A proposal for a healthcare environment with a real-time approach

Eliza H.A. Gomes*

Department of Informatics and Statistics (INE),
Federal University of Santa Catarina (UFSC),
Florianopolis, Santa Catarina, Brazil
Email: eliza.gomes@posgrad.ufsc.br
*Corresponding author

Mario A.R. Dantas

Department of Computer Science (DCC),
Federal University of Juiz de Fora (UFJF),
Juiz de Fora, Minas Gerais, Brazil
Email: mario.dantas@ice.ufjf.br

Patricia D.M. Plentz

Department of Informatics and Statistics (INE),
Federal University of Santa Catarina (UFSC),
Florianopolis, Santa Catarina, Brazil
Email: patricia.plentz@ufsc.br

Abstract: The increased use of IoT has contributed to the popularisation of environments that monitor the daily activities and health of the elderly, children or people with disabilities. The requirements of these environments, such as low latency and rapid response, corroborate the usefulness of associating Fog Computing with healthcare environments since one of the advantages of Fog Computing is to provide low latency. Because of this, we propose the use of a hardware and software infrastructure capable of storing, processing and presenting monitoring data in real-time, based on Fog Computing paradigm. Additionally, we propose the structuring of sensors for the implementation of a simulated healthcare environment, as well as the processing logic for the presentation of results referring to the health of the user.

Keywords: IIoT platform; time constraint; fog computing; healthcare application.

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Biographical notes: Eliza H.A. Gomes is a PhD Student of the Graduate Program of Computer Science (PGCC) in the Department of Informatics and Statistics (INE), Technology Centre (CTC), Federal University of Santa Catarina (UFSC), Brazil. Currently, she is working in the Research Laboratory of Distributed Systems (LaPeSD) supervised by Prof. Mario A.R. Dantas and co-supervised by Prof. Patricia Della Mea Plentz. Her interesting researches areas are: distributed systems, operating systems, computer network and real-time.

Mario A.R. Dantas is a Professor in the Department of Computer Science (DCC) at the Exact Sciences Institute (ICE), Federal University of Juiz de Fora (UFJF) and in the Graduate Program in Computer Science (PPGCC), at the Technology Centre (CTC), Federal University of Santa Catarina (UFSC), with a PhD in Computer Science from the University of Southampton (UK), Visiting Professor at the University of Western Ontario (Canada) and Senior Visiting Researcher in Riken (Japan). He is the author of hundred scientific articles, dozens of chapters in books and three books. He has advised numerous undergraduate, specialisation, master and doctorate research works. He has acted as a consultant on various projects with industry in the areas of IoT, networking, distributed systems, and high-performance environments.

Patricia D.M. Plentz is currently an Associate Professor of Computer Science at the Federal University of Santa Catarina (UFSC), Brazil. She received her PhD and MSc degree from UFSC in 2008 and 2002, respectively, and her BSc degrees in Computer Science from University of Cruz Alta (UNICRUZ) in 2000. Her research interests include real-time distributed systems, forecast of deadline missing and temporal constraints of mobile robots.

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1 Introduction

The Internet of Things is a topic that has been growing and becoming important in the technical, social and economic areas (Rose et al., 2015). This growth has driven the advancement in research and projects related to assisted environments and healthcare, since the IoT offers great potential for continuous and reliable remote monitoring due to its ubiquitous nature, allowing freedom of movement for individuals (Negash et al., 2018).

Healthcare environments are widely used for monitoring the elderly, the disabled or children and are composed of intelligent objects such as sensors for monitoring the environment and vital signs, as well as actuators and mobile devices. These objects are characterised by being heterogeneous and distributed, by communicating through light protocols to save energy and by requiring low latency in data transmission. Fog Computing has been used in this type of environment because it is an intermediate layer between end devices and the cloud data centres that provides processing, storage and analysis of data closer to smart objects, thus low latency (Gomes et al., 2018b).

Low latency is one of the main requirements for healthcare (Bierzynski et al., 2017) environments since in cases of emergencies such as falls or cardiac arrest the fast notification enables the specialist user responsible for the assisted user to act fast and efficiently. Therefore, in this article, we propose the use of a hardware and software infrastructure, based on Fog Computing, capable of storing, processing and presenting data received from sensors embedded in a healthcare monitoring environment in real-time. We understand as real-time a system that presents the results within a time constraint.

The hardware infrastructure presented in this article consists of three layers, the Edge Layer (sensors, actuators and mobile devices), the Fog Layer (Fog nodes and Fog server) and the Cloud Layer (data centres) (Gomes et al., 2018a). On the other hand, the software infrastructure consists of Foglet (software agent), processing and storage software, and healthcare application (the logic of healthcare environment).

Additionally, we propose in this article the build of the monitoring environment, that is, the sensors infrastructure for a simulated environment. Moreover, we propose the data processing logic, the data presentation and the generation of alerts for caregiver's users.

This paper is organised as follows. In Section 2 we present some explanation about related conceptions. Some related works are discussed in the Section 3. Our proposal is described in Section 4. Designed environment and the processing logic are presented in Section 5. Finally, our conclusions and indications for future work are presented in Section 6.

2 Overview

In this section, we present some explanation about related conceptions to this article.

2.1 Healthcare environment

Healthcare is a smart environment where a health monitoring system is set up. It provides e-health services to monitor and evaluate the health of assisted users, which are elders, people with disabilities, children or patients. The health monitoring of these users is carried out by specialist users such as doctors, nurses or caregivers.

The healthcare environment configuration is composed of three main components: sensors, communication, and processing system (Mshali et al., 2018). Sensors are deployed in environments or user accessories such as belts, clothes, glasses, and they are responsible for data acquisition. The data acquired by sensors are transmitted through an access point or base station to a server or portable devices via network communication technologies. The data are stored, processed in the server and presented to specialist users so that they can act in case of abnormality or emergency.

In the next subsections, we present some conceptions and characteristics related to sensors and communication technologies implemented in a healthcare environment.

2.1.1 Sensors

Physical sensors are the most common types of sensors in a healthcare environment and are responsible for collecting data about user physiology and user environment (Lai et al., 2013). There are three main classes for monitoring the assisted user and the environment: Personal Sensor Networks, Body Sensor Networks, and Multimedia Devices (Mshali et al., 2018).

- *Personal sensor networks (PSN)*: usually are sensors deployed in the environment whose goal is to detect daily activities of humans and to measure environmental conditions.
- *Body sensor networks (BSN)*: are composed of sensors embedded in personal accessories such as clothes, belts or glasses. These sensors have the role of monitoring vital signs and health conditions of the assisted user (Wang, 2015).
- *Multimedia devices (MD)*: are audio and video devices responsible for monitoring the movements and promote greater interaction between the assisted user and the healthcare application.

The data collected by sensors can be classified according to the frequency of their receipt in three types of events: constant, interval and instant.

- *Constant*: the data are transmitted continuously.
- *Interval*: the data are transmitted periodically, following a uniform time interval.
- *Instant*: the data are instantaneously transmitted when an event occurs.

Table 1 presents some examples of sensors most used in monitored environments.

2.1.2 Communication technologies

Various communication technologies are used to perform integration between applications, services, and sensors in a healthcare environment. The technologies most popular are wireless protocol such as ZigBee, Bluetooth, Wi-Fi and Bluetooth Low Energy (Sula et al., 2014). On the other hand, others technologies such as Radio Frequency Identification Devices (RFID) and Ultra Wide band (UWB) stand out because they have the role of tracking and identifying people and objects, as well as allowing communication between the sensors or the devices (Lai et al., 2013, Rashidi and Mihailidis, 2013).

- *ZigBee technology (IEEE 802.15.4)*: is an efficient technology for the sensed environment, since it has low cost, low power, and long battery life. It has a low transmission rate with a maximum data rate of 250 Kbps and a range up to 20 meters.
- *Wi-Fi technology (IEEE 802.11)*: is the most popular communication technology. It has an average range of 100 metres and transmission rate up to 54 Mbps. However, it has a disadvantage of consuming much energy.
- *Bluetooth technology (IEEE 802.15.1)*: is used by connecting a variety of devices for data and voice transmission. It has the maximum data transmission rate of 1 Mbps and ranges up to 10 metres.
- *Bluetooth low energy technology (BLE)*: recent technology that provides ultra-low energy consumption and cost. It represents an efficient technology by transferring various small data packages and by offering small connections with the minimum of delay (latency).

Table 1 Health monitoring sensors (Mshali et al., 2018; Rashidi and Mihailidis, 2013)

Category	*Name*	*Measurement*	*Data format*	*Event type*
PSN[a]	PIR[b]	Motion / Identification detection	Categorical	Instant
	RFID[c]	Persons and objects identification	Categorical	Instant
	Pressure	Pressure on mat, chair, etc.	Numeric	Instant
	Smart tiles	Pressure on floor	Numeric	Instant
	Magnetic switches	Open / close door detection	Categorical	Instant
	Temperature	Room temperature	Time series	Interval
	Humidity	Room humidity	Time series	Interval
	Weight	Assisted user weight	Numerical	Interval
BSN[d]	Accelerometer	Acceleration and fall detection	Time series	Constant
	Gyroscopes	Orientation, motion detection	Time series	Constant
	ECG[e]	Cardiac activity	Analogical signal	Constant
	EEG[f]	Brain waves	Analogical signal	Constant
	EOG[g]	Eye movement	Analogical signal	Constant
	EMG[h]	Muscle activity	Analogical signal	Constant
	PPG[i]	Heart rate and blood velocity	Analogical signal	Constant
	Pulse oximeter	Blood oxygen saturation	Analogical signal	Constant
	Blood pressure	Blood pressure	Numerical	Interval
	Glucometer	Blood glucose	Numerical	Interval
	GSR[j]	Perspiration	Analogical signal	Constant
	SKT[k]	Skin temperature	Numerical	Interval
MD[i]	Cameras	Monitoring and tracking	Image, video	Interval, Constant
	Microphone	Voice detection	Audio	Constant
	Speakers	Alerts and instructions	Audio	Instant

Notes: [a]Personal sensor network [b]Passive infrared [c]Radio-frequency identification [d]Body sensor network [e]Electrocardiography [f]Electroencephalography [g]Electrooculography [h]Electromyography [i]Photoplethysmography [j]Galvanic skin response [k]Skin temperature [i]Multimedia devices

2.2 Edge computing and fog computing

According to Chiang and Shi (2016) Edge Computing is a paradigm in which the resources of communication, computational, control and storage are placed on the edge of the Internet, close to mobile devices, sensors, actuators, connected things and end users. An edge device is not a data centre or a simple sensor that converts analogue to digital sign and collects and sends data. An edge device can be conceptualised as any computational or network resource that resides between data sources and cloud data centres.

On the other hand, Fog Computing can be conceptualised as computational elements intermediates, located between edge devices and cloud. It typically provides some way of data management and communication service between edge devices and cloud (Iorga et al., 2017). The main goal of this intermediate layer is to reduce the latency and response time since data do not have to reach the cloud to be processed.

Bonomi et al. (2012) presented temporal requirements of Fog Computing environments. They bound that some data generated by the sensor and device grid require real-time processing (from milliseconds to sub-seconds). All interactions and processes occur throughout the Fog Computing environment are seconds to minutes (to real-time analyses) and until days (transactional analyse).

Despite its increasing use, Fog Computing is often called Edge Computing. However, these approaches have key differences (Iorga et al., 2017):

- Fog Computing can have hierarchical layers while Edge Computing tends to be limited to a small number of layers;
- Unlike the Edge, Computing Fog Computing works with the cloud;
- Beyond computing, Fog Computing also covers network, storage, control and data processing.

2.3 Real-time

With the advent of big data and the use of data streaming, the concept of real-time presented in most current researches has distanced from the one proposed in the classical literature. The survey of (Gomes et al., 2019) presents a classification of articles that propose the use of the real-time approach in big data environments that use data streaming. It can be noted that most articles use the term real-time as fast response and low latency.

In this article, we consider the concept presented by Safaei (2017), Buttazzo (2011) and Stankovic (1988), which define that a real-time system depends not only on the logical result of the computation but also on the time in which the results are produced. For authors, it is a common misconception to consider only fast computation to a real-time system, since the purpose of these systems is to meet the temporal requirements of each task.

The real-time system tasks can be classified:

- As for the consequences of the missed deadline
  - Hard: for the system to work correctly the results have to be produced within the time constraint.
  - Firm: results produced after the time constraint are useless for the system.
  - Soft: results produced after the time constraint are accepted and still useful for the system, although it causes degradation of its performance.
- As for the regularity of activation
  - Periodic: are identical tasks regularly activated at a constant rate.
  - Aperiodic: are the same tasks that are activated irregularly.
  - Sporadic: subset of aperiodic tasks. This task have as main characteristic the known minimal interval constraint between two consecutive activation and, therefore, they can have attributes of critical tasks.

3 Related works

In this section, we present some studies that address the use of Fog Computing for health care environments.

Aghili et al. (2019) presented a security and energy-efficient protocol for e-health systems, called LACO. In other words, it is proposed an authentication and agreement protocol which preserve anonymity and provide a access control mechanism for user, thus maintaining the privacy of information. In addition, the authors present a schema that considers the transfer of access to another user.

Sood and Mahajan (2018) proposed a cloud-based healthcare system developed to predict and prevent the *Chikungunya* virus through the use of wearable sensors, decision tree and Temporal Network Analysis (TNA). The architecture of the proposed system is composed of three layers: *Data Accumulation Layer*, responsible for collecting user data from health, environmental and location sensors; *Fog Layer* is responsible for processing and diagnosing the category of infection in the user in real-time, in addition to generating an immediate alert for the mobile phone of users to take preventive; The information and analyses generated by the *Fog Layer* are stored in the *Cloud Layer* so that disinfection alerts are generated for the citizens.

Rahmani et al. (2018) exploited the strategic position of such gateways at the edge of the network with the aim of providing high-level services such as local storage and real-time processing, and, as a result, the authors present a Smart e-Health Gateway. Besides that, they propose to explore the concepts of Fog Computing in healthcare IoT systems to form an intermediate layer of intelligence between the sensors and the Cloud. Besides, an IoT-based Early Warning Score (EWS) health monitoring is implemented to show the efficiency and relevance of the proposed system, based on medical problems for the case study.

Mahmud et al. (2018) proposed an architecture for the integration and orchestration of Cloud and Fog infrastructure from the interoperable perspective of IoT-Healthcare solutions. The performance evaluation of Fog-based IoT Healthcare solutions carried out through simulation studies with the iFogSim simulator was concerning the delivery of services with satisfactory terms, cost, energy use, and service distribution.

Gia et al. (2017) proposed a low-cost health monitoring system that provides continuous remote ECG monitoring and automatic reporting and analysis. The system consists of energy-efficient sensor nodes and a Fog Layer to take advantage of IoT. The sensors collect and transmit ECG, respiration rate and body temperature information to a smart gateway that can be accessed by caregivers. Also, the system performs automatic decision making and provides advanced services such as real-time notifications for immediate attention.

Our proposal is differentiated since the cited papers offer a fast response (real-time) without assurance that the system response will respect a deadline.

4 Proposed platform

In this article, we propose the use of a hardware and software infrastructure for healthcare environments which can process data and present results withii4 10.02 a.4(Et0.02 (ealthcy1(t

1 *Edge layer*: This layer is composed of sensors, actuators, and mobile devices.

- *Sensors*: as described in the Sub-section 2.1, sensors are devices responsible for capturing data, and they are used in the healthcare environment to monitor the daily activities, and vital signs of the assisted users. The sensors used lightweight communication protocols such as ZigBee, Bluetooth or Bluetooth Low Energy to connect with mobile devices.
- *Actuators*: are devices inserted in the monitored environment to act when necessary. For example, turning on the heater when the room temperature is too low or switching off the gas if a leak is detected. The actuators use lightweight communication protocols such as ZigBee, Bluetooth or Bluetooth Low Energy to connect with mobile devices.
- *Mobile devices*: are devices that have the processing power, are located close to sensors and actuators and have the ability to communicate through lightweight protocols and over the WLAN. Examples of such devices are smartphones, notebooks, and tablets. The main function of mobile devices is to receive and filter the data delivered by the sensors. Besides, they can play the role of sending commands to the actuators when necessary.

2 *Fog layer*: This layer is composed by Fog Nodes and a Fog Server.

- *Fog nodes*: are devices responsible for the temporary storage (S), communication (C), processing (P) and presentation (P) of the data for the specialist user. They can use the WLAN communication network to receive data from mobile devices and the wired LAN network for communication with other Fog Nodes and Fog Server.
- *Fog server*: is responsible for managing the Fog Computing environment and for communicating between the environment and the external network (communication between Fog and the Cloud). It has all the physical and logical information about the Fog Nodes belonging to the environment. The Fog Layer has only one Fog Server, but it can accumulate the server and node function. Scheduling policies are inserted into Fog Server, it becomes responsible for the migration of a task so that the deadline is fulfilled or for the interruption of the running task to execute another with a higher priority.

3 *Cloud layer*: This layer consists of data centres that will be responsible for permanently storing the received data, and present them when requested. This data may be used to conduct research or survey of the health history of the assisted user activity. Actors such as researchers, doctors, nurses or caregivers may have access to these data (respecting the authorisation release of views of this data by the assisted user).

On the other hand, the software infrastructure consists of Foglet, processing and storage software and healthcare application (see Figure 1).

- *Foglet*: is a software agent that is present in each of the Fog Nodes (Bonomi et al., 2014). They are responsible for monitoring the physical state and the services assigned to each machine. This information is analysed locally and also sent for global processing, in other words, sent to Fog Server.
- *Processing and Storage Software*: to perform the processing, storage and presentation of data, we use the Industrial Internet of Things (IIoT) Platform similar to used and implemented by FASTEN project (http://www.fastenmanufacturing.eu/index.php/project/). This platform is open source and composed by Apache software for processing, time series data base for storage and real time business intelligence for data presentation.
- *Healthcare Application*: responsible for the logic of the healthcare environment. It has the function of comparing the received data with normal or standard data, sending commands to the actuators, issuing alerts, presenting the data to the specialist user, as well as sending the data to be stored in the cloud. The development of this application requires prior knowledge of the assisted user so that it is possible to know, for example, what the standard pressure is. In other words, the application is customised and adapted to each environment (home or hospital) and user.

The execution process of the proposed environment is carried out as follows. The data is acquired by sensors and is sent to the mobile devices. Mobile devices filter incoming data to exclude noise and inconsistencies. The data are then sent to the Fog Nodes. In Fog Nodes the data is temporarily stored and processed, respecting the priority given to the task and the time constraint.

Foglets, present throughout the environment, periodically send Fog Nodes information to each other and Fog Server. Based on the information provided by Foglets, Fog Server manages the resources of the Fog Nodes. Besides that, it applies scheduling policies, verifies the need to migrate the task to another Fog Node so that the deadline is met, or stops the execution of the task so that another one with a higher priority can execute. After processing, the data is presented to the expert user through a graphical interface, generating alerts if the health situation of the assisted user is abnormal. An example of an abnormal health situation is much higher than acceptable pressure, or fall detection. Data processing may still return commands to the mobile devices so that they will send them to the actuators.

Finally, after processing and analysing the data, they are sent to the cloud by Fog Server over the Internet. The purpose of sending data to the cloud is for permanent storage. Once stored in the cloud, the data can be analysed by researching users or who have some interest in historical data on the health of the users assisted.

5 Experimental environment

In this section we described the healthcare experimental environment built to implement the hardware and software platform. This environment is composed of sensors and the parameters assigned to them, by IIoT Platform for processing and storage data, and by the processing logic of each set of sensor data.

5.1 *IIoT Platform*

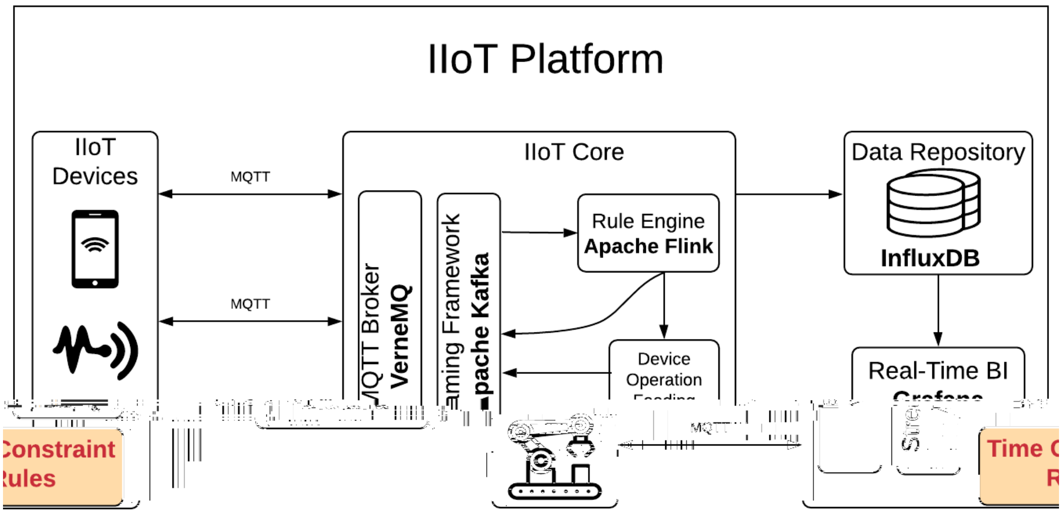
IIoT Platform is an open source unified structure, similar to that used by FASTEN project, which processes, stores and presents the data stream. We chose to use this platform because it is a consolidated structure and structured use of tools determines positively the efficient use of data (Gomes et al., 2018c).

The platform architecture is composed of communication broker, Apache software for data stream processing, data base stream and real-time Business Intelligence (BI) for data presentation. As can be seen in Figure 2, the IIoT platform consists of the Edge Layer with IIoT devices, Fog Layer with IIoT core, data repository and real-time BI.

The Fog Layer consists of seven components, which are: MQTT Broker, Streaming Framework, Rule Engine, Device Operation Feeding, Time Constraint Rules, Data Repository and Real-Time BI.

- *MQTT broker*: is responsible for receiving publish/ subscribe messages which use MQTT protocol (http://mqtt.org/) and send them to the next level. The software used was VerneMQ (https://vernemq.com/), whose objective is to provide a set of characteristics related to scalability, reliability and high performance.
- *Streaming framework*: is responsible for data stream processing. It was used Apache Kafka (https://kafka.apache.org/), a distributed messages platform based on publish/subscribe model. It allows an application to act as a stream processor, consuming a data stream input of one or more topics and producing a data stream output for one or more output topics. Effectively, Apache Kafka transforms the data stream input into data stream output. A topic is a category or feed in which data is recorded.
- *Rule engine*: this component is responsible for determining the rules of data processing. It uses the Apache Flink (https://flink.apache.org/), a framework and distributed processing engine for stateful computations over unbounded and bounded data streams.
- *Device operation feeding*: this component is responsible for sending notifications for edge devices act.
- *Time constraint rules*: this component is our main proposal and it is add to the IIoT Platform architecture. It is responsible for inserting time constraint rules in the processing environment. In other words, this component determines the priority and the processing time of the data, so that they are presented to the user in the given time.
- *Data repository*: is responsible for data storage. The InfluxDB (https://www.influxdata.com/) is used on the platform because is a optimised temporal series data base to be fast, and has high storage availability and data recovery in areas such as operations monitoring, application metrics, IoT data sensors and real time analyses.
- *Real-Time BI*: is responsible for monitoring the information. The IIoT Platform uses Grafana (https://grafana.com/) software for temporal series data analysis.

Figure 2 IIoT Platform (Adapted from (FASTEN, 2019))



5.2 Sensing environment

The designed sensing environment for the simulation is composed of four rooms, which are: room, kitchen, bathroom

Table 4 Personal sensors configuration and data presentation

Sensor	*Data presentation*		*Frequency*	*Place: valor*
Accelerometer	Raw data	Motion average (%)	30 seconds	*Room, kitchen and bathroom*: stopped, walking *Gym*: stopped, walking and running
Gyroscope	Raw data	Position average (%)	30 seconds	*Room and Gym*: sitting, lying and standing *Bathroom and Kitchen*: sitting and standing
GPS	Raw data	Location average (%)	1 minute	Room, kitchen, bathroom and gym

Table 5 presents logic rules and warnings. The main objective of these sensors is to detect falls (Li et al., 2009). For this, it is necessary to detect the location, since there are rooms that is possible that the assisted user can be lying in by choice by the option and not after a fall.

5.2.3 Health sensors

In this section, we describe the rules and warnings of health sensors, which are: body temperature, ECG, blood pressure and pulse Oximeter. We use as a basis for the development of health rules proposed the literature of (Hall, 2015).

Table 6 presents the description of the rules and alerts designed for health sensors. In our proposed rules, we do a comparison of the results with the user activity. Since, according to Hall (2015), body temperature, ECG and blood pressure values change when the person is active (i.e., running or walking). These values can be equal to values presented when the person is sick or ill.

Table 5 Rules and warnings configurations for personal sensors

Rules	*Warnings*
If "lying" >1 minute verify "local"	
If "*place*" = room or gym	CAUTION! User lying for more than 2 minutes
If "*place*" = kitchen or bathroom	ALERT! User lying in an unappropriated place he/she may have fallen

Table 6 Rules and warnings for health sensors

Sensor	*Data presentation*		*Frequency*	*Rules*	*Warnings*
Body temperature (BT)	Raw data	Average	5 minutes	*If 38.3°C <"BT" <40°C and "*running*" or "*walking*" NORMAL SITUATION	EXTREME COLD! BT <36°C LOW FEVER! 37.5°C <BT <38.5°C FEVER!* 38.6°C <BT <40°C HIGH FEVER! 40.1°C <BT <42°C
ECG	Raw data	Average	Continuous	*If "ECG" >100 and "*running*" or "*walking*" MHR[a]= 220 – age ECG = MHR * 0,60 (NO ALERT) ECG = MHR * 0,70 (NO ALERT) **If "BT" >37°C add 18 heart rate for each degree of temperature up to 40°C	BRADYCARDIA! ECG <60 TACHYCARDIA!* ECG >100 ECG = MHR * 0,85 ATTENTION!** High heart rate due to high-body temperature
Blood pressure (BP)	Raw data	Average	5 minutes	*If "*walking*" or "*running*" and "BP" systolic >130 and diastolic >90 normal increase of 20 to 40 mmHg (NO ALERT)	LOW PRESSURE! 100 <Systolic <120 60 <Diastolic <80 HIGH PRESSURE!* 131 <Systolic <200 91 <Diastolic <130 ATTENTION! Systolic and diastolic pressure very closer Systolic – Diastolic <40

Table 6 Rules and warnings for health sensors (continued)

Sensor	*Data presentation*		*Frequency*	*Rules*	*Warnings*
Pulse oximeter (PO)	Raw data	Average	5 minutes		ATTENTION! Low oxygen saturation PO <90% DANGER! Very low oxygen saturation PO <80%

Note: [a]Maximum heart rate.

The objective of measuring body temperature is to inform the caregiver (doctor or nurse) if the assisted user is with hypothermia, with fever or if the high temperature is due to the user's physical activity.

The ECG presents the heart rate and informs the caregiver if the assisted user is with bradycardia or tachycardia. We know that the heart rate may increase if the user is exercising, such as running or walking. In addition, the increase in body temperature raises the heart rate by 18 beats for each degree Celsius of temperature.

The caregiver receives alerts when blood pressure assisted user is low, high or when the systolic and diastolic are very close, which may be considered disturbing. Systolic and diastolic pressures may increase when the user is exercising, that is, running or walking. This elevation can be 20 to 40 mmHg. In this case, the alerts are not generated.

Finally, alerts are generated when blood oxygen saturation is low or very low. In this measurement, we do not include any rules when the user is practising exercises.

6 Conclusions

In this article, we proposed the use of a hardware and software infrastructure based on Fog Computing that meets the temporal requirements imposed by the healthcare environment, that is, a real-time monitoring system. The purpose of the proposal is to provide a system that receives, stores, processes and presents results within a hard deadline. To do this, we use a hardware platform that already exists, and we adapted it to the proposed healthcare environment. Besides, we use the IIoT Platform presented by FASTEN project. This platform is responsible for receiving, processing and presenting data. Additionally, we proposed a software infrastructure with components necessary for results to be presented within a time constraint (Foglets and time constraint rules).

Furthermore, in this article we proposed the sensors and rules structure. In other words, we proposed the sensors structure with possible values and the healthcare logic application with alert rules.

Because it is initial research and therefore a theoretical proposal, we intend as future works to carry out the implementation of the simulated sensor environment and the logic rules. Then, we intend to formulate the time constraint rules applying tasks priority, scheduling algorithm and control of hardware usage.

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