

Smart IoT system for remote patient monitoring

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Abstract – This paper addresses the design and development of a system for remote patient monitoring, employing low-cost sensors and internet of things (IoT) technologies. The proposed remote-monitoring system is intended for patient with lung diseases. In fact, the system includes a dedicated Android application (called EcO2u), which manages data collection related to heart rate (HR) and oxygen saturation (SpO2). The developed application also implements a face-detection function, which allows the identification of the remote patient. The patient's vitals collected by the sensor are sent to and stored in a database, which can be easily consulted (by the patient and by the doctor) through the aforementioned dedicated application.

I. INTRODUCTION

Enabling technologies like big data, the Internet of Things (IoT) [1, 2] and the fifth generation cellular network (5G) are contributing to change the world we live in. The main areas of application are represented by those contexts in which there are "things" that can "speak" and generate new information. Applications include smart home, home automation, smart building, robotics, automotive, self driving car, smart health, biomedical world and smart city [3]. Basically, the purpose of these solutions is to monitor, control and transfer information and then take consequent action.

Over the last decade, extensive research has been carried out on the use of IoT technology also in healthcare for patient monitoring [4, 5, 6]. Remote monitoring (or tele-monitoring) is a tool provided by telemedicine to address and improve this situation. In this regard, telemedicine, which is literally the provision of health services and the exchange of health information at a distance, has potential benefits and enormous capability to bridge the gap in access to quality healthcare and reduce costs [7, 8]. Telemedicine covers a wide range of applications, such as remote consultation, remote monitoring, telecommunications education, remote management (combination of re-

mote monitoring and remote consultation), tele-oncology, telecommunications dermatology, tele-ophthalmology and tele-radiology [9]. Medical remote management is the combination of tele-monitoring and tele-consultation services for a more robust healthcare package [10]. The synergy of these services enables the possibility to constantly monitor home patients with chronic conditions, thus allowing to provide proper post-management treatment (to avoid relapses and deteriorating health conditions). Also, the combination of these services provides a platform where health professionals/rural settlement professionals can consult or interact with their counterparts in the urban areas.

One of the patient's conditions in which tele-monitoring can be particularly useful is pulmonary disease. Pulmonary diseases affect the health of the lungs, impair their function, with negative repercussions on the process of introduction of oxygen essential for the well-being and survival of the human organism. As a consequence, it is apparent the importance of remote monitoring patient's vitals related to such conditions.

On such bases, the present work addresses the development of a system for remote monitoring patient's heart rate (HR) and oxygen saturation (SpO2). Although only two parameters were considered, the proposed platform can be easily adapted to monitor several other parameters of interest, such as skin hydration [11], human posture [12], electrocardiogram.

As detailed in the following, the proposed system includes a multi-purpose, dedicated Android application (named EcO2u), which manages data collection, sends data to a repository and makes them available to the patient and to the doctor. The application also implements a face-detection function which allows the identification of the remote patient. Finally, in case of emergency (for example, if the vitals exceeds pre-established thresholds), the application can send a warning message to both the doctor and the patient.

The present paper is organized as follows. In Section II,

the existing monitoring systems are described and compared to the one proposed herein, highlighting the innovative aspect of the latter. In Section III, the system architecture, the communication algorithm and the hardware are described in detail. In Section IV, the system architecture is described in detail. Section V reports the experimental results obtained in the validation of the system. Finally, in Section V conclusions are drawn and the future work is outlined.

II. STATE OF THE ART FOR PATIENT'S TELE-MONITORING

Most state-of-the-art tele-monitoring systems, although advanced, are affected by some limitations, for example, scarce mobility for the patient, limited availability of systems to verify the patient's identity, etc.

For example, in [13], a system for the management of chronic heart failure focused on the Internet was presented. However, limitations such as the unsupported mobility of the patient (measurements only take place in a domestic environment), did not support medical consultations by the physician. Additionally, the system required a manual recording of the parameters, thus leading to possible incorrect transmission of the readings.

A tele-medicine system for the management of blood pressure (BP) in hypertensive patients was proposed in [14]. The system offered the possibility of transmitting the measurements to doctors via mobile phones. However, the data were collected manually. Further work suggested the automatic transmission of BP readings from the wrist BP Monitor to the android application with Bluetooth technology. The description a multi-level architecture for efficient and effective management of chronic diseases was addressed in [15]; the work, however, did not address the implementation of the proposed architecture.

The development of a tele-control and tele-consultation system for the management of patients with chronic heart failure was addressed in [9]. This system, however, did not allow monitoring of other chronic diseases.

In [16], a remote monitoring system with two components was proposed. The first is a chest sensor belt that contains a 3-axis accelerometer and two electrodes to acquire the patient's ECG signal, the second is a pulse oximeter to obtain the photoplethysmograph (PPG) and heart rate. The two modules communicate with the base station through a network node of ubiquitous sensors, which is also wearable. This system provides only the detection of two vital parameters.

A piece of equipment for the detection of the ECG signal using only 3 electrodes was presented in [17]. The AD8232 sensor used for ECG detection transmits data via Bluetooth; however, to obtain a cleaner signal it is necessary to debug the data.

Finally, in [18], a remote monitoring system with commer-

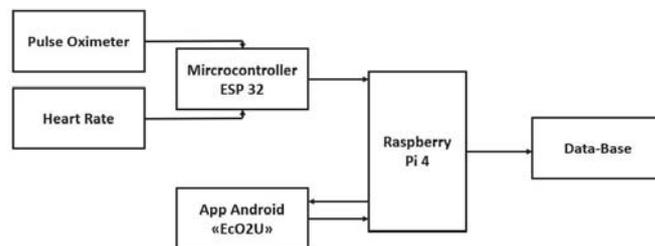


Fig. 1. Simplified architecture of the developed tele-monitoring system.

cially available components was described. This system employed components which are integrated into a system for processing the data obtained.

III. EXPERIMENTAL SETUP

Figure 1 shows the block diagram of the proposed mobile tele-monitoring system.

For the HR measurements and for the SpO2 measurements, the MAX30100 pulse-sensor was used. This is a commercial sensor dedicated to HR measurements. It has two integrated LEDs, RED and IR, used to emit the respective wavelengths. The wavelengths of these LEDs are 660 nm and 880 nm, respectively. Reflected light is detected by a red/ IR photodetector element and sampled by a low-noise 16-bit delta-sigma ADC. The front end of the MAX30100 sensor features an abnormal light cancellation section (ALC), which eliminates light pollution of the photodetector element. The 16-bit ADC is filtered by a discrete time filter to avoid interference and hum of 50-60 Hz. The output sampling rate can be adjusted from 50 Hz to 1 kHz. There is also a temperature sensor that can be used to compensate for changes in the environment and to calibrate measurements.

A microcontroller (Chip ESP32) was also used. The most interesting feature of this commercial controller is that there are more GPIO pins with which to develop more complex projects without having to resort to a GPIO expander such as the MCP23017, the presence of Bluetooth connectivity, touch sensor and more memory.

The monitoring system also includes the Raspberry Pi 4 Model B.

Finally, the experimental setup includes a mobile phone with the EcO2U application placed on a support, in order not to constrain the user. The user must be in a comfortable position and then apply the sensor on a finger of the hand. The sensor is supplied by 5 V power.

IV. DESIGN AND IMPLEMENTATION OF THE TELE-MONITORING APPLICATION

A. Definitions Requirements

All design processes include a requirement-setting phase. A requirement is a required property of the product and has a significant impact on its architecture. The requirements of the proposed remote monitoring system are divided into domain, application and territory requirements.

Domain requirements reflect general features of the application domain. In the specific case we find availability, reliability and security of data. The application requirements include functional requirements (describe the services, or functions, offered by the system (normally activated by user-inputs) and non-functional (describe constraints on the services offered by the system, and on the development process itself). These include: sensor connection, reading vital parameters, loading measurements, parameter analysis and activation of emergency alarms. Finally, we rework the territorial requirements or practical, mobile and easy to use device. These requirements make it possible not to require the use of a qualified person.

B. Architecture

The architecture consists of four main levels.

The first level is dedicated to user registration. This step is essential to associate the device to the individual user and record that information within the database. The patient can register through the android application EcO2U, which was specifically developed for the system. After registration, the correctness of the patient's personal data is verified, as shown in Figure 2(a) and the association with the device through the scanning of the QR code. Data are collected and summarized in the app and then transmitted to the raspberry or to the database. The database checks the data and sends a feedback of correct registration.

Once the registration is complete, the application will refer the patient to the login page (Figure 2(b)). Communication with the Database is also required in the login screen to check the password and the tax code entered.

After the login, the second level is dedicated to the measurement of vital signs. The implemented measuring system includes: 1) a sensor that allows monitoring HR and SpO₂; and 2) the micro-controller for sending the measurements via WiFi to the database.

During the measurement phase, managed through application, the patient must look at the camera and his face should be visible to the app as shown in Figure 3. The framing allows the patient's face detection and identification. Thanks to the frame, a rough visual assessment on the patient's condition can also be done.

The relevant parameters are shown inside the timer to show the subject the course of its measurement.

The third level pertains to the management of the pa-



Fig. 2. Window of the EcO2u application during registration (a). Main menu of the application (b).

tient's medical history. This management is always carried out by means of the EcO2U app using three icons to show: (a) the daily trend by means of a graph of the measurements carried out, (b) reporting symptoms during the day, (c) indicate any symptoms not present to study some correspondence (Figure 2(b)). These operations rely on the exchange of information between application and database.

The fourth and last level examines the remote display of the data. The doctor will need to install the EcO2U application and access it with master's credentials in order to view the parameters. Therefore, the application provides a different layout depending on whether the user is a doctor or a patient in order to make the application user-friendly and intuitive.

V. EXPERIMENTAL RESULTS AND DISCUSSION

The application EcO2U was tested on five voluntary subjects.

First, the functional testing of the software was carried out. The goal was to evaluate the functionality of a software program, with the primary objective of identifying bugs and malfunctions that may occur under certain conditions of use. During this phase it was possible to verify how the sensor interacted with the database and the application itself. Specifically, we examined the correctness of sensor-subject association within the database, the correct functioning of calls inserted in database application to have a correct usability of the information. The session protocol required that, five minutes before starting the measurement, for the subject to sit down and avoid having coffee or nicotine.

Throughout the measurement session, the mobile phone frames the user and the pulse oximeter in order to validate

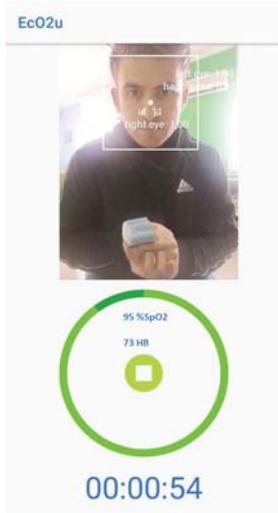


Fig. 3. Window of the EcO2u application while the measurements of the patient's vitals is being carried out.

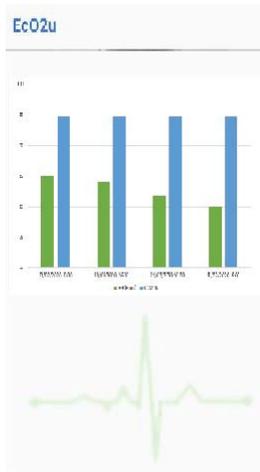


Fig. 4. Tele-monitoring graphic representation.

the measurement. The data are sent automatically to the database and are made visible to the user. If the measurement result, after appropriate processing, indicates a risk for the patient, then the application itself will manage this alarm by informing the doctor and the patient.

Measurements were made in the same environmental conditions. For each subject, 30 HR values were recorded and the mean value and uncertainty were calculated. The measurement of HR and oxygen saturation was repeated twice on the same day.

The measurement results are displayed on a graph in the application (Fig.4). This facilitates the understanding of the temporal trend of the patient's vitals. Table 1 summarizes the obtained results. The related standard uncertainty values are also reported. A $1-\sigma$ % inter-individual reproducibility were valuated for the two measurement sessions.

Table 1. Average values of HR acquired in two sessions. The related standard uncertainty values are also reported.

Subject	HR [Bpm]	HR [Bpm]
	1st session	2nd session
#1	85 ± 3	82 ± 2
#2	71 ± 2	68 ± 2
#3	88 ± 4	85 ± 4
#4	75 ± 1	73 ± 2
#5	70 ± 2	67 ± 1

Table 2. $1-\sigma$ % Reproducibility

Subject	$1-\sigma$ %	$1-\sigma$ %
	1st session	2nd session
#1	3	2
#2	3	3
#3	4	3
#4	2	2
#5	3	1

The $1-\sigma$ repeatability of the samples was evaluated as a percentage change of the variation between measurements that occurs when one person measures the same item several times, using the same measuring equipment. Results are summarized in Table 2.

Also the SpO2 saturation was measured for the five subjects during the two measurement runs: the obtained values were all in the range 97-99 [%SpO2].

VI. CONCLUSION AND FUTURE WORK

In this work, a system for patient tele-monitoring was presented and experimentally validated. Also, a dedicated application was specifically developed. Not only does this application allow the collection of the patient's vitals and communication with the remote doctor, but it also implements a face-recognition function. The proposed system is very flexible, as the number of monitored parameters could be extended by including additional sensors.

In practical applications, such a system can facilitate patients' monitoring outside of clinical facilities.

Future work will require to develop and implement the doctor-side of the application, in order to achieve a fully-functional tele-monitoring system. Integrate the face recognition system will allow the same application to validate or not the measurement. , this happens thanks to the intervention of the doctor that viewing the video recognizes the patient. The proposed system could also be integrated with an augmented reality application to deliver a more user-centered experience to both the patient and the doctor [19].

Additional work will also be dedicated to implement machine learning algorithm that, based on the processing of

the recorded patient's vitals, can help to predict possible aggravation of the patient's health conditions.

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