platform with its three main modules (service engineering, AI module and IoT module).

AI module, so that the available smart door can be updated with new data. The tenant wants to enter the door and uses his fingerprints and the camera at the door captures a small video sequence. This video is sent to the AI module and the IoT module will receive a reply if the person is verified. To ensure interoperability there is a WoT-based data model available in the IoT module and a corresponding openHAB connection that both systems can communicate with each other to transfer semantic information. Each time there is a data transfer from one module to another module, a privacy and security filter will be applied to ensure that only authorized actions will occur.

This paper focuses on the IoT module, so the AI module and service engineering module will not be described in detail. The AI module of ForeSight offers so-called base services which are important for common AI use cases like object identification. Otherwise, there are complex use cases of the housing industry like a tenant change process. Such use cases benefit enormously by intense AI support. To simplify service engineering for service providers we will offer GUI-driven configuration tools, that companies are able to describe their digital business models easily. The service provider does neither need to consider technical details of the AI module nor the IoT module or the complexity of different smart home middleware systems like openHAB.

As stated before, openHAB needs to be extended to fulfill an adequate IAM mechanism. In doing so, we decided to use a sidecar approach (see Fig. 3). That means, openHAB is handling its core functions and as a sidecar, we use a proxy server and the tool Auth-router, so common logging functions and configuration options will be available for the system by using these third party tools. The sidecar approach will simplify the consideration of existing systems, for example, logging and tracing.

Besides adequate logging functionality, user and group management need to be addressed as well. We decided to use RBAC as a strategy to add IAM to openHAB. RBAC is minimizing configuration effort during the system's maintenance because necessary changes can be done by changing one specific role or group. This mechanism can be understood by tenants, which is important

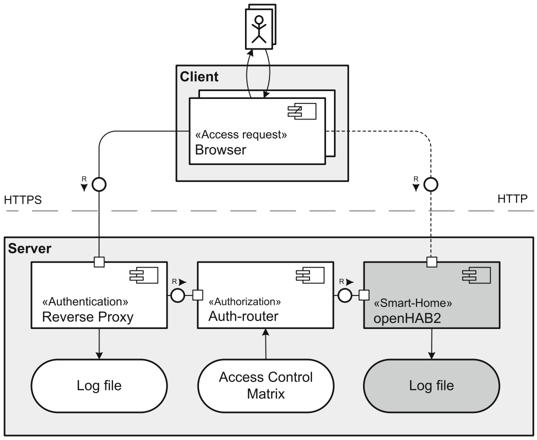


**Fig. 3.** Sidecar approach: Two external tools, here Proxy Server and Auth Router will extend the openHAB environment by enabling relevant services, for example, logging and tracing.

for accepting such safety-relevant systems in their own home. Furthermore, it is possible to combine this strategy with the sidecar approach. Additionally, RBAC does not need to change openHAB's core data model, so it is possible to extend openHAB by developing such a binding. We created this binding, which offers Auth-router functionality to the user openHAB's backend. The procedure for creating a user is shown below (see Fig. 4). For openHAB it is then possible to generate one specific sitemap for each role and so IAM of systems' resources are ensured. The routing ensures that no user can access sitemaps which are generated for different roles. Our openHAB binding considers user management as well.

ForeSight considers the concept of TOs that combine aspects of three research areas: smart environments (i.e. the physical infrastructure such as sensors, actuators and networks), ambient intelligence (an intelligent network of sensors, radio modules, and computers to proactively but sensibly support people in their lives [16]), AI (agent systems, machine learning techniques). TOs represent physical as well as virtual objects. They aggregate and abstract sensor data of devices to deduce value-added services to users. Several TOs such as sensors, actuators, and lighting in a building can be combined to execute a coordinated activity, e.g. to guide residents through a building.

## 5 Implementation

We developed an openHAB extension to connect to the WoT-based IoT module of ForeSight [17]. This extension will be continuously improved and maintained. Beside the WoT binding we added user management support for openHAB by generating and calling exact one sitemap for each role and restricting the access

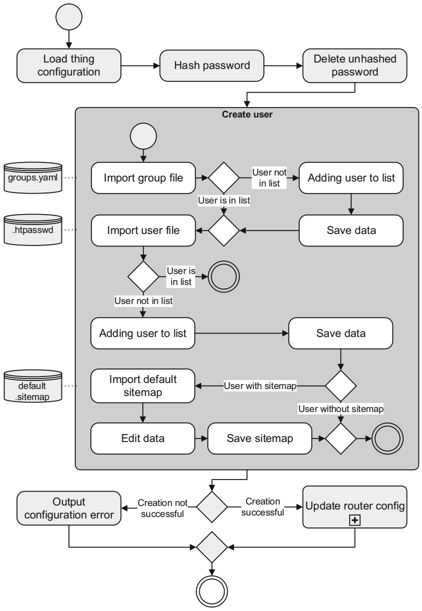


**Fig. 4.** openHAB Auth Binding - create user procedure.

for non-authorized users. The ForeSight platform with all of its submodules is currently being developed until the end of 2022.

## 6 Discussion

Challenges of semantics and interoperability have long been known in the era of the IoT, especially if different subsystems should work together flawlessly without an overlying de-facto standard. Our approach of trying to offer a WoT-based cloud application, where an AI module and different smart home middleware systems are allowed to connect seems promising for us: We are confident to fulfill all requirements European laws are demanding. Furthermore, we think that it is possible to create a holistic IAM from cloud-driven systems which are often offering CapBAC strategies to smart home middleware systems, that need to be extended in relation to their specific software architectural patterns. Therefore, we need to create strategies to integrate other smart home middleware systems besides openHAB as well, either advanced approaches like universAAL or existing systems like HomeKit or Z-Wave. It is important for ForeSight that lots of existing smart home middleware systems are becoming part of ForeSight, so that ForeSight can achieve its goal to play an important role in the smart living domain.

Extending openHAB by RBAC was helpful to improve access control for tenants in that chosen scenario for a first proof of concept. Hopefully, we will be able to switch from the sidecar approach to a native openHAB solution. Currently, the openHAB developer community seems to work on such strategic ideas for the upcoming major update (version 3.0).

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