Building an optimized remote healthcare monitoring scenario in order to alleviate the pressure of COVID-19 pandemic

Elena-Anca PARASCHIV, Marilena IANCULESCU, Mihail-Cristian PETRACHE

National Institute for Research and Development in Informatics – ICI Bucharest

elena.paraschiv@ici.ro, marilena.ianculescu@ici.ro, cristian.petrache@ici.ro

Abstract: COVID-19 pandemic has had a major impact on most aspects of everyday life and that has led to a significant faster evolution in the digitalization of medical services. Telemedicine and eHealth continue to provide solutions to mitigate this pandemic's effects, with the aim of helping isolated coronavirus patients, as well as people with chronic conditions. This paper presents how COVID-19 pandemic has been influencing the development of remote healthcare monitoring systems as a result of the need to maintain a remote communication between patient and medical specialist and to provide reliable care. In order to demonstrate how a remote healthcare monitoring scenario can be optimized and personalized according to the needs, specificities and the evolving health status of a patient, the building of the Healthcare Monitoring Component from the ongoing RO-SmartAgeing system is presented. This component, based on a series of medical sensors, connected to an Arduino board that collects and transmits data, through a Wi-Fi network, to the Fog/ Edge level, offers both the means to real-time monitor the patient's vital signs and to alert healthcare specialists in case of an abnormal measured value. The gathered information is filtered and then sent to a database in the Cloud allowing further analysis and health data-based applications to be provided. The benefits of this solution that allows the real time visualization of medical data, as well as its storage, processing and subsequent analysis are highlighted and correlated with the specificities induced by COVID-19 pandemic.

Keywords: remote healthcare monitoring, smart homes, sensors, COVID-19.

Conturarea unui scenariu optimizat de monitorizare la distanță a sănătății vizând atenuarea presiunii induse de pandemia COVID-19

Rezumat: Pandemia COVID-19 a avut un impact major asupra majorității aspectelor vieții de zi cu zi și acest lucru a dus la o evoluție semnificativ mai rapidă a digitalizării serviciilor medicale. Telemedicina și eSănătatea continuă să ofere soluții pentru atenuarea efectului acestei pandemii, cu scopul de a ajuta pacienții cu coronavirus izolați, precum și persoanele cu afecțiuni cronice. Această lucrare prezintă modul în care pandemia COVID-19 a influențat dezvoltarea sistemelor de monitorizare a stării de sănătate la distanță ca urmare a necesității de a menține o comunicare la distanță între pacient și medicul specialist și de a oferi îngrijiri de calitate. Pentru a demonstra potențialul monitorizării asistenței medicale la distanță, este prezentată Componenta de Monitorizare a Stării de sănătate din sistemul în curs de dezvoltare RO-SmartAgeing. Această componentă permite utilizarea senzorilor medicali ce pot colecta și transmite informațiile, printr-o rețea Wi-Fi, la nivelul Fog/Edge, oferind astfel posibilitatea de a alerta specialiștii din domeniul sănătății în cazul unei valori anormale măsurate. Informațiile colectate sunt filtrate și apoi trimise într-o bază de date din Cloud. Beneficiile acestei soluții care permite vizualizarea în timp real a datelor medicale, precum și stocarea, prelucrarea și analiza ulterioară a acestora sunt evidențiate și corelate cu specificitățile induse de pandemia COVID-19.

Cuvinte cheie: monitorizare la distanță a stării de sănătate, case inteligente, senzori, COVID-19.

1. Introduction

Digital healthcare technologies have undoubtedly proved to bring a major dynamic potential able to support a shift from the reactive approach of the traditional healthcare domain towards a proactive and preventative one. Furthermore, comprehensive, continuous reshaping and improvements of the healthcare services are facilitated by the tremendous advancements in the information and communication technology (ICT) domain, by a fast and broad implementation of

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the emerging technologies, and also by the wider acceptance of the digital technologies in the daily routines and activities.

Digital healthcare includes tools and technologies such as electronic health records, wearables for vital signs monitoring and activity tracking, mobile health applications, smart scales and chatbots (Accenture 2020 Digital Health Consumer Survey, 2020). It has gained popularity in the recent years due to the enhancing integration of data science and healthcare.

The storm that COVID-19 pandemic has brought all over the world is firstly having a huge impact at the level of medical and social domains, forcing them to accelerate the digitalization of the medical system, to make telemedicine be used on quite a regular basis, to develop and implement appropriate digital healthcare solutions or to better sustain innovations to optimize the outcomes and costs.

Remote healthcare monitoring (RHM) involves the use of digital technologies in order to support a more efficient medical care, to improve the link between healthcare providers and patients, to prevent the dysfunctionalities and abnormalities, to avoid unnecessary hospitalization, to increase the quality of the patients' life, their independence and health in a familiar place like his home. (Coardos & Marinescu, 2020).

A smart home enables a remote safe monitoring of the patient in an as less possible intrusive manner, which has proved to be a reliable alternative for taking care of the patients, including the coronavirus ones, in an efficient manner, alleviating the medical systems from the pressure and burden brought by the COVID-19 pandemic.

In 2020, the COVID-19 pandemic struck the entire world with direct and dramatic repercussions and compulsory changes both at social and economic levels, and individual one. Suddenly, the healthcare systems have faced the urgent need to accelerate the acceptance, implementation and use of digital healthcare technologies, including the remote healthcare monitoring. People were forced either to isolate themselves (almost) completely during lockdowns, or to accept the social distancing. Furthermore, the monitoring and treatment of most of the other diseases, except the coronavirus one, were put on a second level, as the clinical units were directed to treat with priority the patients with COVID-19.

Although the benefits of the healthcare remote monitoring had already been accepted and its development had been pushed up by the widespread use of the Internet of Things (IoT)-based devices, before the COVID-19 pandemic global beginning, the healthcare remote monitoring couldn't gain its rightful adoption. Among the most relevant reasons for this limitation were: the lack of appropriate regulations, standards, budget or IT literacy, the inadequate access to (smart) devices, and also some unsolved technological issues like interoperability and cybersecurity. In the context of the current pandemic, the need to provide a sustainable management of the health status both for the coronavirus patients and for the other patients with chronic diseases has led to an expansion of RHM.

The main strengths provided by the broadly use of RHM are: it provides support for diagnostic and improved therapeutic protocols decision-making, especially if it is based on Artificial Intelligence for predictions (Kapoor A. et al., 2020); it sustains the shift from the traditional reactive healthcare approach to a proactive one; it ensures a more equal and qualitative access to medical care for a larger range of patients; it strengthens the link between the healthcare providers and the patients, with direct implications on the patients' health education and empowerment regarding their own health status.

During COVID-19 pandemic all these capabilities were intensively used and completed with opportunities like: the proactive monitoring of the quarantined coronavirus patient, limiting thus the others' exposure to the virus; tracking the (potential) contagious patients; safeguarding the healthcare providers against being infected; increasing number of patients that can be taken care of by a single physician.

Even if the COVID-19 pandemic had such a big impact on the utilization of digital healthcare technologies, it is not uniform among different categories, as it can be seen in Figure 1.

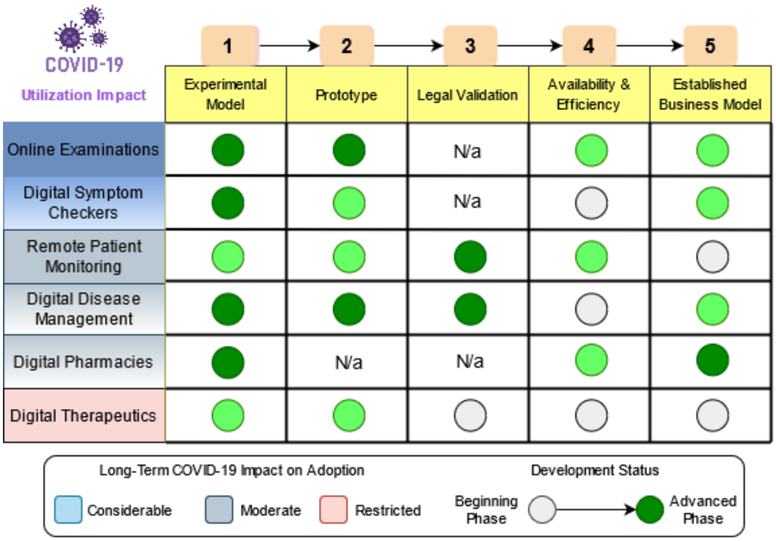

Figure 1. Impact of COVID-19 pandemic on different DHSs
(Source: adapted from Matzkin A., 2020)

However, despite the drawbacks, there is no doubt that the RHM is a valuable support for the provision of healthcare services and that is will continuously evolving to meet the needs both for the patients and healthcare providers.

The main purpose of this paper is to present an underdevelopment digital solution able to highlight how the remote healthcare monitoring can be perceived as a dynamic scenario to provide appropriate, continuous and effective healthcare services in the context of the COVID-19 pandemic. The paper is organized as follows: Section 2 briefly reviews some relevant related works from the current literature. Section 3 presents how RHM can be facilitated through smart homes, especially during the current pandemic. For a practical demonstration, it is illustrated how the capabilities of the Healthcare Monitoring Component from the ongoing RO-SmartAgeing project can be enlarged. In Section 4 the expected results of the proposed technical solution are discussed. In Section 5 some conclusions are drawn and the future work directions are presented.

2. Literature review

Throughout the past year, as the world has faced an unprecedented global pandemic, governments were forced to prompt a state of emergency and a mandatory lockdown in order to end the virus' spread, these methods being considered the most efficient during those times. As a response to this pandemic, appropriate technologies as IoT have been used for the implementation of different monitoring systems in order to support the communication between patients and their caretakers or doctors. That is why, RHM devices have been deployed not only for the infected patients, but for people who work or stay at home, as well. In this context, IoT technologies, including wearable sensors and medical devices, have proved to have a vital role for the early detection of certain COVID-19 specific anomalies. As patients' symptoms may differ from one another and their vital signs can suddenly change, remote monitoring systems are critical and essential for managing this pandemic. Therefore, a considerable number of studies have shown the impact an RHM system may have and its importance in alleviating the pressure of COVID-19 pandemic.

Considering that IoT represents a promising solution in the advancements made in the eHealth area, another interesting system is presented in (Băjenaru et al., 2020) and it consists in a technological integrated platform for non-intrusive monitoring and assistance services. This platform ensures that all the gathered data collected from the IoT devices (smartwatch, smart insole, depth camera and quality of life analysis forms) are received and sent to other services to be further stored, visualized, analyzed or used to trigger a response for other devices, making it an available and scalable system.

A remote patient monitoring program was also implemented in New York by (Tabacof et al., 2020) and it implies the development of a system which aims to monitor the physiology and symptomatology of confirmed or suspected COVID-19 patients, through precision recovery. Thus, an application that collects physiological data and symptoms information, via an intelligent device, was deployed, making it possible for the clinicians to visualize the data in order to guide the patient to a weekly video call, in case of low risk of respiratory diseases or to an immediate video call with a qualified physician in the case of a high risk for certain respiratory deteriorations. The patient would be further guided to home care supervision, to a medical specialist or to the emergency, depending on the physicians' diagnostic. This method was applied on 112 patients in order to establish the most frequent mild to moderate symptoms (dyspnea, anxiety or chest pain), proving that remote healthcare monitoring services not only help the patients in need, but they also broaden the knowledge of researchers and medical specialists.

Furthermore, a system aiming to limit the spread of COVID-19 was developed by (de Lima et al., 2020) and it involves the implementation of an application which has the function of real time examination, prediction and spatial vision for COVID-19 in Brazil, this country being one of the most affected as a consequence of this pandemic. The COVID-SGIS system gathers all the COVID-19 information captured from 27 federative units using the Brazil.io database and, based on the integrated time series ARIMA models, it was implemented an algorithm for the prediction of the confirmed cases of positive Covid-19 and total deaths, with a 6-days projection. The results shown a confidence interval of 95% with an error, related to the predicted and the actual values, between 2.56% and 6.50%, providing a cost-efficient, compendious and stable method in order to address tot this situation accordingly.

Another program that has implemented a remote patient monitoring for COVID-19 patients is described in (Aalam et al., 2021) and it is based on software platforms (Power Automate, Forms and Quickbase) that assures the security of the transmitted data in order to respect the patients' privacy and protection. The daily surveys are sent to the discharged COVID-19 patients with simple and essential questions and the corresponding data is automatically analyzed and eventually flagged out in case of emergency or respiratory deterioration-related answers. This telehealth method can provide a safe and valuable evaluation as it enables the prevention of unnecessary exposure.

Therefore, the continuous development of IoT technologies towards the healthcare sector has become an important tool in order to take care remotely of patients. The implementation of such systems has proven an incredible efficiency during this pandemic and they are likely to be further used and deployed much more in the near future. The aforementioned remote monitoring-related works have been performed in order to help COVID-19 patients, disregarding their symptoms, to keep their vital parameters in normal ranges and to also maintain the communication between patient and the medical specialist. In addition to these studies, RO-SmartAgeing project aims to remotely monitor a patient's health parameters and send the corresponding data to the doctor as to be further visualized and analyzed.

3. Facilitating healthcare monitoring through smart homes

3.1. RO-SmartAgeing, a system sustaining ageing-in-place

3.1.1. Brief description

"Non-invasive monitoring and health assessment of the elderly in a smart environment (RO-Smart Ageing)" is an ongoing project that is in its software development phase. As the ageing-associated degenerative processes have quite a high dynamic that affect the lifestyle, health and independence of a senior, the RO-SmartAgeing system aims to provide both a personalized, flexible and scalable solution for monitoring a senior in a customized smart environment that is adapted for his home, and healthcare support services able to improve the real-time management of the senior health status, the quality of his lifestyle and the physician-caretaker-patient relationship. RO-SmartAgeing system has a hierarchical structure in order to provide distinct functionalities.

3.1.2. Enlarged capabilities of Healthcare Monitoring Component in the context of COVID-19 pandemic

Among its several components and modules, the RO-SmartAgeing system comprises a Healthcare Monitoring Component (HMC) that allows the collecting of several main important senior's health and ambient parameters through some devices from the smart environment, which is personalized and set up periodically according to the evolution of the senior health status.

This HMC has the potential to be further adapted and improved in order to enlarge the type of patients that can be monitored in a familiar place, as their home. This aspect can have a considerable importance taking into consideration the fact that during the pandemic some clinical units have been closed for other patients than coronavirus ones (so there were fewer resources for examining and treating them), that a great number of patients must be under a strict continuous monitoring, that people suffering from COVID-19 are at risk of a sudden and severe deterioration of their health and that it is compulsory to avoid as much as possible the institutionalization in order to preserve the hospital beds available for sicker persons. Moreover, remote examinations and access to the patient's vital sign parameters allow not only to keep the patients and healthcare providers coming into contact, but also a better insight to the patient's personal conditions and evolution.

3.2. Overview of the proposed Healthcare Monitoring Component

The Healthcare Monitoring Component has as its main objective the management of some health and ambient parameters, starting from their collecting through a number of wearable sensors and health monitoring devices, to the transmission of them to the cloud, in order to be processed, analyzed and stored.

HMC comprises the collection, management, storage and transmission of all data provided by the above-mentioned technology connected to an Arduino Mega or by independent devices such as sphygmomanometer, glucometer, smart watch, sleep monitoring device or smart scale. From the point of view of data transmission, HMC is accessed by the system administrator; the other authorized users aren't allowed to view it, they can only interact with sensors – be they wearable or not. Some of the monitoring devices can be placed for measurement on different areas of the patient's body. From the point of view of medical data configurations and management, the physician/healthcare provider is the particular authorized user who is allowed the access.

3.2.1. The early phase of development: identifying the most appropriate monitoring devices, IoT, sensors

Taking into account that wearable medical devices and telemedicine have proven encouraging performances in managing the communication between patient and doctor, and also the deployment of remote patient monitoring - which provides a viable and quick transmission of healthcare data -, different scalable and manageable IoT devices designed to support a better lifestyle of people, not only in terms of COVID-19 pandemic, have been developed.

- **MySignals – The first option**

Therefore, as a consequence of a market research carried out in 2019 by the project team in order to identify reliable and slightly invasive solutions for the HMC of RO-SmartAgeing system, a device that met most of the system's requirements was selected. Eventually, it proved to have noticeable drawbacks.

At the beginning of the research, MySignals, a platform based on IoT sensors and eHealth applications (MySignals HW v2, 2021), has turned out to be one of the most effective solutions used in research up to that moment. It allows the measurement of 20 health parameters (as the blood oxygen level, heart and breath rate, electrocardiogram signal, blood pressure, glucose level etc.) providing the real time visualization of the gathered data in a MySignals application, to the user's account via Wi-Fi or Bluetooth, making it possible for the patient to share the quantified data with the doctor. This system facilitates the remote communication between doctor and patient and it also enables the connection with third parties through the Libelium's API, in order to provide the development of other web application, but with additional costs.

MySignals Hardware

MySignals board includes the micro-controller, power supply and sensors circuits, Bluetooth and Wi-Fi modules and Jack connectors for the specific sensors which measure the following relevant parameters: Electrocardiogram (ECG), Airflow, Blood Pressure, Glucometer, Body Temperature, Electromyogram (EMG), Volumes of air (inspired and expired), Galvanic Skin Response, Body Position, Snore's vibrations, Pulse and Oxygen in blood (SpO2). Each sensor has to be attached to the specific jack connector in the board in order to function properly. The MySignals board operates when it is coupled with Arduino UNO board, enabling thus the uploading of the specific C++ code so as each sensor might function and show the real-time parameters.

MySignals Software

Libelium MySignals includes a development platform that can be adapted to any health monitoring system requirements. The platform is based on Arduino UNO and it requires the download of C++ libraries that allow the sensors' reading in order to control and send the relevant information to the Libelium Cloud.

As it is shown in Figure 2, this data can be visualized via Bluetooth, on the patient's smartphone/ tablet or it can be sent via Wi-Fi to a Third-Party Cloud (directly through the MySignals board or based on the patient's device) in order to be visualized and processed for another medical application.

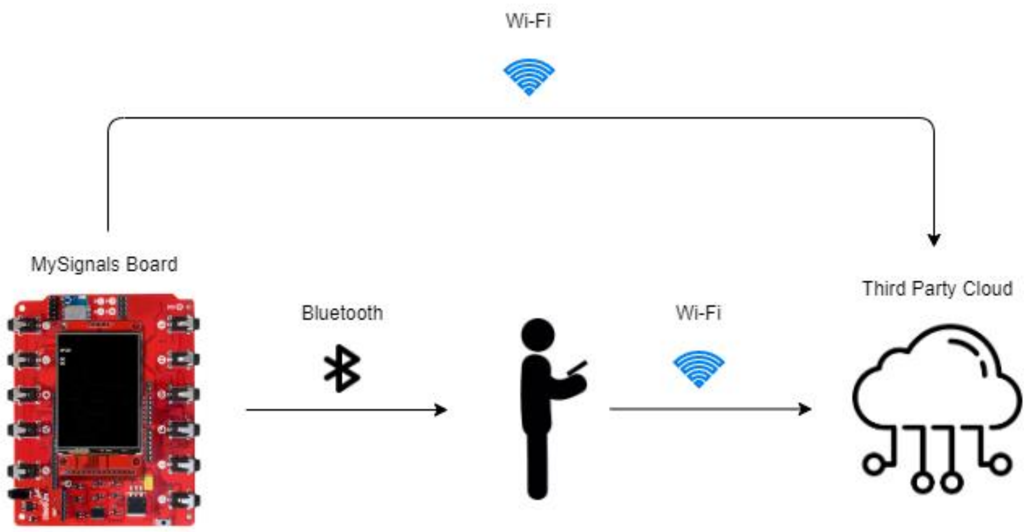

Figure 2. The data flow for MySignals platform (Source: own)

All of the hardware components of MySignals have their own downloadable code which requires the import of it, through the open-source Arduino Software (Arduino IDE), in order to be further uploaded on the Arduino board, consequently with the MySignals board. This represents the deployment of the first steps of the monitoring platform assembling, providing a smart and easy system for the development of any eHealth applications.

Benefits and Drawbacks of MySignals development platform

It can be generally assumed that MySignals is one of the most developed platforms as it uses a large number of sensors and it provides prerequisite solutions in order to be further developed by other users for personalized eHealth applications. It also benefits from a user-friendly, functional smartphone application which allows the real-time data visualization, making possible for any patients to be aware about their own health.

However, the cost for purchasing one of these kits is not largely accessible, and the development based on the data gathered in the Libelium Cloud requires an annual fee in order to obtain the access to MySignals Cloud API.

Taking all these restrictive aspects into account, it was finally decided not to select MySignals as RO-SmartAgeing development platform due to the fact that the above-mentioned drawbacks might extemporarily compromise the implemented system.

Furthermore, the latest update (in April 2021) on MySignals website specifies that the device is no longer available, which might have led to a huge inconvenience regarding the further use and development of the RO-SmartAgeing system if MySignals platform had been chosen.

- **The RO-SmartAgeing medical blackbox – The selected solution**

Given the circumstances, it has been decided that the best solution for the development of HMC from the RO-SmartAgeing system was to create a personalized device with independent, low-cost, Arduino-compatible sensors that can be assembled and used to monitor different health parameters. The sensors used for this component are described in Table 1.

Table 1. RO-SmartAgeing medical blackbox's sensors

Parameter	Sensor	Characteristics
ECG	AD8232 – Single Lead Heart Rate Monitor	• It measures the electrical activity of the heart muscle; (adapted from Single-Lead, Heart Rate Monitor Front End, AD8232, Data Sheet).
Pulse and Oxygen in Blood	Sparkfun Pulse-Oximeter MAX30101&32664	• It contains a pulse oximetry and heart rate module, internal LEDs, photodetectors, low-noise optical and electronic elements with ambient light rejection property; (adapted from SparkFun Pulse Oximeter and Heart Rate Monitor Hookup Guide).
Body Temperature	DS18B20 Temperature sensor	• The temperature measuring range: –55 ° C - +125° C. (adapted from Programmable Resolution 1-Wire Digital Thermometer, DS18B20, Data Sheet).
Volatile Organic Compounds from breath	MQ3 Alcohol sensor	• It is used to detect the concentration of volatile organic compounds from breath; • It detects: alcohol, benzene, methane, hexane, carbon monoxide etc. (adapted from MQ3 – Gas sensor, Data Sheet).
Urine biochemistry	TCS3200 colour detection sensor	• It can detect, based on urine strips, different parameters of urine biochemistry; (adapted from TCS3200, TCS3210 Programmable Color Light-To-Frequency Converter, Data Sheet).

These sensors were interconnected with an Arduino Mega board, as it is presented below in Figure 3, in order to collect the data from them, and a NodeMCU ESP8266 module designed to send the gathered information, via Wi-Fi, to the gateway device.

A Raspberry Pi 4 Model B represents the gateway device and it has both the role of receiving the relevant data from the sensors, through Arduino and NodeMCU 8266 module, and the role of sending all of this information to the Cloud, in order to be processed and visualized.

An LCD is programmed to display the parameters capable of being measured by the medical blackbox and, with the help of the keypad, the user is able to press the corresponding key for measuring the desired parameter, providing the corresponding information with a 10 seconds delay.

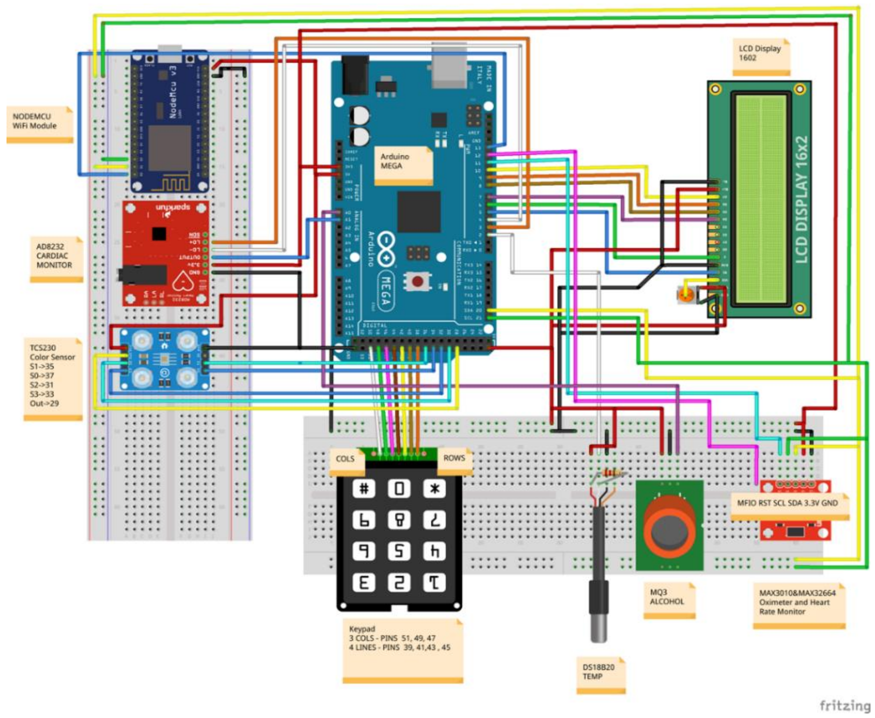

Figure 3. The interconnected sensors for the Medical blackbox (Source: own)

A CAD software was used to design the blackbox for the healthcare monitoring component based on the specific measurements of the elements: the printed circuit board (PCB), sensors etc. This medical blackbox is pictured in Figure 4 which depicts the front view of the medical blackbox: the LCD display shows the parameters that can be measured (1 – Temperature; 2 – Alcohol; 3 – Pulse and Oxygen Saturation; 4 – EKG; 5 – Spectrogram); the Sparkfun Pulse-Oximeter is placed as to be accessible for the user's finger; the keyboard is used to specify the desired parameter to be measured; the MQ3 alcohol sensor allows the detection of the volatile compounds' concentration; the TCS3200 colour detection sensor is being covered as to not register data from the environment.

An important thing to note is that RO-Smart Ageing's medical blackbox includes the Pulse-Oximeter sensor, which is essential in terms of COVID-19 pandemic as it can early detect any decrease in the blood oxygenation of the staying-at-home coronavirus patient. So, it is of great importance to daily monitor the saturation of oxygen and to automatically send this information to the personal doctor or caretaker in order to prevent any deterioration of health status. The RO-SmartAgeing system is particularly provided with this capability.

Figure 4. The medical blackbox of the healthcare monitoring component (Source: own)

3.2.2. Healthcare Monitoring Component architecture

The functionality for allowing smart devices and sensors to communicate with each other or with a user has been broadly developed lately, notably in the healthcare domain, and it has been integrated in the concept of IoT (Florian et al., 2018), especially through the deployment of remote monitoring systems. IoT can be defined as the interaction between the real environment and the digital one, as well as the integration of the system's sensors, in order to accomplish complex functions which require a higher degree of intelligence. In this context, the Healthcare Monitoring Component of the RO-SmartAgeing system was designed based on an IoT architecture (Ianculescu et al., 2020). It has been chosen the most appropriate configuration of this monitoring system that relies on sensors, Wi-Fi networks, Fog devices and Cloud infrastructure in order to store, process and visualize the patients' vital parameters. This architecture consists of 5 layers, designed in Figure 5.

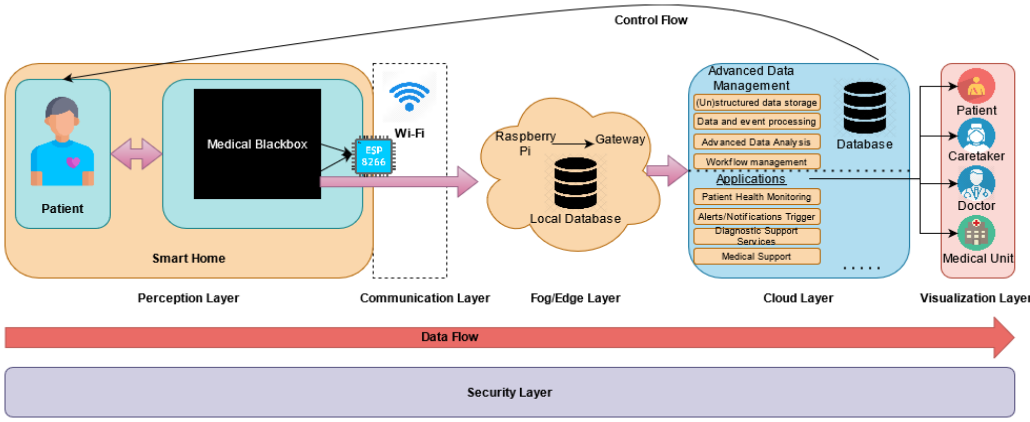

Figure 5. The Healthcare Monitoring Component architecture (Source: own)

The *Perception* layer contains the medical blackbox and the information gathered from the patient based on the medical blackbox's connected sensors. It aims to obtain the most appropriate health parameters, chosen according to the current needs and specific requirements of the staying-at-home patients.

As mentioned above, the RO-SmartAgeing medical blackbox is currently transferring data based on the NodeMCU ESP8266 (connected to the Arduino board, both being integrated in the blackbox) via Wi-Fi to the gateway, which is represented by the Raspberry Pi assigned to that specific patient, taking into consideration the Fog/Edge server. Thus, the *Communication* layer is developed, and the main protocol is established through the Wi-Fi network. The *Fog/Edge* layer provides capabilities of local analysis, validation, pre-processing and local storage. One of the main characteristics of the Fog/Edge's local analysis, in this system, is that it has the capability of detecting abnormal values of the gathered parameters, triggering an alarm for any critical situations. This feature of Fog/Edge Computing is essential in terms of COVID-19 disease, as the blood oxygen level of a patient can suddenly decrease, so an alarm message sent in this situation could be of crucial importance. At the same time, if there are no signs of instability and the sensors collect normal values, the data is pre-processed and sent to the Cloud. The filtered data is transmitted to the *Cloud* layer which includes an advanced data management based on the storage, analysis and processing of the received information, as well as an efficient workflow management, in order to provide the most appropriate services. It is also the component that enables the implementation of certain applications designed for this dynamic and valuable system: remote health monitoring, medical and diagnostic support. The information received from the *Perception* layer goes through all these steps in order to be stored and analyzed in the Cloud, allowing thus the patient and the caretaker, doctor and clinical unit to visualize it and provide the required assistance.

3.2.3. A healthcare monitoring scenario

This section presents an understanding of the functionality of RO-SmartAgeing Healthcare Monitoring Component and the way it is managed for measuring the pulse and the oxygen saturation, two of the most valuable parameters in terms of COVID-19 pandemic. As it is still in its early stages, this component was only tested to monitor the mentioned parameters and send the data to the Cloud. In addition to this, the deployment of the alarm setting application and the optimization of these sensors are stipulated as a future work. As it was previously described in Table 1 and shown in Figure 4, the medical blackbox provides a series of sensors meant to gather all the relevant data and send it to the next layer. Once the device is plugged in, the LCD display lights up and the blackbox waits for the patient to use one of the sensors.

In the context of COVID-19 pandemic, it was established that the most used sensor for every coronavirus patient was the pulse oximetry, the blood oxygenation level being an important measurement as it is able to provide information relevant for controlling this disease. Figure 6 shows a test for measuring the pulse and saturation of the oxygen in blood (SpO2) parameters, displaying a value of 91 beats per minute (bpm) and a concentration of 96% for the level of oxygen in the blood, after a patient places a finger on the sensor.

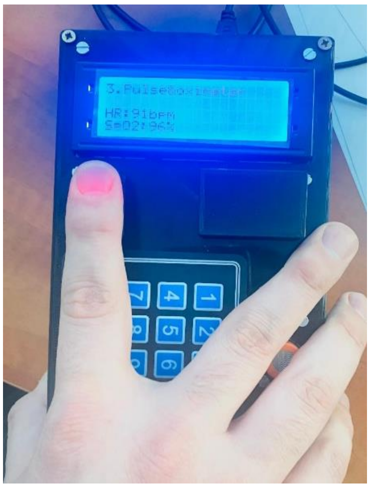

Figure 6. Medical blackbox test for measuring pulse and blood oxygenation level (Source: own)

The sensor used for this implementation contains two chips: MAX30101 and MAX32664. The first one performs the detection using its internal LEDs which emit a light to the arteries and arterioles in the subcutaneous layer of the patient's finger in order to sense, based on the photodetectors, the quantity of absorbed light, process called photoplethysmography. MAX32664 receives and analyzes this information and applies its algorithms to compute and determine the heart rate and the SpO2. This implementation is being possible due to the Arduino Library developed for this sensor which is previously uploaded on the board. In order to stop the measurements, the device needs to be plugged out. The data is then being transferred to the gateway (Raspberry Pi) which has the Fog/ Edge role, filtering the information based on the received values, further sending the data to the Cloud server as to be stored in the patient's file and to be visualized later by the medical specialist, caretaker or even the patient himself.

4. Results and discussion

Many recent research studies (and experiments) were performed for assessing the use of IoT technologies in the medical field and RHM systems have proven to be efficient solutions. In this context, RO-SmartAgeing can be easily identified as a solution for building a personalized smart home for an elderly patient.

In the current stage of the ongoing system, the project team has designed the RO-SmartAgeing system, has identified and acquired the most appropriate IoT-based technologies and devices, has built a specific medical blackbox for gathering several vital signs, and has developed the first version of the Healthcare Monitoring Component. Moreover, due to the COVID-19 pandemic threats and consequences, a special importance has been put on providing solutions for monitoring the health parameters able to provide vital information about a possible coronavirus infection or evolution.

The proposed solution is based upon a series of sensors connected to an Arduino board with the important capability of sending the relevant information to a local database. The applicability of the delivered system is then tested on a patient, providing 96% SpO2 concentration and a pulse of 91 beats per minute.

These first practical results demonstrate that one of RO-SmartAgeing main functionality provided by the HMC that comprises the customized RO-SmartAgeing medical blackbox, can fully support an optimized remote healthcare monitoring scenario due to the healthcare data collected in a controlled, personalized and secured manner. The data is further transferred to the Fog/ Edge server, represented by the assigned Raspberry Pi, where it is locally analyzed, and then it is stored in the Cloud's database, being available for visualization, advanced analysis and processing.

According to the needs and specificities of the patient, the monitoring scenario can be customized and adapted according to the changes in the patient's health status. Although this paper mostly highlighted the RO-SmartAgeing medical blackbox, associated applications based on the collected health data are being developed. Thus, some of these ones provide the doctor with the capabilities to remotely reconfigure the devices from the smart home environment, to establish the most appropriate parameter measuring intervals or to access various reports based on stored data.

The alarms triggered in case a vital sign parameter has an abnormal value are managed in the Fog layer in order to implement a faster response, as this layer is closer to the source of data, namely the patient. Moreover, the periodical measurement of these medical parameters allows a clearer image of the health status evolution and facilitate preventative measures even if a slightly deterioration is perceived. During COVID-19 pandemic, this RHM allows patients with chronic conditions or coronavirus to get the care they need while keeping them out of hospitals, both for their protection, and of the medical staff. A key aspect of the RHM from the RO-SmartAgeing system is the ability to set parameters between two or more different vital signs, such as oxygen saturation, respiratory rate and heart rate, in order to decrease the number of false positive alarms coming through the system. These alarms can be set for a range of patients and customized for a specific person.

However, there are several limitations to this approach due to the early stages of the system's implementation. The final HMC, meant to interconnect the ambient and the medical modules, is not yet accomplished, therefore the Cloud database is not completed, nor does the trigger transmission application. Some difficulties have been encountered with the measurements provided by the Pulse oximeter, therefore a more accurate calibration should be done.

5. Conclusion and future work

Remote healthcare monitoring implies the use of specific medical devices to monitor the patients' health status outside the clinical units. Avoiding as much as possible the hospitalization while having access to high quality and safe healthcare has become a stringent necessity since the COVID-19 pandemic spread. Based on the aforementioned results, the RO-SmartAgeing's medical blackbox proves to be an improving tool in the detection of healthcare parameters measurements as it is composed of several medical sensors which are capable of sending the acquired data for further storage and analysis.

The proposed solution clearly emphasizes the importance of a monitoring system in terms of COVID-19 pandemic and it offers an experimental model of such a system that both elderly people or other types of patients can benefit from.

In light of all of the foregoing, this paper aimed to present an early development version of the Healthcare Monitoring Component from the RO-SmartAgeing system, together with its benefits, enlarged possible functionalities, and opportunities to become a common medical service support both for patients with different pathologies and their doctors.

As a future approach, RO-SmartAgeing system will be further developed based on its settled objectives, being also constantly reconfigured according to the actual advancements of smart IoT sensors and devices. HMC will be enlarged by including a blackbox for gathering ambient parameters and other Wi-Fi medical devices like a sleep analyzer and a smart scale. The data stored in the Cloud will be used in specific applications targeting a large range of needed functionalities for a personalized management of the health status of the patient.

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Elena-Anca PARASCHIV is a Software Engineer in the "Digital Applications in Health" Service at National Institute for Research and Development in Informatics - ICI Bucharest and a master's student in "Intelligent Systems and Computer Vision" at the Faculty of Electronics, Telecommunications and Information Technology, University Politehnica of Bucharest. She graduated from the Faculty of Medical Engineering, University Politehnica of Bucharest and the research fields and topics of interest include artificial intelligence applied in the medical field (processing and analysis of medical images and medical data), telemedicine and the development of healthcare equipment.

Elena-Anca PARASCHIV este inginer de sistem software în Serviciul *„Aplicații digitale în Sănătate"* din cadrul Institutului Național de Cercetare-Dezvoltare în Informatică - ICI București și studentă la masterul *„Sisteme inteligente și vedere artificială"* din cadrul Facultății de Electronică, Telecomunicații și Tehnologia Informației, Universitatea Politehnica din București. A absolvit Facultatea de Inginerie Medicală din cadrul Universității Politehnica din București. Domeniile și subiectele de interes pentru activitatea de cercetare cuprind: inteligența artificială cu aplicații în medicină (prelucrare și analiză de imagini și date medicale), telemedicina și dezvoltarea de echipamente pentru asistență medicală.

Marilena IANCULESCU is Senior Researcher III and Head of “Society-Oriented IT Systems and Applications” department in National Institute for Research and Development in Informatics – ICI Bucharest. Graduated from the Faculty of Automatic Control and Computer Science, University Politehnica of Bucharest. Currently, she and PhD student at Computer Science Department, University Politehnica of Bucharest. Expertise sector: eHealth & eInclusion, eLearning, eBusiness, web applications, database systems. She has an extensive experience in project management and software development. She has coordinated and participated in national research projects, mainly in eHealth domain. She was reviewer for several journals and conferences. She is author/coauthor of more than 100 scientific papers published in Romania and abroad. She has received several awards for excellence in eHealth.

Marilena IANCULESCU este Cercetător Științific gradul III și Șef al Departamentului „Sisteme și Aplicații pentru Societate” din cadrul Institutului Național de Cercetare-Dezvoltare în Informatică - ICI București. A absolvit Facultatea de Automatică și Calculatoare, Universitatea Politehnica din București și este doctorand la Departamentul de Calculatoare şi Tehnologia Informaţiei, Universitatea Politehnica din București. Sectorul expertizei: eHealth & eInclusion, eLearning, eBusiness, aplicații web, sisteme de baze de date. Are o vastă experiență în management de proiecte și dezvoltare software. A coordonat și a participat la proiecte naționale de cercetare, în principal în domeniul eHealth. A fost recenzor pentru mai multe reviste și conferințe. Este autor/ coautor a peste 100 de lucrări științifice publicate în România și în străinătate. A primit mai multe premii pentru excelență în eHealth.

Mihail-Cristian PETRACHE is a Programmer of "Society-Oriented IT Systems and Applications" department in National Institute for Research and Development in Informatics – ICI Bucharest. He graduated from the Faculty of Industrial Engineering and Robotics, UPB Bucharest. His research fields and topics of interest include eHealth, eCulture, Computer Aided Design, web applications and Internet of Things.

Mihail-Cristian PETRACHE este programator al departamentului „Sisteme și aplicații informatice orientate spre societate” din cadrul Institutului Național de Cercetare-Dezvoltare în Informatică - ICI București. A absolvit Facultatea de Inginerie Industrială și Robotică, Universitatea Politehnica din Bucureşti. Domeniile sale de cercetare și subiectele de interes includ: eHealth, eCulture, Computer Aided Design, aplicații web și Internet of Things.