Non-invasive Wireless Mobile System for COVID-19 Monitoring in Nursing Homes

Marta Botella-Campos[1][a], Sandra Viciano-Tudela[1], Sandra Sendra[1,2][b] and Jaime Lloret[1][c]

[1]*Instituto de Investigación Para la Gestión Integrada de Zonas Costeras (IGIC), Universitat Politècnica de València, Camino de Vera, S/N. 46022, València, Spain*

[2]*Departamento de Teoría de la Señal, Telemática y Comunicaciones (TSTC), Universidad de Granada, C/ Periodista Daniel Saucedo Aranda, S/N, 18014, Granada, Spain*

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Abstract: The recent global pandemics are generating serious problems in the elderly population and those who suffer from previous ailments. When a person is infected, he / she is usually isolated from the rest of persons in his / her room to avoid transmitting the virus. In most cases, especially those who live in nursing homes, often remain in bed with difficulties in moving. So, their monitoring and control of evolution is sometimes difficult. To solve this problem, this paper presents a non-invasive wireless mobile system to monitor elderly people in nursing homes. The system is composed by an electronic device with several sensors to monitor vital signs such temperature, cough, blood pressure, heart rate, oxygen saturation and, difficulty breathing of patients and an Android application to manage the medical data. Additionally, the system uses a local server to store the data and provide it to the nurses and physicians. Both the application and the process of collecting data have been tested together to check the correct generation of alerts and patients' labelling of degree of urgency.

1 INTRODUCTION

In late 2019, a new virus belonging to the Coronaviridae family SARS-CoV2 (severe acute respiratory syndrome coronavirus 2) was detected in Wuhan. Prior to the presence of this new outbreak, SARS-CoV (Severe Acute Respiratory Syndrome Coronavirus) emerged in November 2002 in the Chinese province of Guangzhou, causing severe respiratory syndromes among the population, and the MERS-COV (Middle East Respiratory Syndrome-related Coronavirus) gave rise to the acute respiratory syndrome in the Middle East.

Recent studies show that the new SARS-CoV2 shares 94.6% of aa (amino acids) with the previous SARS-CoV in the seven replicase domains conserved in ORF1ab, used for the classification of CoV species. For this reason, the new virus has been classified as SARS-CoV2, thus indicating that both belong to the same species (Zhou, 2020a).

Although the origin of this virus is not yet clear, it seems to have a zoonotic origin. That is, it is believed to have been caused by an animal infecting a human. A wide range of species have been considered to be precursors of this infection, though the hypothesis that has become more relevant is that this virus originates from a species of bat. Despite several studies show that there is a high identity relationship between the short region of RNA-dependent RNA polymerase (RdRp) of a bat coronavirus (BatCoV RaTG13) for 2019-nCoV, there is a discrepancy between different authors (Zhou, 2020b), and some of them point out that the origin is in the pangolin species.

Whichever the origin of the virus may be, the damage it can cause is becoming more relevant over time. Since the entry of the virus in multiple countries, the pandemic is causing a health crisis to try and stop the number of infections and deaths. The high number of cases worldwide is due to the fact that

[a] https://orcid.org/0000-0002-1317-286X
[b] https://orcid.org/0000-0001-9556-9088
[c] https://orcid.org/0000-0002-0862-0533

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this virus has a high contagion capacity, while SARS-CoV and MERS-CoV are caused by nosocomial infections (that is, within the hospital environment) (Guo, 2020).

As the studies progress, one of the most important aspects is to avoid further harm to the patient and even death. One of the most prominent symptoms that it produces is a severe pneumonia. However, other indicative symptoms of the disease may appear. According to one study, the manifestations of COVID-19 are fever (90% or more), cough (about 75%), and dyspnoea (up to 50%). A small but significant number of patients have gastrointestinal symptoms, and approximately 2% of the patients have acute Respiratory Distress Syndrome (ARDS), acute kidney injury (AKI) and myocardial injury (Jiang, 2020).

It should be noted that different risk groups have been established against COVID-19 taking into account the age of the population and the patient's clinical history. Among these risk groups, we find adults over 65 years of age, including those living in nursing homes, and people of any age with serious underlying conditions, such as: diabetes, asthma, and immunosuppressed people, among others. In addition, the number of asymptomatic patients who have the virus but do not show any symptoms must be taken into account. These individuals are carriers of the virus, causing new cases of contagion. The only way to detect the presence of the virus is by using rapid tests, in which many research groups are currently working on. Other valid tests are the reverse-transcription polymerase chain reaction (RT-PCR) tests, which is not only expensive but slow. However, it is also the most reliable. For this reason, some research groups are developing new detection methods such as Chest CT (Chest computed tomography) which is based on images that detect the presence of the virus. (Ai, 2020).

With the increasing availability of mobile phones, many research groups are developing massive data storage systems at a health level, intended to develop new technologies and communications networks to allow remote monitoring of patients. An example of this is the study carried out by Sendra et al. in 2018, where children with chronic diseases where monitored through an intelligent system. In this case, parents or caregivers receive an alert whenever there is an alteration of the parameters (Sendra, 2018a). Furthermore, Sendra et al. developed in 2018 an intelligent system based on LoRa, to observe babies' progress inside the incubators, by monitoring parameters such as humidity, temperature and weight (Sendra, 2018b).

Lloret et al. presented in 2017 an architecture for intelligent continuous monitoring of chronic patients using 5G. To do this, they used an automatic learning system with Big Data that used collected data from different hospitals, to compare it with the data received by the patient itself, and thus, be able to diagnose and generate alarms (Lloret, 2017).

Because of the severity of this disease, it is highly relevant to be able to anticipate disorders as soon as possible. In this paper, we aim to monitor patients infected with COVID-19 in nursing homes, as it is one of the most vulnerable risk groups. By developing an application that monitors different parameters such as: heart rate, oxygen saturation, temperature, blood pressure, dry cough, dyspnoea, chills and blood in urine, we intend to create a system able to alert doctors whenever necessary, in order to improve the quality of service given in care rooms. Moreover, the proposed solution will allow doctors to follow-up other subjective parameters such as: muscle pain, dizziness, expectoration of blood, etc. Furthermore, caregiver and doctors will be informed in real-time of the emergency level of the patient, by means of an alarm sent to their mobile phones.

The rest of this paper is structured as follows. Section 2 presents some previous works related on the proposal where similar existing systems and applications are presented. The proposed system is presented in Section 3. Section 4 presents results and the operation of our system. Finally, the conclusion and future work are presented in Section 5.

2 RELATED WORK

In this section, different applications developed to monitor, and control certain diseases are analysed.

Lopes et al. (Lopes, 2011) showed SapoFitness, an Android application that allows dietary monitoring and evaluation. To do this, the application records the user's health status daily, in addition to their food intake and physical exercise. To offer a greater experience, an alarm system was installed to inform the user of the best diet to follow according to their physical activity. Furthermore, it allows the user to share their achievements on social networks such as Facebook and Twitter.

In 2012, Årsand et al. (Årsand, 2012) developed a mobile health application to assist patients with diabetes. This application consists of a diary that allows patients with diabetes to receive personalized information to achieve objectives related to their health issues, with data being collected manually and through automatic wireless data transfer.

Park et al. (Park, 2016) developed a mobile application to predict the most relevant factors that produced migraines. To do this, a study of people who suffered from this disease was carried out. Participants were asked to download the application and introduce their data every time they felt a headache, by selecting among different factors. Sixty-two participants kept diary entries until the end of the study. The results showed that the most relevant common factors were stress, fatigue, sleep deprivation, hormonal changes, and weather conditions. Moreover, the type of factors and the medication used were proven to give a characteristic pain in each case.

Meanwhile, Hartzler et al. (Hartzler, 2016) showed NutriWalking (NW), an application focused on patients with type 2 diabetes mellitus and depression that allows them not only to maintain healthy nutritional habits, but also to provide personalized daily exercise goals for each user. In the future, they intend to improve this application to allow users to establish contact with each other through the development of a social network.

BENECA (Energy Balance on Cancer) mHealth is an application developed by Lozano-Lozano et al. (Lozano-Lozano, 2019). The objective of this application is to monitor the energy balance of people who have overcome breast cancer. In this study, eighty breast cancer survivors participated to obtain data of feasibility, pre-test and post-test differences regarding their lifestyles, quality of life, and motivation to perform physical activities. According to the results obtained, this study concluded that the quality of life of these patients can be improved through monitoring.

Garcia et al. (Garcia, 2019) proposed a mobile phone application for cerebral stroke detection. This application allows to establish the index of demographic incidents of cardiovascular accidents. Furthermore, according to the results obtained, the application was able to distinguish which persons suffered a cardiovascular accident. In this case, three of the most characteristic factors that occur during strokes were analysed. Moreover, patients' smiles were analysed as well as their capacity to repeat a sentence and whether they were able to raise their arms. In addition to contacting emergency services to reduce wait time, the application alerts a family member via Short Message Service (SMS).

Although there are currently many applications to monitor various diseases, it should be noted that none of them monitor hospitalized patients nor elders in nursing homes. Furthermore, many applications rely on user inputs rather than medical supervision. Moreover, none of these applications deal with the prevention and medical care of elders suffering from COVID-19.

For these reasons, in this paper we present an application developed to track COVID-19 patients and alert health carers whenever a patient's urgency state changes for the worse. By monitoring different parameters such as heart rate, temperature, blood pressure, etc., we aim at easing the triage of patients in order to improve the efficiency and quality of service given in care rooms, as well as allowing carers to have real-time access to a patient's state without the need of physical presence.

3 PROPOSED SYSTEM

This section presents the proposed system. The platform is composed by an electronic device with several sensors, which transmits the data using a wireless interface card compatible with the IEEE 802.11b/g/n, and a mobile phone with a management software developed in Android to collect and manage the data.

3.1 Overall Description

After analysing the most common symptoms produced by the COVID-19 virus and the difficulty of having real-time monitoring systems (especially in nursing homes) due to the high cost of these systems, we believe it is necessary to develop low-cost system to allow the control of vital signs in patients as well as their progress.

As Fig. 1 shows, the proposed system is composed by a series of sensors that to monitor the most common parameters of this disease, in a non-invasive way. These are: temperature, dry cough, blood pressure, heart rate, oxygen saturation, chills, blood in urine and dyspnoea. The data is collected in real-time by a wireless node and sent to the local server to be saved into the database. This way, the local server maintains the patients' medical records that will be access by nurses or physicians through an Android application in a smartphone or tablet. In this system, both the server and smartphones will be locally managed to preserve the patients' intimacy.

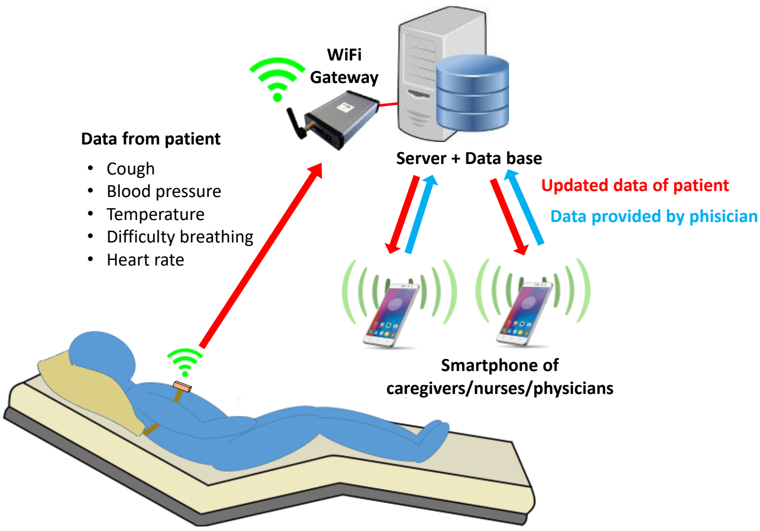

Figure 1: Diagram description of proposal.

3.2 Hardware Used to Develop the System

To develop the electronic device in charge of collecting data, we decided to use a NodeMCU (NodeMCU, 2020) module based on the ESP8266 (ESP-12) processor at 80MHz. This device contains 9 GPIO pins with I2C and SPI, 1 analog input and a 4 MB flash memory. Finally, it includes a wireless interface compatible with the IEEE 802.11b/g/n standard. Though it is possible to develop our systems with other microprocessors, its size (smaller than 3x5 cm) makes it ideal for this type of application. As we mentioned before, the system is composed by several sensors to measure fever, cough, blood pressure, heart rate, oxygen saturation and difficulty breathing, among others. To measure them, non-invasive sensors are used.

3.2.1 Temperature Monitoring

In order to measure the body temperature, a thermistor in contact with the person's body will be used. A thermistor is a sensor that modifies its electrical resistance depending on the temperature. Its operation is based on the resistance change of a semiconductor material according to temperature. We can work with negative temperature coefficient thermistors (NTC) or positive temperature coefficient thermistors (PTC). In NTC thermistors, the resistance decreases as their temperature increases while PTC thermistors increase their resistance as their temperature increases. In our case, the use of an NTC will be chosen because its behaviour is practically linear throughout its entire working range.

3.2.2 Heart Rate Monitoring

The AD8232 ECG module is a sensor that measures the heart rate (AD8232, 2020). It is a low-cost data acquisition card used for biopotential measurement such as the electrical activity of the heart. Electrocardiograms can be extremely noisy, so the AD8232 acts as an operational amplifier for measuring PR and QT intervals. This module has a maximum current consumption of 170 µA with a working temperature range from -40 to 85 degrees. It is designed to extract, amplify, and filter small biological signals. Finally, it can be configured to obtain the ECG waveform or directly the output as an analog reading.

To measure the cardiac rhythm, a differential measurement with 3 electrodes is performed. The electrodes must be connected to the patient according to the Einthoven triangle (See Fig. 2).

3.2.3 Cough and Dyspnoea Monitoring

The measurement of cough and breathing difficulties is usually translated into involuntary movements of the patient's chest. Additionally, dry cough produces dry short bumps of noise or voice with great amplitude. Taking advantage of these characteristics and the measurement properties of the accelerometers and microphones, it is possible to measure both events and differentiate them.

The MMA8451 (MMA8451, 2020) is a low-cost and high-precision 3-axis accelerometer with 14-bit ADC. This device is capable of detecting movement, inclination, and basic orientation. Its working range is Microphones are sensors able to detect how loud

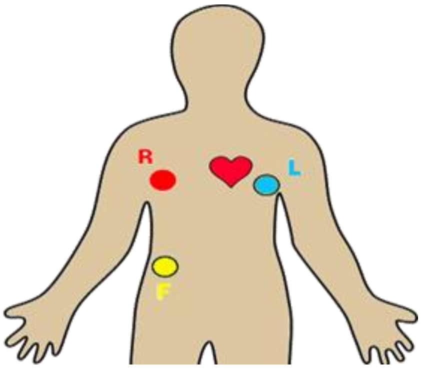

Figure 2: Position of electrodes to measure ECG.

from ±2g to ±8g, and it can be easily used with microcontroller modules such as Arduino. This sensor can be accessed by using the I2C communication protocol, so it can share the medium with other I2C devices.

a sound is. There are several types of microphones; the most popular ones are the condenser microphones and piezoelectric microphones. Condenser microphone are essentially capacitors formed by a thin diaphragm mounted in front of a plate. When sound reaches the condenser, the diaphragm vibrates thereby changing the distance between the conductors and effectively changes the capacitance between the diaphragm and the plate. A LM358 op-amp could be used to amplify the detected signal. When cough is detected, the microphone will detect short, high intensity noise bumps that will be recorded along with the accelerometer data.

The data from both sensors will be combined according to the following table (see Table 1):

3.2.4 SpO_2 Monitoring

The optical pulse oximetry (Mannheimer, 1997) is a non-invasive method to determine the percentage of oxygen saturation in blood. Its operation is based on the fact that haemoglobin (Hb) and saturated haemoglobin (oxyhaemoglobin, HbO2) have different light absorption coefficients for different wavelengths. Oxygenated blood absorbs more infrared light, while poorly oxygenated blood absorbs more red light. There are parts of the body where the skin is thin enough and blood vessels are visible. In these places, it is possible to identify this difference of light absorption to determine the degree of saturation. To monitor this parameter, a MAX30102 module will be used.

The MAX30102 (MAX30102, 2020) is a sensor manufactured by Maxim Integrated that incorporates the pulse and oximeter functions in a single integrated. It can de used together with an Arduino-type processor module using the I2C communication protocol.

The MAX30102 sensor incorporates two LEDs, one red spectrum (660 nm) and one infrared (880 nm), as well as photodiodes to measure reflected light and an 18-bit ADC. The MAX30102 is placed on the skin, for example on the finger or wrist. The sensor detects the reflected light and determines the degree of saturation.

3.2.5 Blood Pressure Monitoring

Blood pressure is measured with a commercial device equipped with a wireless communication interface. There are different devices with same characteristics. In our case, we have used the Beurer BC57 blood pressure monitor (Beurer BC57, 2020). This device allows automatic measurements, arrhythmia detection and contains a wireless Bluetooth interface that allows us to communicate with our module.

Finally, using the different described sensors the entire electronic solution would be composed as follows (see Fig 3). These devices will be placed in a small box that will be fixed in the chest of patient with an elastic belt, similar to the ones used by runners.

3.3 Android Application

In this section, the proposed application to monitor patients infected with COVID-19 virus is presented.

The flowchart of the application is depicted in Fig. 4. Once the application is started, the user must be connected to the main Local Area Network (LAN) to access the collected data and medical records of the patients. Moreover, the user credentials must be granted by the Information Technology department of the organization in order to access the database. If the user is not connected to the main LAN or does not have credentials to access, a notification message will be shown to inform the user of the terminal. However, if the mobile phone is connected to the main LAN and

Table 1: Relation of accelerometer and microphone.

Event	Accelerometer	Microphone	Result
Cough	1	1	The patient has cough
Difficulty breathing	1	0	The patient has difficult to breath
No event	0	0	The patient is OK.

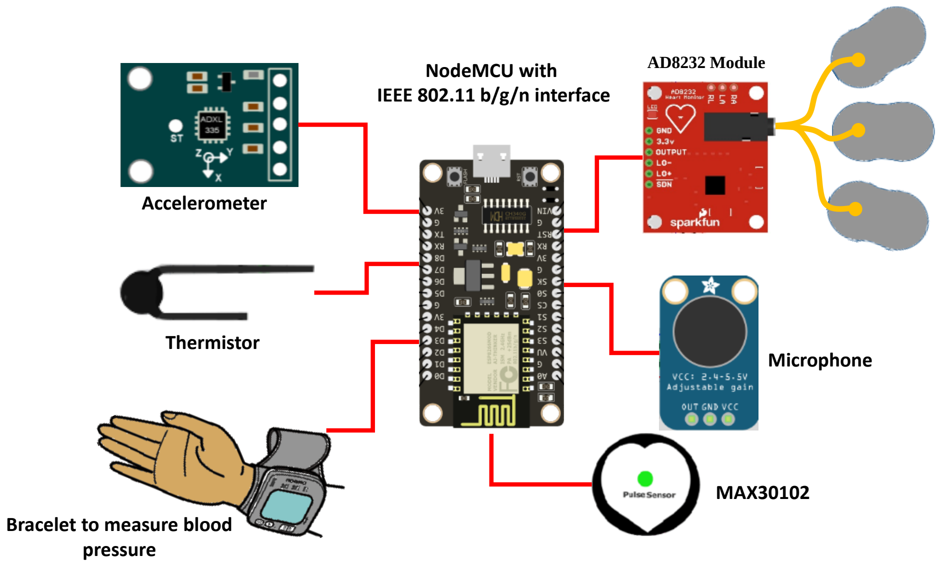

Figure 3: Diagram of hardware solution.

the user has credentials, the application will show the main activity, in which the user will be able to see the list of patients being monitored sorted by degree of urgency, following the Manchester Triage System (MTS) shown in Table 2.

New patients can be added by clicking the Add button and filling the registration form. To access medical information related to a patient, the user must click on the corresponding row. By doing this, the application will jump to its second activity where the monitored parameters are shown by default.

Table 2: Manchester Triage System.

Group	Urgency	Code	Wait time
1	Life risk	Red	0 min
2	Very urgent	Orange	10-15 min
3	Urgent	Yellow	60 min
4	Semi urgent	Green	2 hours
5	Non-urgent	Blue	4 hours

However, this view presents two tabs: Monitored data and Medical records, that the user can click to navigated through the patient's profile. As said before, the first tab shows the parameters being monitored in real-time, while the second tab shows additional information, such as the patient's contact person and the list of medical visits registered since the patient was enrolled. These records can be access by clicking on a row of the grid, while new records must be added by clicking the New Record button. When selecting a previous visit, the user will be able to enter in consultation mode to see the previous diseases, the doctor's consultation, and the follow-up of the symptoms. However, in this mode, the user will not be able to edit the gathered information. When creating a new record, the user will enter in Edition mode, where the information gathered in the last medical visit will be presented for the user to edit. Fig. 5 shows the different screens of the proposed application.

Additionally, the application will send a notification message to the terminal whenever the level of urgency changes. Fig. 6 shows two examples of notification messages sent to the terminal.

These notification messages will only be sent when the urgency level is yellow or higher, meaning that the doctor will have 60 min or less to visit a patient. Among the information given in these messages, the user will be able to see the level of urgency determined by the colour of the icon, as well as the name of the patient in need of medical care and the cause of the alert.

The algorithm used to determine the level of urgency of a patient is shown in Algorithm 1, where the values of the urgency level correspond to the groups of the Manchester Triage System shown in Table 2.

As the algorithm shows, the absence of one of the monitored signals will trigger a red flag. However, if all sensors are working correctly, the system starts tracking the different parameters starting with the heart rate. This way, if the heart rate of the patient is higher than 90 bpm, the system will trigger a red flag. Nevertheless, a heart rate equal or lower than 90 bpm will trigger a blue flag.

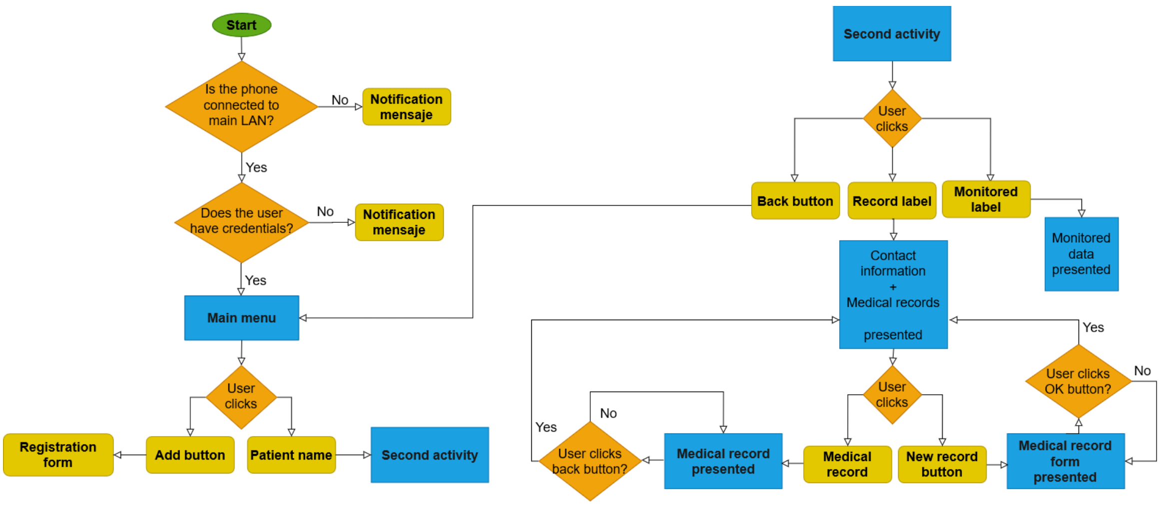

Figure 4: Application flowchart.

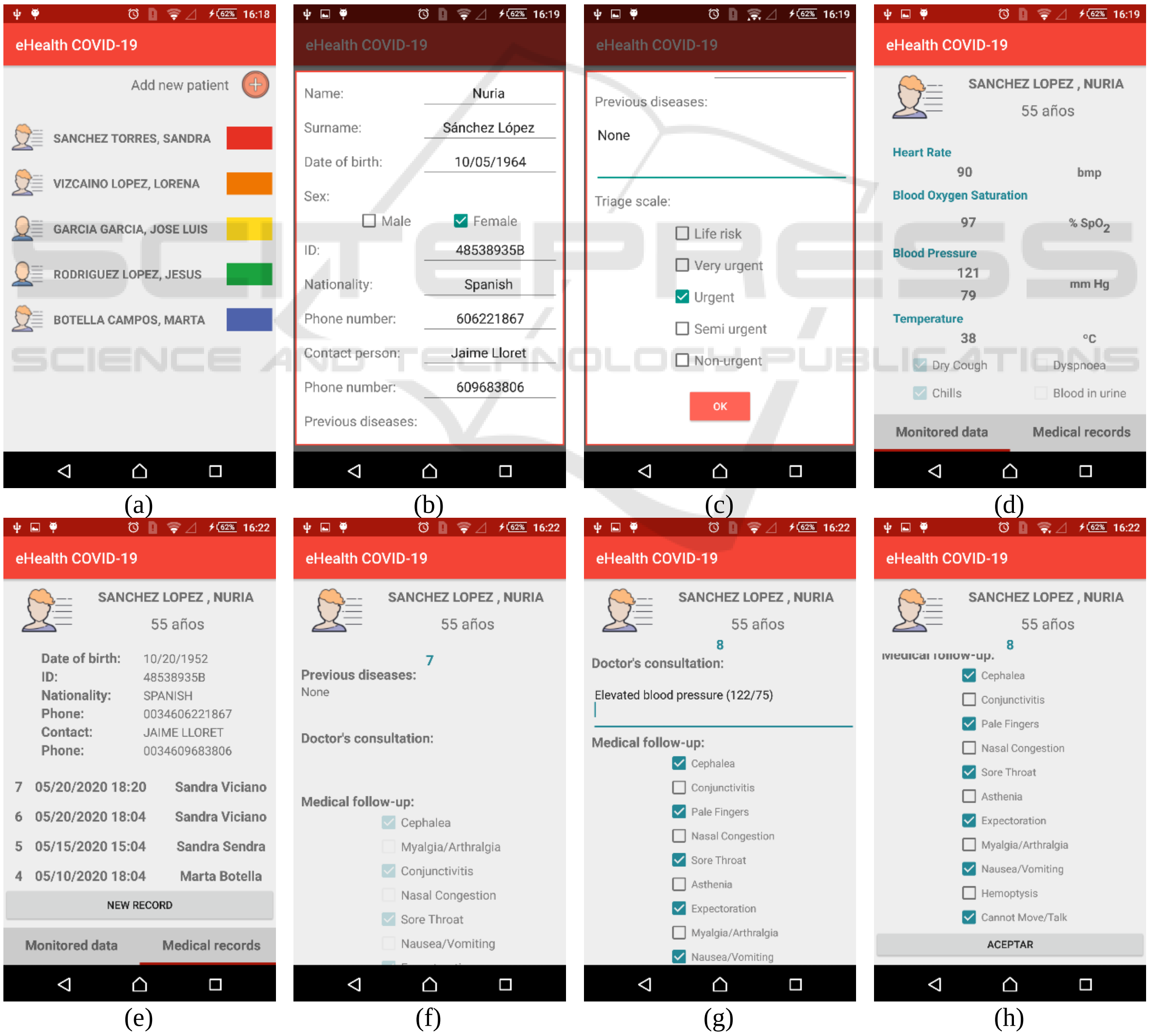

Figure 5: Screenshots of the proposed application.

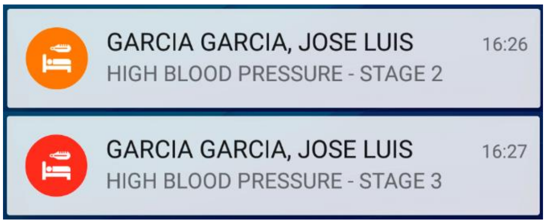

Figure 6: Notification messages.

4 RESULTS

This section presents the detection of parameters and the alert generation. The section also includes some screenshots of the Android application when notification messages are received.

To evaluate the correct operation of our application and proposed system, values are measured in 6 anonymous patients. The measured values are labelled with a value from 0 to 3 (depending on the type of parameter), following the values of Table 3. As we can see, some parameters such as cough or dyspnoea have only 2 possibilities, that is, the patient has cough, or the patient has not cough. However, other parameters such as heart rate are always present in the patient. For this reason, an additional state has been considered for temperature, blood pressure, blood oxygen saturation and heart rate. This additional parameter indicates that the sensor is not collecting data. For a patient with serious diseases such as COVID-19 may imply a dangerous situation and the patient would be labelled as very urgent to be assisted by a nurse or physician as soon as possible. Other parameters such as chills or cough are not symptoms that require urgent attention and therefore patients with these symptoms would be labelled in yellow, according to Manchester Triage System (Table 2), if the patient does not have any another serious symptom. Fig. 7 shows the data collected in 6 patients of these 8 symptoms, while Fig. 8 shows the labels they would receive, considering the measured data and the Manchester Triage System.

Algorithm 1: Triangle algorithm.

```
currentStatus = 5 -> blue flag
if(signal is absent)
        currentStatus = 1 -> red flag
else
        if(heartRate > 90)
                currentStatus = 1 -> red flag
        else
                currentStatus = 5 -> blue flag
        if(oxygenSaturation < 90)
                currentStatus = 1 -> red flag
        else if(oxygenSaturation >= 90 && oxygenSaturation < 95)
                currentStatus = 2 -> yellow flag
        else
                currentStatus = 1 -> blue flag

        if(bloodPressure >= 140)
                currentStatus = 2 -> orange flag
        else if(bloodPressure >= 120 && bloodPressure < 140)
                currentStatus = 2 -> yellow flag
        else
                currentStatus = 1 -> blue flag

        if(temperature > 38)
                currentStatus = 2 -> orange flag
        else if(temperature >= 37 && temperature < 38)
                currentStatus = 2 -> yellow flag
        else
                currentStatus = 1 -> blue flag

        if(dyspnoea)
                currentStatus = 1 -> red flag
        else
                currentStatus = 5 -> blue flag

        if(dryCough && dyspnoea)
                currentStatus = 1 -> red flag
        else
                currentStatus = 5 -> blue flag

        if(dryCough && temperature >= 37)
                currentStatus = 1 -> orange flag
        else
                currentStatus = 5 -> blue flag

        if(chills && temperature >= 37)
                currentStatus = 1 -> orange flag
        else
                currentStatus = 5 -> blue flag
```

Table 3: Measured ranges and its value to make decisions.

Chills		Dry Cough		Dyspnoea		Blood in urine		Temperature		Blood Pressure		Blood Oxygen Saturation		Heart Rate	
Monitored range	Value	Monitored range	Value	Monitored range	Value	Monitored range	Value	Monitored range	Value	Monitored range	Value	Monitored range	Value	Monitored range	Value
No chills	0	No Cough	0	No Dyspnoea	0	No blood	0	t < 37°	0	BP<120	0	95<SpO_2<100	0	HR < 90 bpm	0
Chills	1	Cough	1	Dyspnoea	1	Blood	1	37°< t < 38°	1	120<BP<140	1	90<SpO_2<95	1	HR > 90 bpm	1
								t > 38°	2	BP<140	2	SpO_2< 90	2	No signal	2
								No signal	3	No signal	3	No signal	3		

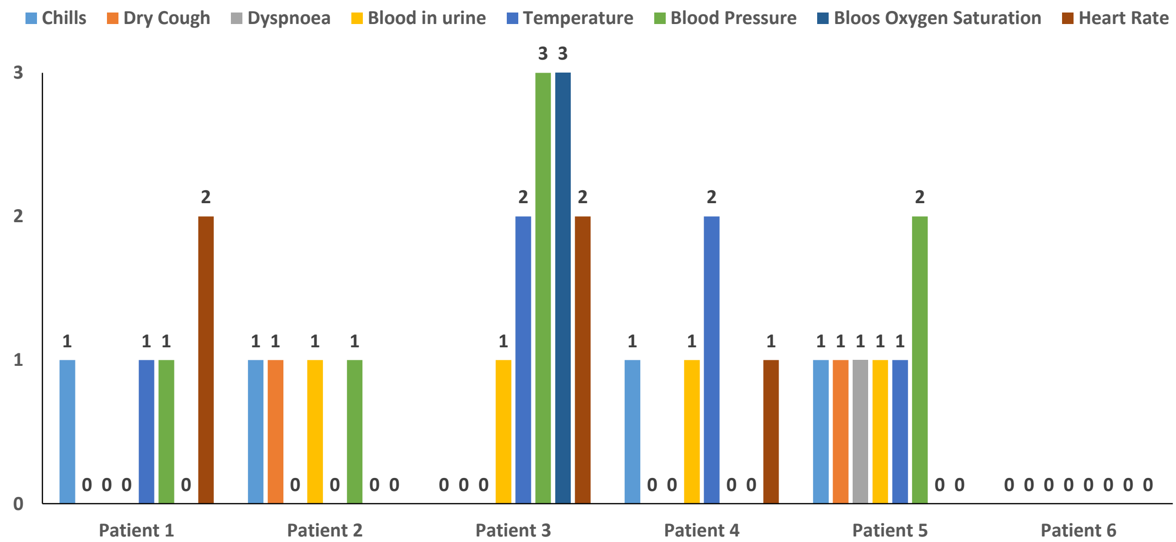

Figure 7: Data from patients.

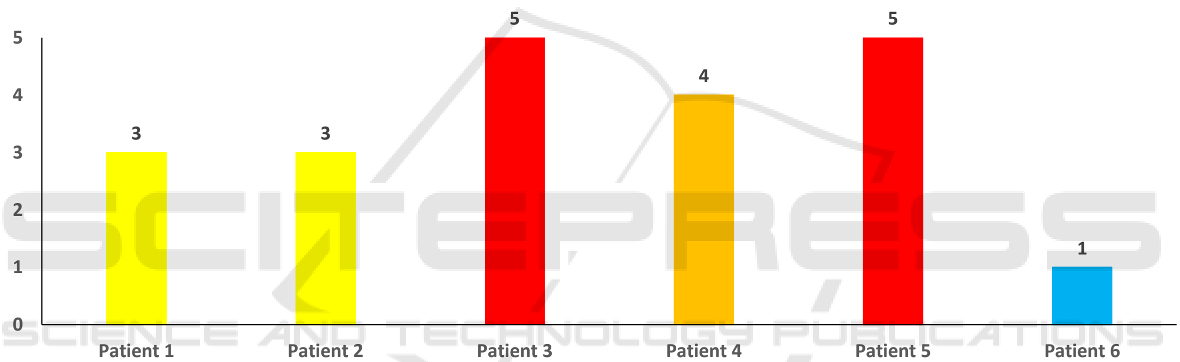

Figure 8: Label assigned according to Manchester Triage System.

5 CONCLUSION AND FUTURE WORK

COVID-19 disease is being especially serious for elderly people who are in nursing homes. When persons are infected, they are usually confined in their rooms and often remain in bed with difficulties in moving.

In order to facilitate the monitoring and care of these patients, this paper has presented a system consisting of an Android application for data management and a multisensor device to monitor the vital signs of patients. Through the application, nurses and doctors can monitor patients and they are also notified if any patient worsens his condition. The system is designed to process data locally (inside the network of the nursing home) in order to preserve the privacy of patients and their clinical data.

As future work we would like to include other sensors to automatically collect data and apply machine learning systems to catalog other diseases and symptoms. Finally, we would like to extend the application to use it in hospital environments.

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