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A home hospitalization system based on the Internet of things, Fog computing and cloud computing

Hafedh Ben Hassen [a,b,*], Nadia Ayari [a], Belgacem Hamdi [a,c]

[a] University of Monastir, Electronic & Microelectronics' LAB, Faculty of Sciences of Monastir, Monastir, 5000, Tunisia
[b] University of Monastir, Department of Electrical Engineering, National Engineering School of Monastir, Monastir, 5000, Tunisia
[c] University of Sousse, Higher Institute of Applied Science and Technology of Sousse, Sousse, 4000, Tunisia

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ABSTRACT

In recent years, the world has witnessed a significant increase in the number of elderly who often suffer from chronic diseases, and has witnessed in recent months a major spread of the new coronavirus (COVID-19), which has led to thousands of deaths, especially among the elderly and people who suffer from chronic diseases. Coronavirus has also caused many problems in hospitals, where these are no longer able to accommodate a large number of patients. This virus has also begun to spread between medical and paramedical teams, and this causes a major risk to the health of patients staying in hospitals. To reduce the spread of the virus and maintain the health of patients who need a hospital stay, home hospitalization is one of the best possible solutions. This paper proposes a home hospitalization system based on the Internet of Things (IoT), Fog computing, and Cloud computing, which are among the most important technologies that have contributed to the development of the healthcare sector in a significant way. These systems allow patients to recover and receive treatment in their homes and among their families, where patient health and the hospitalization room environmental state are monitored, to enable doctors to follow the hospitalization process and make recommendations to patients and their supervisors, through monitoring units and mobile applications developed for this purpose. The results of evaluation have shown great acceptance of this system by patients and doctors alike.

1. Introduction

The world is witnessing the wide spread of the new coronavirus (COVID-19), as many countries have had thousands of infected cases and deaths due to the epidemic, such as Italy and Spain, which recorded the largest number of deaths up to March 2020. People can become infected with COVID-19 disease by other people who have the virus, as this virus spreads by direct contact. It may spread through respiratory droplets when the person coughs or sneezes. It may also spread if a person touches a surface on which the virus is present and then touches his mouth, nose, or eyes [1]. This virus poses a major risk, especially for the elderly and people with chronic diseases such as high blood pressure, heart disease, and diabetes [2]. As a result of the outbreak of the new coronavirus, most hospitals around the world are experiencing problems to tolerate a large number of infected people, as this virus has started to spread among the medical and paramedical teams of these hospitals, and this can cause a great risk to the health of patients staying in hospitals. In addition to the spread of this virus, the world is also witnessing a significant increase in the number of elderly people. Where according to the World Aging and Health Report 2015 of the World Health Organization, the number of people aged 60 and over will increase from 900 million to about 2 billion between 2015 and 2050. This significant increase in the number of elderly people increases patient dependency, chronic diseases, and disability [3] in addition to the large financial burdens that will be incurred by the economies of the countries concerned, as spending on hospital accommodation will increase [4].

Given this significant increase in the number of elderly people who often suffer from chronic diseases and who often need hospitalization, and the rapid spreading of the new coronavirus (COVID-19), we believe that home hospitalization must be adopted by governments to limit the spread of this virus and maintain the health of patients who require a hospital stay.

Home hospitalization is a smart and pioneering model of health care and is one of the most promising health services that aim to alleviate the suffering of patients, especially the elderly, by avoiding the trouble of moving to hospital institutions for treatment and allowing them to

* Corresponding author. University of Monastir, Electronic & Microelectronics' LAB, Faculty of Sciences of Monastir, Monastir, 5000, Tunisia.
E-mail addresses: hafedh.benhassen@enim.u-monastir.tn (H. Ben Hassen), ayarinadia13@yahoo.fr (N. Ayari), belgacem.hamdi@gmail.com (B. Hamdi).

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receive continuous care in the comfort of their homes [5–8]. This hospitalization aims to alleviate the burden of the disease in two ways, one of which is medical and human, given that receiving treatment in the family environment is of great importance and positively affects the benefit of medicines. The second aspect is the economic aspect, especially since the cost at hospitals has witnessed a significant increase, whereas home hospitalization greatly reduces the cost of health care.

For the success of the home hospitalization process, the patient must adhere to the doctor's recommendations, and his or her health also must be monitored periodically for medical intervention in case of health turbidity. Likewise, the environmental factors of the hospitalization room must be monitored, since these environmental factors can hinder the patient's recovery process and also can cause a risk to health. Among these environmental factors that must be monitored is the temperature, whose high or low rise can lead to many risks, and significantly for the elderly it can affect the brain, heart, cardiovascular and respiratory systems, and it can also lead to death in some cases [9]. Humidity also can cause health problems for patients suffering from respiratory diseases such as asthma or allergies [10]; not to forget the dangers of smoking to the patient and human health in general, as well as gas leaks that have health effects on the eyes and respiratory system and can cause deaths.

Nowadays, with the great evolution in the IoT area, it is expected that many smart objects and devices will have a tremendous ability to gather and share information between them [11]. The IoT has been relied upon in many applications and its use has seen wide acceptance in almost all fields, including the field of health care, where it is extensively applied in monitoring patient health remotely [12,13], and its different technology provides a solid approach to improving safety, health, and the wellbeing of humanity [14,15]. Cloud computing in recent years has provided many of the resources that are supported to take advantage of the IoT in terms of processing, ubiquitous computation and storage, and to share these resources in easy and simple ways [16]. Many Cloud and IoT-based solutions have been suggested in the literature [17,18], which add to the many benefits of Cloud computing to support ever-increasing data volumes. However, moving to the IoT cannot be considered a simple application of Cloud computing. Recently, a new concept of computing has emerged that is attracting much attention as compared to Cloud computing, because of its ability to meet requirements that have not yet been addressed through Cloud computing; it is termed Fog computing [19]. Fog computing extends the computing resources of the Cloud to the network edge of the IoT, allowing many connected devices to offer services such as storing and processing data to their users. Its structure also provides support for real-time data analysis for all geographically distributed devices with limited capacity for data storage and processing, thereby reducing the amount of data exchanged between devices and the Cloud [20].

This paper aims to contribute to finding new and innovative solutions to develop the healthcare systems in light of the problems experienced by most healthcare institutions during this period, like the congestion and the lack of resources, as a result of the rapid spreading of the new coronavirus (COVID-19) through the development of a low-cost, reliable, and safe home hospitalization system based on important modern technologies, that is, the IoT, Fog computing, and Cloud computing. This system enables patients to recover and receive treatment in their homes and between their families, and avoids them the risk of infection with the new coronavirus, especially for elderly people who often suffer from chronic diseases and weak immunity, and find it difficult to move to hospitals. The main contributions of this paper are:

- Proposing a home hospitalization system based on IoT, Fog computing, and Cloud computing.
- Developing an environmental sensing unit and a mobile application that plays the role of the Fog server and enables the viewing and analysis of the environmental factors of the hospitalization room in real-time.
- Developing a vital signs sensing unit and a mobile application that plays the role of the Fog server and enables the nurses to measure patients vital signs and prepare medical reports.
- Developing a mobile application for doctors that enable them to monitor the environmental status of hospitalization rooms and the health status of patients and provide recommendations to nurses and patients and their relatives.
- Developing a mobile application for patients and their relatives that enables them to follow the hospitalization process, the environmental status of the hospitalization rooms, and doctors' recommendations.
- Evaluating the proposed home hospitalization system by the patients and doctors.

The remainder of this paper is organized as follows. Section 2 presents related works to the home hospitalization system proposed in this paper. A detailed description of the proposed system is presented in Section 3, while Section 4 explains the implementation and results. Finally, the conclusion and future works are presented in Section 5.

2. Related works

This paper proposes a home hospitalization system in which patient vital signs, and environmental factors of hospitalization rooms are monitored using the IoT, Fog computing, and Cloud computing. This section presents the most important works based on these technologies, which offer systems and solutions to monitor patient health and environmental factors.

In recent years, the IoT, Fog computing, and Cloud computing have been utilized to monitor patient health as described in many research works, due to the ability of these technologies to provide quick, safe, and low-cost solutions [21–23]. At [24] for example, an IoT-based smart healthcare system is designed that collects patient information from different sensors and allows a doctor to monitor patient physiological parameters remotely, and diagnose diseases quickly, and also provides alerts to both the guardian and the doctor by sending SMS or emails in a timely manner. In Refs. [25] an e-health system for elderly's health monitoring based on IoT and Fog computing was proposed, where this system periodically collected physiological and public health parameters of the elderly using the Mysignals HW V2 platform and an Android application that plays the role of Fog server and enables the elderly and their families to monitor their health and communicate with health care providers. An IoT-based application has been proposed that explains the benefits of the concept of Fog computing [26]. This application aims to provide reliable, accurate, and immediate heart rate monitoring via embedded wearable devices, mobile edge devices, and Cloud services. In recent years, the use of smartphones and tablets has increased in health monitoring applications, where they are used as mobile computing devices and as Fog servers that process data and send it to the Cloud [27–30]. A mobile application was used at [31] to monitor the patient's heart in real time as an application through the pulse rate sensor, which measures the patient's pulse and then sends it to storage in a remote database. This application also sends notifications to the doctor if a problem is discovered in the heartbeat. A mobile application was also used to develop a system for monitoring vital signs at work [32].

As for monitoring environmental factors, it has been discussed in many studies. At [33] for example, guidance was provided on how to use technology for environmental monitoring. At [34] a complex event processing engine (CEP) was introduced to monitor the environment based on IoT that detects anomalies in real-time. In Ref. [35] is offered a smart system for monitoring and internal environmental management based on environmental sensors and Cloud computing, where this system collects data related to internal gases and then it stores and processes environmental data in the Cloud, and this system enables users to monitor the environment and receive warnings if air quality exceeds the legal limit, through a web-based monitoring platform. At [36] an environmental monitoring system for internal thermal comfort has been proposed to explore the thermal comfort of people in indoor environments, depending on the IoT.

As we have seen in this section, there are many studies done based on the IoT, Fog computing, and Cloud computing to monitor patient health and monitor environmental factors, but we did not find works that merged monitoring patient's health and monitoring environmental factors in one system despite the significant impact of environmental factors on patient health; also most of these systems rely mainly on the Internet to send data to the Cloud, and when the Internet is interrupted, these systems become useless and for this, we believe that these systems will not be implemented and accepted in most developing countries because these countries do not have a good infrastructure for the Internet in all regions. In the home hospitalization system proposed in this paper, we will merge monitoring the health status of patients and monitoring environmental factors in one system, as this system will allow patients to recover in their homes and avoid the difficulties and risks of moving to health institutions. The problem of the Internet outage will be overcome also by relying on Fog computing along with Cloud computing.

3. Proposed home hospitalization system

This section describes the proposed home hospitalization system based on IoT, Fog computing, and Cloud computing. This section will be divided into two parts, the first part presents the proposed system's architecture, while the second part presents the architecture of the Cloud computing used in this system.

3.1. Proposed system's architecture

In this paper, we propose a home hospitalization system based on the IoT, Fog computing, and Cloud computing, whereby in this proposed system the environment of the hospitalization room is monitored in addition to monitoring patient health remotely to ensure a good hospitalization process. Fig. 1 illustrates the architecture of this proposed system.

In this proposed system, the hospitalization room's environment is monitored through an environmental sensing unit and a mobile application that plays the role of the Fog server and enables the viewing and analysis of the environmental factors of the hospitalization room in real time, while the patient's health is monitored through a vital signs sensing unit and a mobile application that plays the role of the Fog server and enables the nurses to measure the patients' vital signs and prepare medical reports. This proposed system also provides a mobile application for the doctors that enable them to monitor the environmental status of hospitalization rooms and the health status of patients and provide recommendations to nurses and patients and their relatives, and a mobile application for patients and their relatives that enable them to follow the hospitalization process, the environmental status of the hospitalization rooms, and doctors' recommendations. For data storage, we chose the NoSQL database due to their ability to solve relational database problems such as the problem of heterogeneity of data and its ability to deal with large amounts of data, as it has great scalability and high flexibility [37–39]. Below is a detailed description of the hospitalization room's environmental monitoring and patient's health monitoring process.

3.1.1. Hospitalization room's environmental monitoring

In hospitals, the environmental factors are often suitable for the hospitalization process, but in the home hospitalization process, these factors can be outside the limits of ideal values and therefore adversely can affect the hospitalization process and can also represent a risk to the patient's health and for this, we consider that environmental monitoring of the hospitalization room is necessary for the home hospitalization process. As shown in Fig. 1, the proposed architecture of the hospitalization room's environmental monitoring is mainly based on the environmental sensing unit and a mobile application installed on a tablet

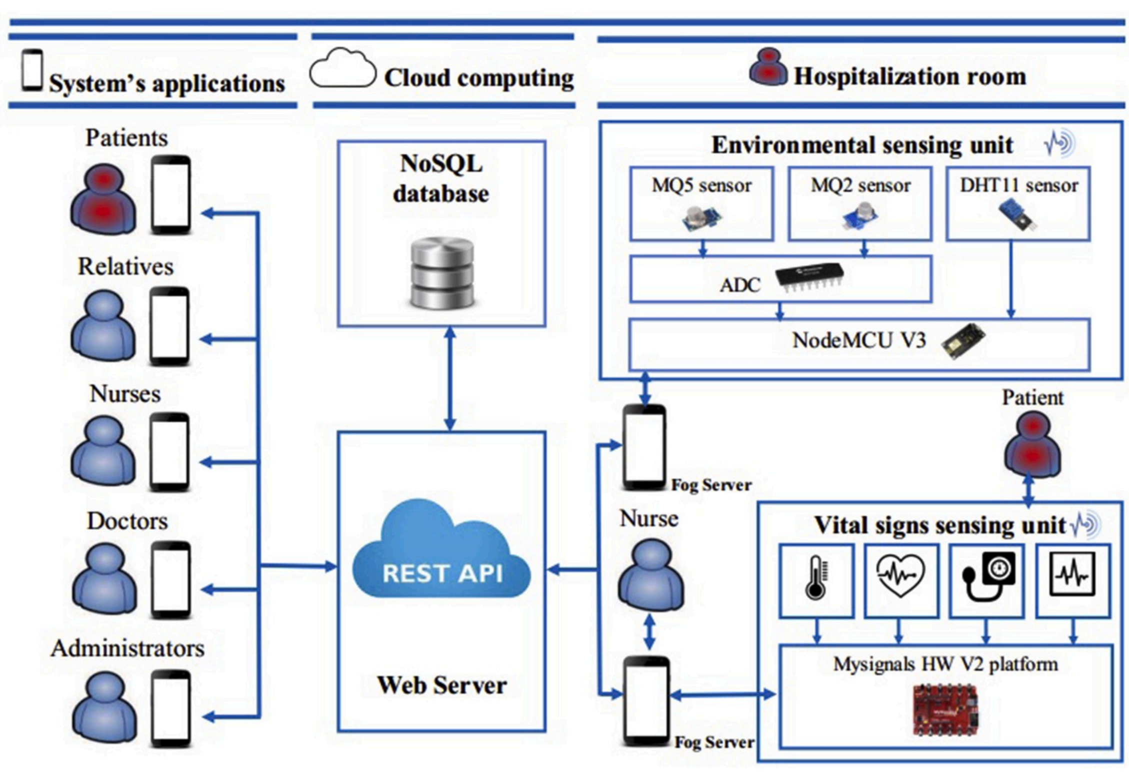

Fig. 1. The general architecture of the proposed home hospitalization system.

device that plays the role of a Fog server.

The proposed environmental sensing unit is composed of three modules for the detection of environmental factors. The modules used are the temperature and humidity detection module (DHT11 sensor), the gas leak detection module (MQ5 sensor), and the smoke detection module (MQ2 sensor). These three detection modules are connected to the NodeMCU V3 board, which collects the values of environmental factors and then sends them to the Fog server via the WiFi periodically. The temperature and humidity detection module (DHT 11) returns numerical values and for this, it is directly connected to the NodeMCU V3 board; however, the gas leak detection module (MQ5 sensor) and the smoke detection module (MQ2 sensor) return analog values and for that we use an analog/digital converter (ADC) to convert the values of these modules. Table 1 presents the components of the proposed environmental sensing unit in detail.

The Fog server receives the data sent by the environmental sensing unit and then displays it in real time. It also analyzes this data if it is within the limits of ideal values or not. If this data is outside the limits of ideal values, the Fog server sends an alert to all actors in this system in real time, otherwise, it stores this data locally and processes it and then sends it to the Cloud via the Internet through the REST API for permanent storage and further processing and analysis.

Table 1
The components of the proposed environmental sensing unit.

Component	Description
NodeMCU V3	The NodeMCU V3 is an open-source ESP12E module based development platform for creating IoT connected objects [40–42]. This development platform is based on the ESP12E module and it integrates GPIO, PWM, I2C, 1-WIRE buses and an ADC, all on a single board with a WiFi connection shield, and all of that thanks to the NodeMCU firmware.
Temperature and humidity detection module (DHT 11)	This sensor-based module provides a digital output proportional to the temperature and humidity measured by the sensor. The technology used to produce the DHT 11 sensor guarantees high reliability, excellent long-term stability and very fast response time.
Smoke detection module (MQ2 sensor)	This module is based on the MQ2 gas sensor to detect smoke, hydrogen, LPG, I-butane, propane, methane and alcohol. It provides high sensitivity, which is adjustable by a potentiometer, and fast response time.
Gas leak detection module (MQ5 sensor)	This module is based on the MQ5 gas sensor to detect (for demotic and industrial uses) gas leaks. It can detect LPG, natural gas, city gas... With a fast response time, it is ideal for quickly detecting the presence of a gas. It is equipped with a potentiometer to adjust the sensitivity.
Analog to digital converter (ADC)	This module is an analog-to-digital converter (ADC) that converts an analog quantity into a digital value (coded over several bits), proportional to the ratio between the input analog quantity and the maximum value of the signal. Since we have in this system analog sensors (gas sensor MQ2 and gas sensor MQ5) then we need an analog-to-digital converter because the NodeMCU V3 contains a single analog input and for that, we will use the MCP3008-I/P analog-digital converter from Microchip Technologie Inc. The MCP3008-I/P communication with the NodeMCU V3 is performed using a simple serial interface compatible with the SPI protocol.
Power supply	For the power supply to the NodeMCU V3, the voltage must be between 3.3 V and 9 V. Under no circumstances should this input voltage be exceeded. It can thus be seen that the card is powered by connecting a 3.3 V power source to one of the 3.3 V terminals, by connecting to a micro USB with a USB cable or by connecting a source to VIN. For this, we used a 5 V power supply to power the NodeMCU V3 and the other modules of the system.

3.1.2. Patient's health monitoring

In the hospitalization process in hospitals, patient health is continuously monitored, with a nurse visiting the patient to monitor and record vital signs and compare them with previously captured data. The frequency of visits is related to the suggested schedule from the patient's doctor. Electronic instruments are generally used to measure patient vital signs; these instruments are generally large and are not easily transmitted. Vital signs are usually recorded in the form of a graph, which doctors often see daily during their visits.

In the home hospitalization system proposed in this paper, the patient's health is monitored almost the same way as the patient's health is monitored in hospitals, where the nurse visits the patient according to the appointment schedule provided by the supervising doctor. During these visits, the nurse verifies the patient's health, measures vital signs, and prepares a medical report that is sent to the doctor for every visit made. The process of measuring patient vital signs is carried out through the sensing unit and a mobile application installed on a tablet that plays the role of Fog server, as shown in Fig. 1.

The vital signs sensing unit of this system is the MySignals HW V2 platform, which is a development platform for medical devices and e-health applications. The MySignals HW V2 platform is the most complete on the market, as it supports many biomedical sensors to measure biometric parameters such as ECG signals, blood pressure, blood oxygen, pulse, respiratory rate, and body temperature. It is small in size and can be carried easily to the patient's home to measure vital signs. The MySignals HW V2 platform relies on the Atmega 328 (Arduino UNO) microcontroller to manage various sensors and also allows tablets and smartphones to communicate with it, via built-in WiFi and BLE modules.

The process of measuring vital signs is done by the patient's wearing the vital signs sensors to be measured; then the mobile application installed on the tablet plays the role of Fog server and communicates with the MySignals HW V2 platform via WiFi to measure these vital signs, where it sends a request to the MySignals HW V2 platform to measure the required vital signs. MySignals HW V2 measures these vital signs and then sends the measurements to the mobile application. The mobile application analyzes these measurements, and displays and stores them locally. Based on the results of the measurements, and some oral questions that the nurse asks the patient and his relatives, the nurse writes a medical report through the mobile application and then sends the measurements and the report to the Cloud for permanent storage and further analysis via REST API. Through these measurements and medical reports stored in the Cloud, the supervising doctor can, through a mobile application, monitor the patient's health status and provide recommendations and instructions to the nurse and the patient and his relatives to ensure a good hospitalization process and timely intervention if there is a risk to the patient's health.

3.2. Proposed cloud computing architecture

Cloud hosting represents a radical change of the traditional hosting options such as shared hosting and dedicated hosting, where it has many advantages that improve it as compared with traditional hosting [43]. Cloud hosting has a strong and flexible infrastructure that allows expanding the used resources easily, and also ensures the availability of data permanently, in addition to providing a high level of protection. It is also a low-cost hosting, where the cost of hosting is calculated against the amount of use of the Cloud resources, unlike the traditional hosting whose cost often exceeds the cost of resources used.

The home hospitalization system proposed in this paper relies on Cloud computing to host the REST API and data storage where the Microsoft Azure Cloud Platform will be used, which is one of the most prominent Cloud computing platforms [44]. Fig. 2 shows the Cloud computing architecture proposed in this system.

The Microsoft Azure Cloud platform is a provider of Cloud services that include infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS) created by Microsoft using its network of data centers that it is constantly expanding all over the world, as it provides a variety of Cloud computing, storage, and application services for all types of users from the business sector and institutions. It allows the creation of applications and services, examination, management, and dissemination over a huge global network using the unique tools and frameworks it provides. Security and privacy are also included on the Azure platform. The Microsoft Azure Cloud platform provides the ability to store data securely with ready access, while providing the possibility to increase the storage space at any time depending on the user's business activity. As in the case of Cloud computing services, the cost is only based on the space consumed, and the total cost is calculated depending on the hours of access and data usage. It also provides the possibility to create applications with ease, and publish compatible applications globally on all web platforms and mobile phones spread, and be able to develop and respond very quickly with the ability to manage web applications and examine and publish them widely with ease.

For data storage in this proposed system, we have relied on Azure Cosmos DB, which is a globally distributed and multi-model database service of Microsoft that provides flexible storage and fast data access with implementation of wire protocols for common NoSQL databases including Azure Tables Storage, Gremlin, Cassandra and MongoDB.

MongoDB was chosen as a data storage system, which is a system of databases of the category called NoSQL, or more accurately, the Non-Relational Database Management System, and it utilizes BSON (Binary JSON) files. Likewise, MongoDB considers Schema-less as it does not adhere to a specific schema, so the content of files may vary from time to time. MongoDB is also considered a scalable system as it can cope with thousands of requests simultaneously without affecting the speed of performance [45]. As in MySQL, which consists of tables, MongoDB is also composed of collections, which in turn contain documents, so that the size of the collection depends on the number of documents contained within it. We can say that one of the most important differences between MongoDB and MySQL is that the file structure does not adhere to certain rules, as we find that the rows' components are the same in one table. They must be subject to the schema rules that have been defined as MongoDB does not support any scheme and therefore the file structure can change from time to time within the same collection [46].

Node.js was chosen to develop the REST API due to its superiority over other web development technologies such as PHP/Nginx in computational performance and its great use in real-time and high-speed applications [47,48]. Node.js is a free software platform in JavaScript oriented towards highly competitive event network applications that must be able to scale up. It uses the V8 virtual machine, the libuv library for its event loop, and implements the CommonJS specifications under the MIT license. Among the native modules of Node.js, there is HTTP which allows the development of HTTP server. It is, therefore, possible to do without web servers such as Nginx or Apache when deploying websites and web applications developed with Node.js. Concretely, Node.js is a low-level environment for executing server-side JavaScript. Node.js is used in particular as a web server platform; it is used by LinkedIn, Microsoft, Yahoo, and PayPal.

REST API connects between the proposed system's applications and the database, where the applications can store, retrieve, and manage data through Web Services using HTTP requests and JSON data model [49]. To develop the REST API will use the Express.js framework, which is a helpful web application framework for Node.js released as a free and open-source program designed to build web applications and APIs [50]. In addition to the Mongoose Library, an Object Data Modeling (ODM) for MongoDB and Node.js, it is used to manage the relationships between the Express.js framework and the MongoDB database [51].

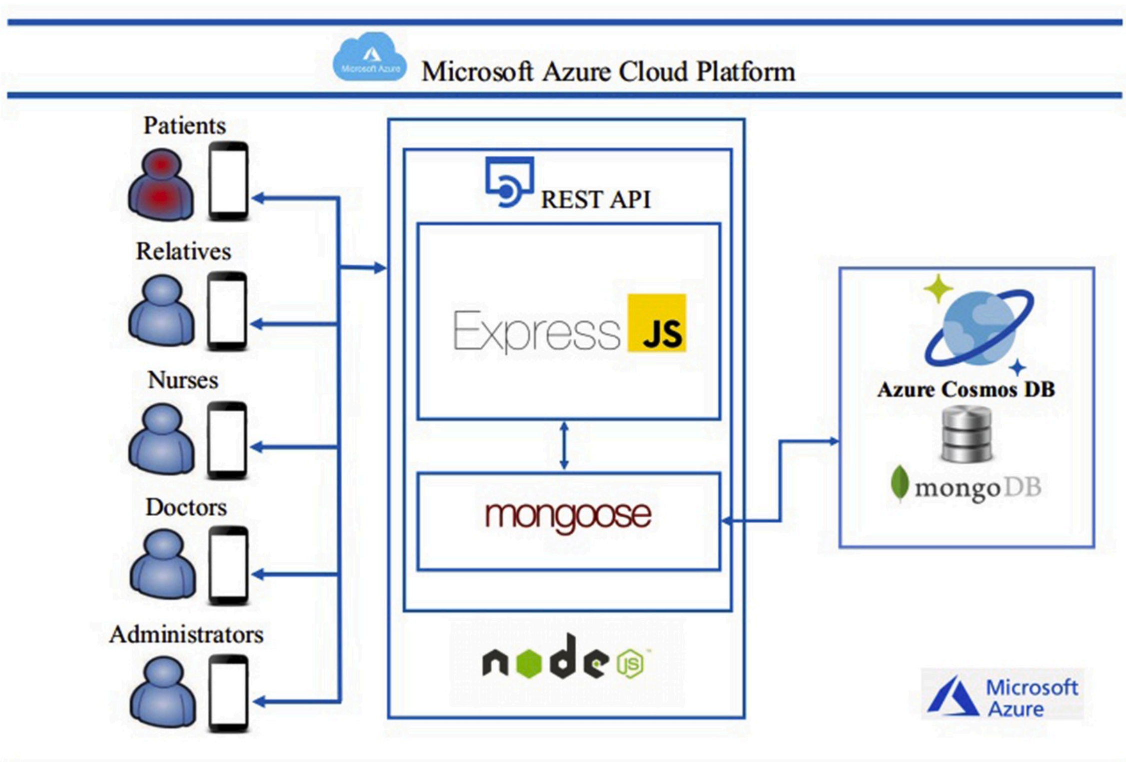

Fig. 2. The architecture of the proposed Cloud computing.

4. Implementation and results

This section explains the process of implementing the proposed home hospitalization system, where an in-depth look is given to the implementation of the hospitalization room's environmental monitoring process and the implementation of the patient's health monitoring process, and the display of the mobile applications for different actors in this system, in addition to discussing the characteristics and advantages of this proposed system and its evaluation using the System Usability Scale (SUS).

4.1. *Implementation*

4.1.1. *Hospitalization room's environmental monitoring*

Monitoring the environmental factors of the hospitalization room is very important in the home hospitalization process, given the impact of these factors on the patient's health. To monitor these environmental factors we have developed an environmental sensing unit based on the NodeMCU V3 board that senses environmental factors and an Android application that plays the role of the Fog server, where this application communicates with the NodeMCU V3 board and collects the sensed data of the environmental factors and then processes, analyzes, displays them in real-time, and stores them locally, and sends the information to the Cloud for permanent storage and further analysis. Fig. 3 shows the

Fig. 3. The environmental sensing unit and the Android application interfaces.

environmental sensing unit and the home interface of the Android application developed to monitor the environmental factors of the hospitalization room.

The environmental sensing unit senses the temperature and humidity via the DHT11 sensor, the smoke via the MQ2 sensor, and the LPG gas via the MQ5 sensor. The MQ2 sensor and MQ5 sensor are analog sensors, the NodeMCU V3 board contains only one analog input pin, so we used the MCP3008-I/P analog-digital converter to connect these analog sensors to the NodeMCU V3 board. Whereas the DHT11 sensor is a digital sensor, so we connected it directly to the NodeMCU V3 board that has 10 GPIO pins which can be used for digital input and output operations.

To sense these environmental factors and communicate with the Android application, we have programmed a C++ script using the Arduino IDE. This script makes the NodeMCU V3 board work as an HTTP Server using WiFi Access Point mode for making the Android application installed on the tablet communicate with the NodeMCU V3 board via WiFi without having to connect to a router. In this script we have developed, an SSID name and password are assigned to access the NodeMCU V3 board as well as to install its IP address. With this IP address, the NodeMCU V3 board can deliver web pages and web services to all connected devices within its network. This script returns the environmental factors that are sensed in JSON format consumed by the Android application, where the Android application sends HTTP requests to the NodeMCU V3 board. The NodeMCU V3 board senses the environmental factors and then returns the sensed data to the Android application in JSON format. This is, of course, after the tablet device on which the Android application is installed has connected to the NodeMCU WiFi Access Point by entering the SSID name and password and doing the necessary settings.

The Android application periodically collects environmental factors and displays them in real-time, it also stores these environmental factors locally and processes and analyzes them. For example, if these factors are outside the scope of health factors such as recording a gas leak or sensing smoke in the room or a significant increase or decrease in the degree of humidity or room temperature, the Android application gives a sound alert and also sends an alert to the relatives of the patient, the supervising doctor, and the system administrators. This alert is a notification sent to each of them arriving via their applications, in addition to an SMS message that arrives in real time to intervene to save the patient if these factors represent a real risk to patient health.

The Android application also sends the sensed environmental data to the Cloud for permanent storage and further analysis, and this data is also stored locally for a specified period, to be displayed if the application is not able to send the data to the Cloud.

Initially, our idea was for the NodeMCU V3 board was to send the sensed data directly to the Cloud via the Internet, and through mobile applications, this data would be accessed, but we retreated on this idea because it will increase system cost, as we will need a router to connect the NodeMCU V3 board to the Internet. In addition to that, in many regions, especially in developing countries, there is no Internet connection, and even when present, Internet speed is often low, so that we chose to rely on an Android application installed on a tablet device that plays the role of a Fog server to collect this data and send it to the Cloud via 3G/4G. Even if the Android application is unable to send this data to the Cloud, it stores the data locally and alerts the patient if environmental factors represent a danger to him or her through this application, and the patient's supervisors are then alerted via SMS.

Fig. 3(a) shows the Android application interfaces dedicated to the settings where the environmental sensing unit ID is determined, the ideal ranges for environmental factors, and the phone numbers of the patient's supervisors are also imported. Fig. 3(b) shows the Android application interfaces dedicated to displaying measurements of the hospitalization room's environmental factors.

4.1.2. Patient's health monitoring

The patient's health monitoring in this proposed system is carried out by the nurse who periodically visits the patient according to the schedule set by the supervising doctor to measure vital signs and prepare a medical report that is sent to the doctor on every visit made. The process of measuring patient vital signs and writing the medical report is done through an Android application installed on a tablet device.

Fig. 4 illustrates some interfaces of this application, where the nurse can after logging in by entering the login and password see the schedule of visits for all the patients to be visited. After that, the nurse chooses the relevant visit to perform the health monitoring process (measuring the patient's vital signs and preparing the medical report). The nurse can also view the reports of previous visits, the recommendations of the supervising doctor, and the patient profile.

The patient's vital signs are measured through this Android application that plays the role of the Fog Server, and the vital signs sensing unit which is the MySignals HW V2 platform in this system.

In this system, SpO2, heart rate, body temperature, and electrocardiogram (ECG) are measured. This system can be expanded to measure other patient data such as airflow, blood pressure, blood sugar, galvanic skin response, and electromyography (EMG). A C++ script is programmed using the integrated development environment Arduino IDE to make the Mysignals HW V3 platform able to measure these vital signs and send them to the Android application via WiFi connection.

Fig. 5(a) shows the process of measuring SpO2 and heart rate, where the sensor is placed on the index finger of the patient, and through the Android application, a request for measuring SpO2 and heart rate is sent to the MySignals HW V2 platform. This platform measures SpO2 and heart rate and then sends the measurements to the Android application to store locally before sending to the Cloud. Regarding the patient's body temperature measurement, the sensor is placed on the index finger or on the part where the temperature is measured, and through the Android application a request for measuring the body temperature is sent to the MySignals HW V2 platform. This platform measures the body temperature and then sends the measurements to the Android application to store locally before sending to the Cloud, as shown in Fig. 5(b).

As for the electrocardiogram (ECG), Fig. 6 shows its measurement process where the sensors are connected to the patient's chest, and through the Android application, an ECG measurement request is sent to the MySignals HW V2 platform, this platform measures the ECG and visualizes the data in real time on its screen and through the Android application is done to evaluate the obtained ECG measurements results.

After performing the patient vital signs measurement process, the nurse prepares and saves the medical report as shown in Fig. 7. After saving the medical report, this Android application deletes this visit from the nurse's visit list, and encrypts the measurements and the medical report and sends them to the Cloud for permanent storage and more analysis through the REST API via the Internet. If there is no Internet connection, this data will be stored locally and sent to the Cloud automatically at the first Internet connection.

4.1.3. Home hospitalization system's applications

In the home hospitalization system proposed in this paper, there are four groups of actors, which are the doctors, the nurses, the patients and their relatives, and the system administrators. Each of them plays a specific role in this system through its Android application. In the previous subsection, we presented the nurses' Android application that allows them to measure the patients' vital signs and prepare the medical reports. In this subsection, we will present the Android applications for the doctors, the patients and their relatives, and the system administrators. React Native has been used to develop the various applications of this system It is an open-source mobile application framework created by Facebook that is used to develop Android and iOS applications using ReactJS, and it allows developers to use all the native functionality of these platforms [52].

Fig. 8 illustrates some Android application interfaces for the doctors,

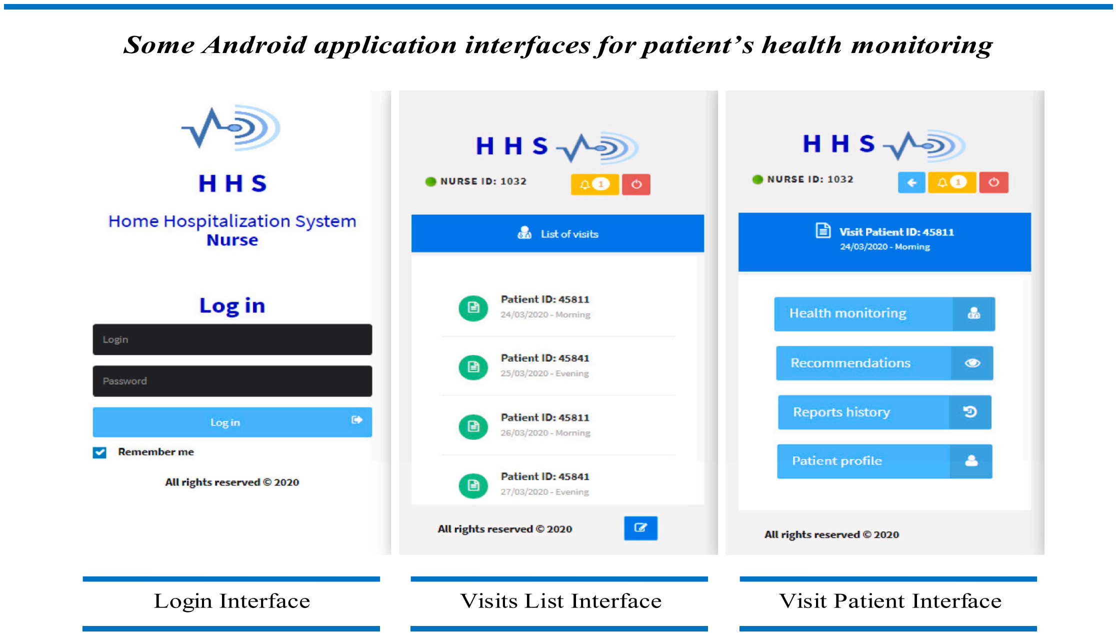

Fig. 4. Some Android application interfaces for patient health monitoring.

where after logging in, each doctor can view the profiles of patients and follow the environmental condition of the hospitalization rooms (Fig. 8(a)), and the health status of patients by viewing the measurements and medical report for each patient (Fig. 8(b)).

Through this Android application, the doctor also manages each patient's medications, determining the time to take each type of medicine, in addition to providing recommendations to patients and their relatives to ensure a good hospitalization process. This Android application also provides notifications to the doctors when adding any medical report for one of the patients or when the environmental condition of any hospitalization room poses a risk to the patient's health.

Fig. 9(a) shows some Android application interfaces for patients and their relatives, where the patient or a member of his relatives after logging in can view the list of visits that the nurse will make to the patient to follow his or her health, in addition to viewing the list of the patient's medications and the time to take each type of them, the recommendations of the supervising doctor, and the environmental condition of the hospitalization room. This Android application also provides notifications when the nurse's visit is approaching, the date of taking the medications is approaching, when the supervising doctor sends a recommendation, or when the environmental condition of the hospitalization room poses a risk to the patient's health.

Fig. 9(b) illustrates some Android application interfaces for system administrators, where this Android application enables them to manage the patient and their relatives' accounts, manage doctors' accounts, and manage nurses' accounts in addition to managing the home hospitalization process. The start and end date of each hospitalization process are determined for each patient, and scheduling the visits of the nurses to the patients, and the management of the environmental sensing units for each hospitalization room are done by adding an ID and Code PIN for each environmental sensing unit and linking it with the patient's account, and determining the ideal values for each environmental factor. This Android application also allows for following the environmental factors of each hospitalization room and receiving notifications when the environmental condition of a specific room poses a risk to the patient's health.

4.2. Discussion and evaluation

The home hospitalization system proposed in this paper represents a paradigm shift for smart healthcare systems. This system allows patients to recover and receive treatment in their homes and between their families and avoids for them the difficulties of moving to hospitals and the risk of infection with the new coronavirus, which is especially important for the elderly, who often suffer from chronic diseases and weak immunity. This system also addresses the problems of congestion and lack of resources suffered by most health institutions and hospitals during this period. Through this system, the health of the patients and the environmental condition of the hospitalization rooms are monitored remotely and periodically throughout the hospitalization period, which allows doctors to follow the processes of hospitalization and supervise the patients remotely.

This proposed system is distinguished from other smart health care systems proposed in the literature, as it is easy to apply, of low cost, reliable and safe, and it also integrates monitoring the health of patients and the environmental factors of the hospitalization rooms in one system, which allows doctors to diagnose the state of their patients. Furthermore, it can be applied in rich and developed countries, as in poor and developing countries.

Most of the smart healthcare systems proposed in recent years primarily monitor patients' health remotely using sensors and electronic devices connected to the Internet, that send patients' vital signs measurements to doctors in real time. At [24] for example, a smart IoT-based healthcare system is designed to allow measuring, viewing, and monitoring the patient's vitals using a set of sensors. This system also sends an alert to the doctor and the patient's family whenever the vitals reach or exceeds a certain limit. The data recorded in the form of an Excel sheet is also collected in Google Drive for future analysis, as it can be viewed through a web application and a mobile application. In Ref. [25], an e-health system was also proposed to monitor the health of the elderly based on IoT and fog computing. This system allows the collection of physiological and public health parameters for the elderly periodically. It uses the Mysignals HW V2 platform and an Android application that plays the role of Fog server and enables the elderly and their families to monitor the health state, and communicate with healthcare providers. The problem with these two proposed systems is that they are based

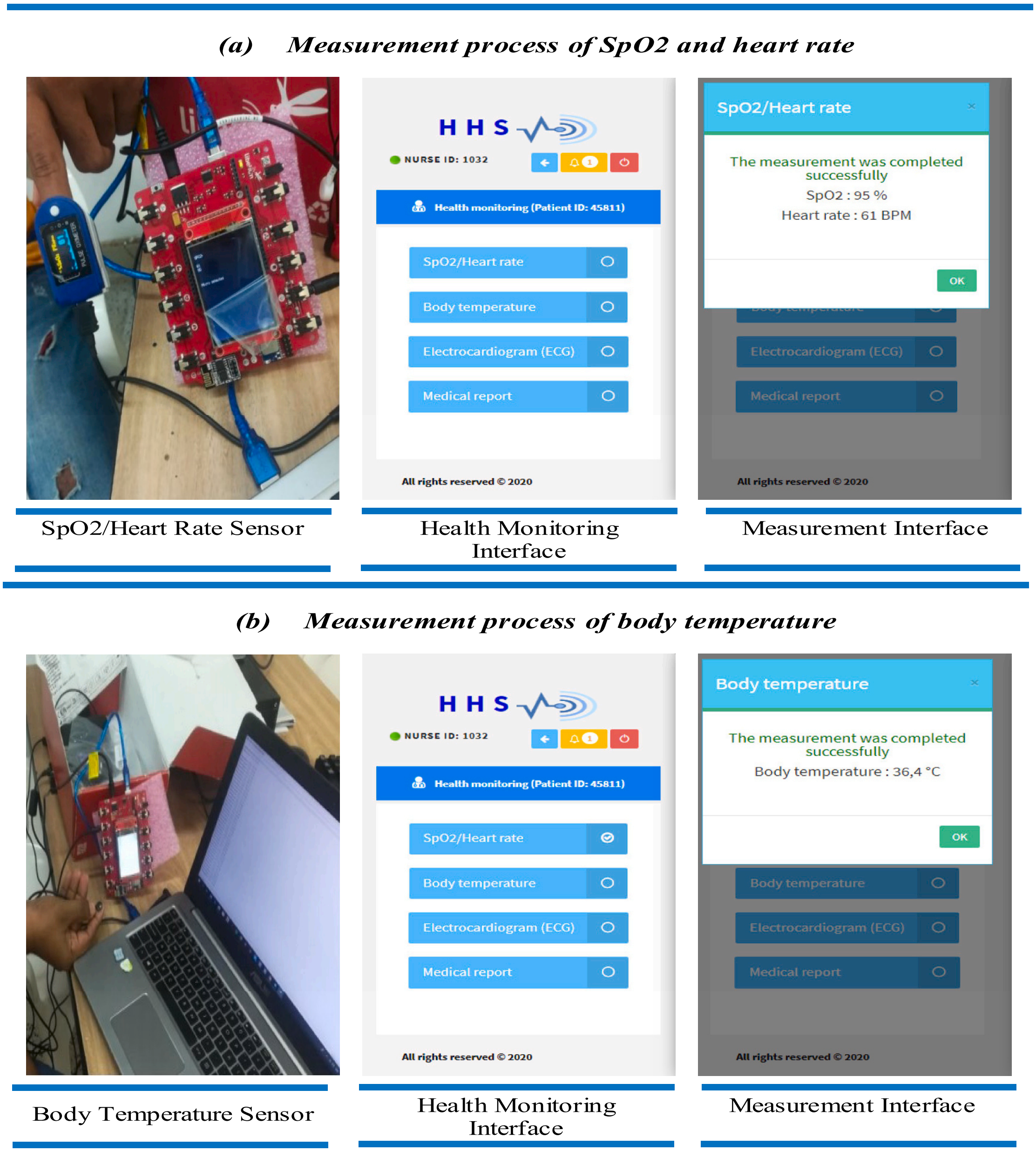

Fig. 5. Measurement process of SpO2, heart rate, and body temperature.

primarily on the Internet, and since in many regions, especially in developing countries, there is no connection to the Internet, and even if it exists, the speed of the Internet is low, we believe that such systems will not be implemented and accepted in most developing countries. They do not have good infrastructure for the Internet in all regions due to limited financial capabilities to provide smart sensors to monitor patient health remotely for all patients, unlike the developed and rich countries that can overcome these obstacles.

Concerning the home hospitalization system proposed in this paper, we believe that it can be easily implemented and accepted in developing countries and developed countries alike due to its solution to the Internet infrastructure problem and its low cost. In this proposed system, we will not need a vital signs sensing device for each patient to monitor its health, but we will need one device (vital signs sensing unit) for each nurse and a mobile application that plays the role of Fog server communicating with the vital signs sensing unit, through which the nurse measures the vital signs of patients and prepares medical reports at each visit. This application solves the Internet connection problem wherein case the Internet coverage does not reach the patient's home, this application will store data locally and send it to the Cloud at the first Internet connection. The environmental sensing unit is also distinguished by its low cost, as the cost of making its prototype is just a few dollars. This unit is installed in the hospitalization room at the start of each home hospitalization process, and at the end of the hospitalization process it is used for another patient hospitalization process; this of course reduces the cost of this system. This unit collects environmental factors data for the hospitalization room and sends it to the cloud via the Internet through a mobile application installed on a tablet device that plays the role of Fog server. The data is stored also locally in this application. The patient is alerted if these environmental factors represent a danger to him or her through this application (Fog server) without the need to connect to the Internet, and all supervisors of the patient are alerted via SMS. Alerts are sent to their mobile applications via the Fog server if there is an Internet connection. For data storage, Cloud computing platforms provide reliable storage that maintains data security and with low cost. This is why we chose the Microsoft Azure Cloud

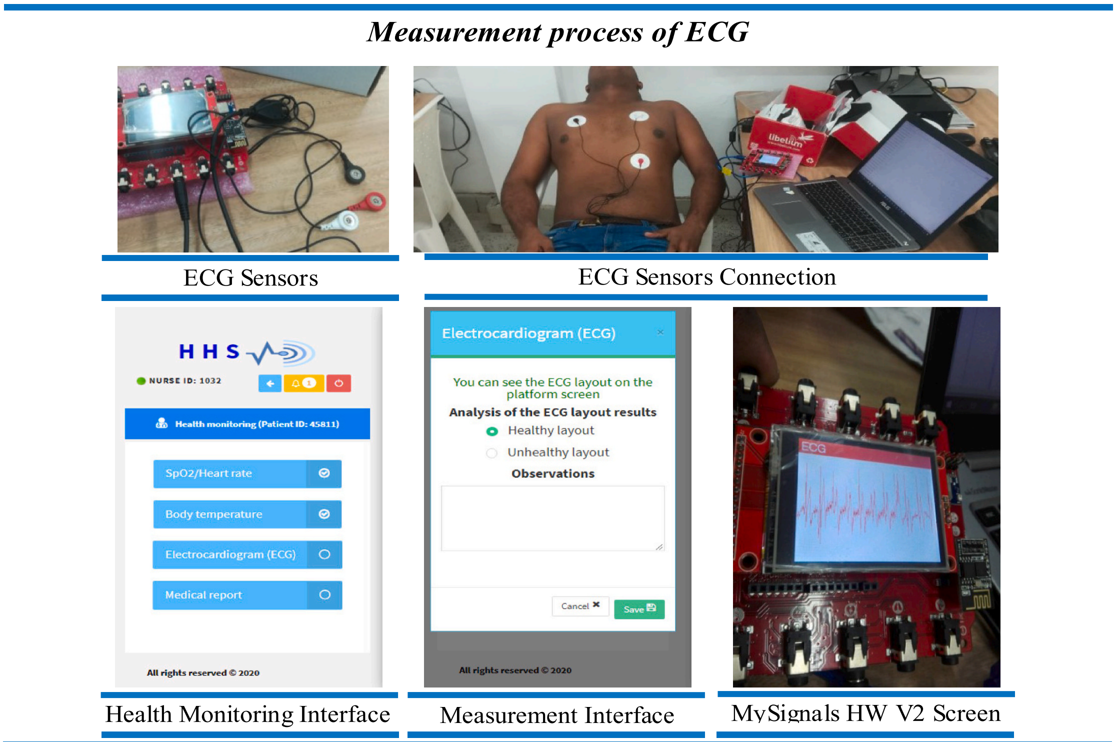

Fig. 6. Measurement process of ECG.

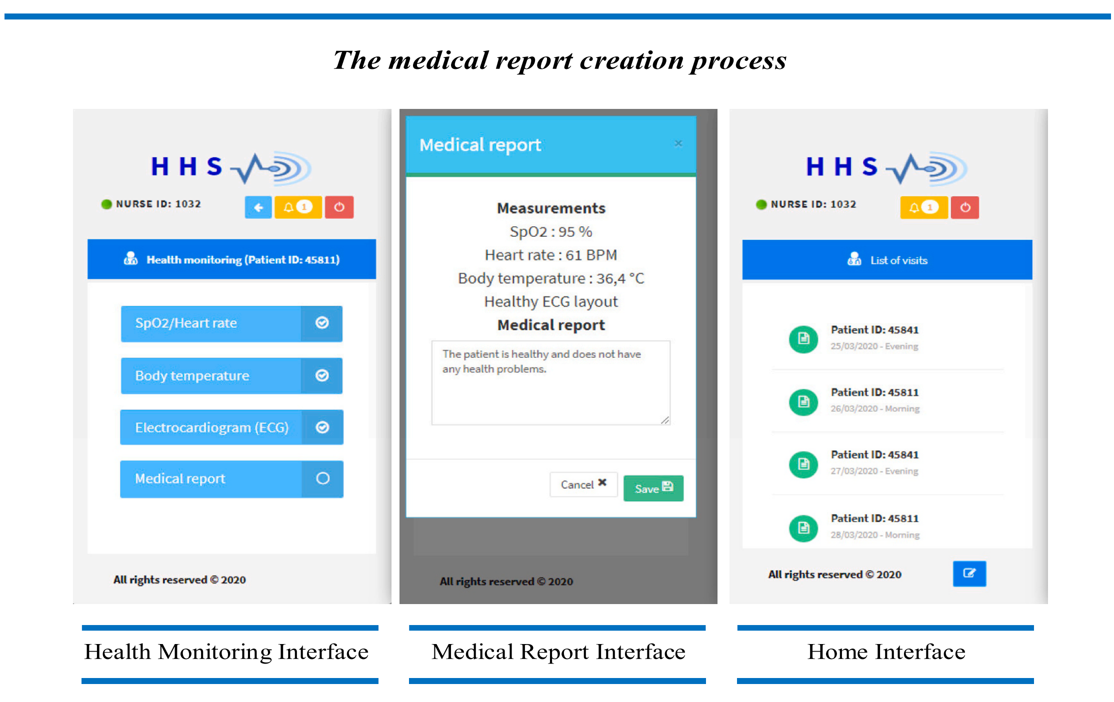

Fig. 7. The medical report creation process.

platform for data storage and the hosting of the applications of the proposed system.

To evaluate the home hospitalization system proposed in this paper, we have used the System Usability Scale (SUS), as this scale provides a fast and reliable tool for measuring ease of use [53,54] and allows the evaluation of a variety of services and products, including mobile devices, mobile applications, and websites. To detect most usability problems, it is acceptable to evaluate with five users as described in Ref. [55]; based on this, five hospitalized patients between the ages of 45 and 61 years and five doctors were selected to conduct usability testing. To evaluate the proposed home hospitalization system, the system model was explained and a demonstration was made of its various applications for both patients and doctors, after which they were asked to complete the SUS questionnaire. The questionnaire is composed of 10

Fig. 8. Some Android application interfaces for the doctors.

questions to assess system usability, where each of the questions is classified based on the amount of agreement, from one (Strongly Disagree) to five (Strongly Agree), as shown in Fig. 10(a). After patients and doctors have finished answering questions, the SUS scores are calculated as shown in Fig. 10(b).

Table 2 displays the values of the SUS questionnaires provided by each patient, the SUS value per patient, and the average SUS calculated for all patients. Table 3 shows the values of the SUS questionnaires provided by each doctor, the SUS value per doctor, and the average SUS calculated for all doctors.

The evaluation score obtained in the SUS evaluation for patients is 91.0, while for doctors it is 93.0. According to theory [53] and as shown in Fig. 10(c), the usability is excellent, because we need to score above 80.8 to get a degree A, which is the higher degree in usability.

As seen in the evaluation, the home hospitalization system proposed in this paper was very well accepted by patients and doctors alike, but we believe this system must be improved and some adjustments made for it to be applied to coronavirus patients safely, among these changes and improvements, the patient was made to measure vital signs by him or herself, and video communication was added between patients and doctors. However, for these changes and improvements, we believe that poor and developing countries will not be able to implement the system due to the cost increase and the lack of good Internet coverage in all regions.

5. Conclusion and future works

In this paper, a home hospitalization system based on the IoT, Fog

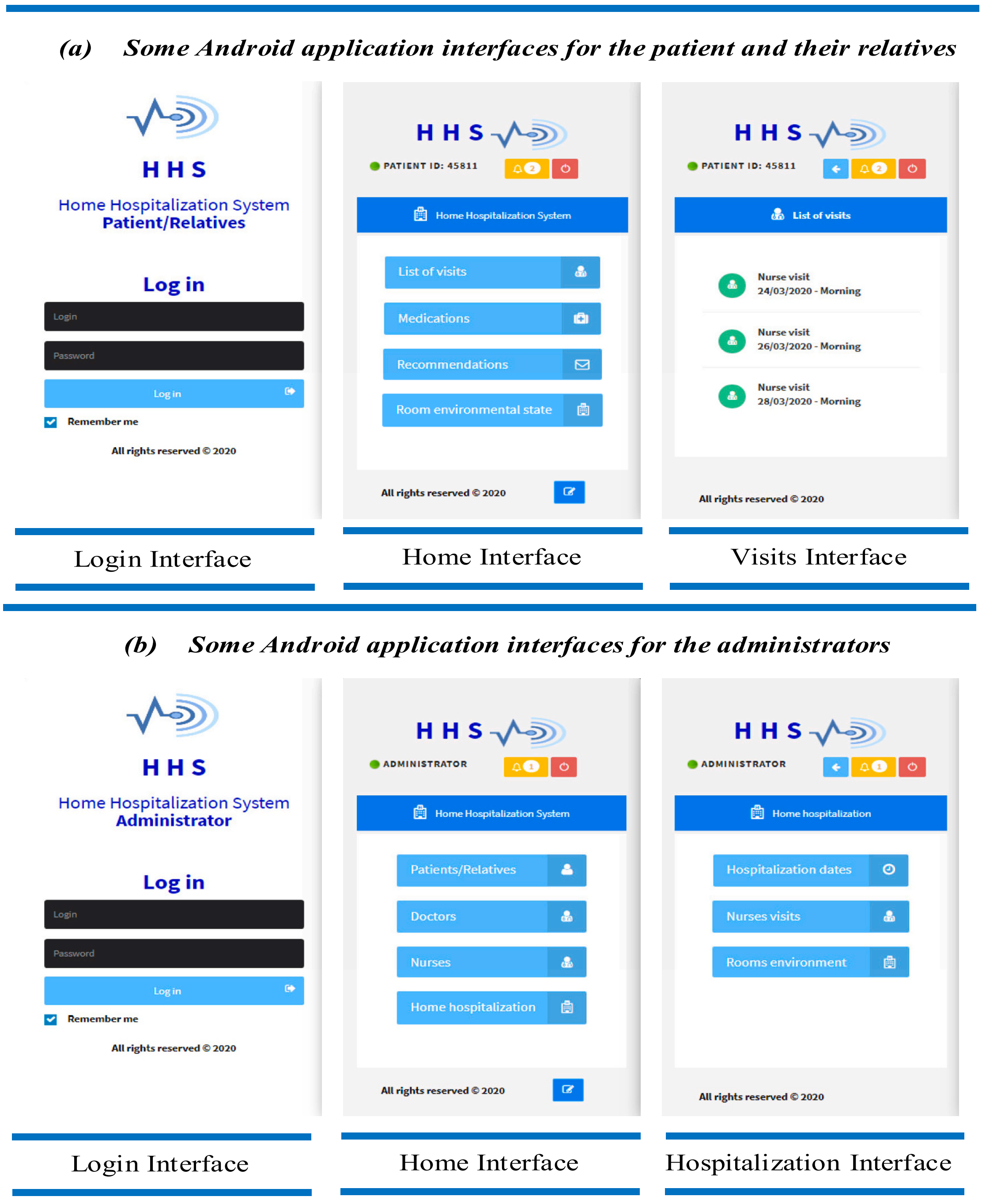

Fig. 9. Some Android application interfaces for the patient and their relatives and the administrators.

computing, and Cloud computing have been proposed. This system allows patients to recover and receive treatment in their homes and among their families, where the patients' health and the environmental factors of the hospitalization rooms are monitored periodically, through a vital signs sensing unit and environmental sensing units that are installed in the hospitalization rooms and mobile applications developed for this purpose. This system also enables doctors, patients, and their family members to manage and monitor hospitalization operations through their mobile applications. The home hospitalization system proposed in this paper is distinguished by its low cost, reliability, and safety in addition to its ability to solve the problems currently witnessed in hospitals, as it can substantially reduce the burden on them. This system has received very good acceptance by patients and doctors alike according to the results of the usability evaluation.

As future work, changes will be made to this system to make it more appropriate to the quarantine operations of coronavirus patients, as we will develop the patients' mobile application to enable them to measure vital signs by themselves, and we will add video communication between the patients and their supervising doctors via this application. We will develop also a smart bracelet that the coronavirus patients will wear. This bracelet measures the patient's temperature and pulse in real time and sends them to the Cloud for storage and analysis, to rescue the patient quickly in case his or her health condition is disturbed. This bracelet also sends the coordinates of the patient's location via GPS to the Cloud in real time to interfere if the patient violates the quarantine.

(a) SUS questionnaire

		Strongly Disagree 1	2	3	4	Strongly Agree 5
1	I think that I would like to use this system frequently.					
2	I found the system unnecessarily complex.					
3	I thought the system was easy to use.					
4	I think that I would need the support of a technical person to be able to use this system.					
5	I found the various functions in this system were well integrated.					
6	I thought there was too much inconsistency in this system.					
7	I would imagine that most people would learn to use this system very quickly.					
8	I found the system very cumbersome to use.					
9	I felt very confident using the system.					
10	I needed to learn a lot of things before I could get going with this system.					

(b) Calculation of the SUS Score

- For each of the odd-numbered questions, subtract 1 from the score.
- For each of the even-numbered questions, subtract their value from 5.
- Take these new values which you have found, and add up the total score. Then multiply this by 2.5.
- Then we get a general value of usability on a scale between 100 (excellent usability) and 0 (ease of use-free).

(c) SUS Score

SUS Score	Grade	Adjective Rating
>80.8	A	Excellent
68-80.8	B	Good
68	C	Ok
51-68	D	Poor

Fig. 10. The system usability scale (SUS).

Table 2
Patients' SUS score.

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
1	5	4	5	5	5
2	1	1	2	2	1
3	4	5	5	5	5
4	1	2	2	2	1
5	5	5	4	5	5
6	2	2	1	1	1
7	4	5	5	4	5
8	1	2	1	2	2
9	5	5	4	5	4
10	1	1	2	1	1
SUS score	**92.5**	**90.0**	**87.5**	**90.0**	**95.0**
Average SUS score			**91.0**		

Table 3
Doctors' SUS score.

	Doctor 1	Doctor 2	Doctor 3	Doctor 4	Doctor 5
1	5	5	5	5	5
2	1	2	1	1	2
3	5	5	5	4	5
4	1	2	2	1	1
5	5	5	4	4	4
6	2	1	1	1	1
7	5	5	5	5	5
8	1	1	2	2	1
9	4	4	5	5	5
10	1	1	2	1	1
SUS score	**95.0**	**92.5**	**90.0**	**92.5**	**95.0**
Average SUS score			**93.0**		

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Hafedh Ben Hassen: Conceptualization, Methodology, Software, Investigation, Writing - original draft. **Nadia Ayari:** Software, Investigation, Validation, Writing - review & editing. **Belgacem Hamdi:** Methodology, Validation, Project administration, Writing - review & editing.

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