A Microcontroller Based System for Controlling Patient Respiratory Guidelines

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Abstract. The need of making improvements in obtaining (in a non-invasive way) and monitoring the breathing rate parameters in a patient emerges due to (1) the great amount of breathing problems our society suffer, (2) the problems that can be solved, and (3) the methods used so far. Non-specific machines are usually used to carry out these measures or simply calculate the number of inhalations and exhalations within a particular timeframe. These methods lack of effectiveness and precision thus, influencing the capacity of getting a good diagnosis. This proposal focuses on drawing up a technology composed of a mechanism and a user application which allows doctors to obtain the breathing rate parameters in a comfortable and concise way. In addition, such parameters are stored in a database for potential consultation as well as for the medical history of the patients. For this, the current approach takes into account the needs, the capacities, the expectations and the user motivations which have been compiled by means of open interviews, forum discussions, surveys and application uses. In addition, an empirical evaluation has been conducted with a set of volunteers. Results indicate that the proposed technology may reduce cost and improve the reliability of the diagnosis.

Keywords: Respiratory rate · Arduino · Wearable devices

1 Introduction

The process that living things use to introduce oxygen in their body and get rid of carbon dioxide that is not need is what is commonly known as breathing.

According to the World Health Organization (WHO) in 2004 there were 64 million people suffering from respiratory diseases and, at least, 3 million died for this reason [1].

The Spanish Society of Pneumology and Thoracic Surgery (SEPAR in Spanish) conducted a study which concluded that on January 5, 2016, five of the ten diseases that cause more mortality in the world occur in the respiratory field. Furthermore, according to data published by the National Statistics Institute (INE in Spanish) of Spain in 2014, the diseases that have recorded the highest increase in hospital discharge are related to respiratory pathologies [2].

Early diagnosis may be the key to deal with some of these respiratory diseases [3], among many others. Such diagnosis passes through the recognition of patterns that are abnormal, similar to those formulated when monitoring the respiratory rate.

The respiratory rate corresponds to the number of inhalations and exhalations that a human being performs in a unit of time. The respiratory rate of a persons in resting state is considered as the normal respiratory rate. The normal rate depends on several factors such as age, sex, etc.

Monitoring a normal respiratory rate may reveal abnormal patterns that may indicate many health problems [4]. There are several studies which state the health benefits that the recognition of respiratory rate provides [5–10].

Probably, the small impact that this measure has on the daily clinic practice is due to the lack of technology for obtaining and monitoring the respiratory rate in a non-invasive, easy, comfortable and reliable way.

Nowadays, the methods to measure the respiratory rate in a non-invasive way go through the direct vision, monitors of impedance and with capnographs. However, these methods are limited and have a poor accuracy in getting results.

For all aforementioned facts, this paper presents a design, implementation and test of a low cost and easily usable instrument which obtains the respiratory rate in a non-invasive, precise and accurate way. Furthermore, such instrument connects to a user application so that the breathing rate can be monitored and stored, saving the relevant information in a database along with other data.

The rest of the paper is structured as follows. Section 2 shows the proposal and the details of its development. Section 3 describes how the satisfaction generated by the proposed technology has been measured. Section 4 discusses the proposals that exist and the main differences between them. Finally, Sect. 5 includes a brief summary of the idea, the strengths and weaknesses, and the lines that are open to continue working.

2 Contribution

2.1 Proposed System

The proposed system (cf. Fig. 1) consists of a device for measuring respiratory rate and the software tool for managing the user information and data obtained from the device.

Firstly, the physician considers if it is appropriate to monitor the respiratory rate of a patient (cf. Fig. 1 - Step 1). Then, she has to register the patient in the application by entering the data which is necessary. This data is stored in the database (cf. Fig. 1 - Step 2).

To monitor the respiratory rate, the physician places the device on the patient (cf. Fig. 1 - Step 3). Thereafter, the data acquisition and transfer begins. This is done

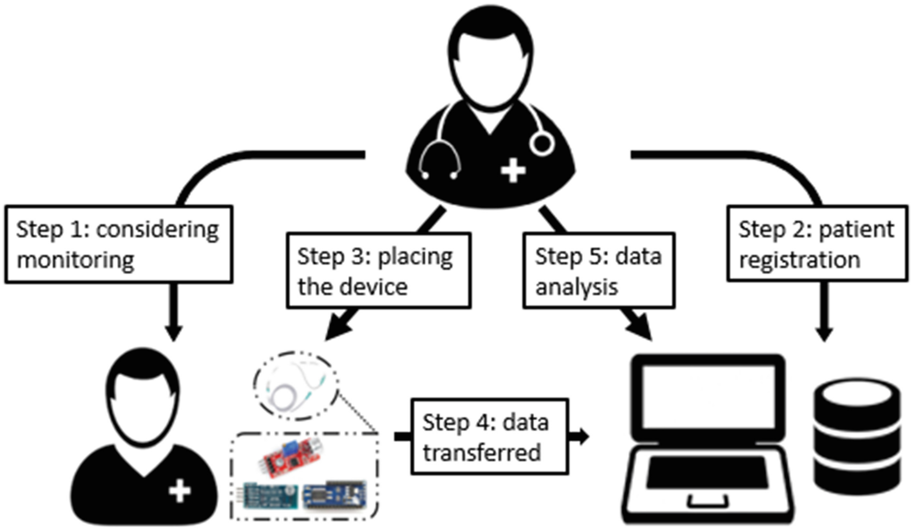

Fig. 1. Overview of the proposal.

through a Bluetooth connection to the application where a graphic is painted according to such data (cf. Fig. 1 - Step 4).

Finally, the health personnel can analyze the data obtained, save and consult the relevant information when necessary (cf. Fig. 1 - Step 5).

2.2 Development Details

For the process of development of the proposed technology, a user-centered methodology is followed. This methodology encompasses a heterogeneous set of methodologies and techniques that share a common goal: to know and understand the needs, objectives, motivations, limitations, behavior and characteristics of the user [11].

In order to clearly understand the development process that has been followed to obtain the technology which proposed in this paper, it is divided into two stages:

2.2.1 Stage 1. Knowing the End Users Thoroughly

In order to learn about the scenario and its users, open interviews, discussion groups and surveys are carried out. This is intended to explain the proposal to users and receive an opinion about it. With the help of these methods, the necessary changes can be made to make the study more fruitful and better adapted to reality.

The end users of this technology are both patients—who need to be monitored—and physicians—who take control of this monitor. Therefore, the technology should fulfill their needs. On the one hand, it should be comfortable for the patient and on the other hand, it should be easy to handle for the doctors, among other things.

In addition, the needs that physicians have when obtaining and storing the information of the different patients have been known. Consequently, a set of functional requirements have been stipulated for the proposed technology, i.e., a device in charge of obtaining the respiratory rate, a user application where the doctor manages such device and the information concerning the patient, and a database where all the information is stored.

Once this stage is finished, the data that the application and the database must contain and the functional requirements that the application and the device must comply with are known. Thereafter, the development of each part may start.

2.2.2 Stage 2. Development of the New Technology

At this stage, the development of the different parts of the proposed technology is explained separately.

Development of the Device. The development of this part is performed over an Arduino system [12, 13]. For the detection of sound, a microphone KY-037 is connected to the hardware part of Arduino through its analog output since it is the one that obtains a voltage signal in real time. This microphone captures the small changes in the air pressure that occur when one breathes and then, converts such changes into a measurable electrical signal which is analogous to the sound that want to be measured.

The hardware part connects to the Arduino software part wirelessly through a Bluetooth device (i.e., Bluetooth JY-MCU). The software part states the COM port where Bluetooth is anchored and the Arduino board model which is used. Additionally, a program based on the language Processing [14] (i.e., Arduino programming language) is developed to indicate the data that want to be obtained.

Development of the Application. For the development of the desktop application, Microsoft Visual Studio 2015 has been used [15] together with the C# programming language.

The application consists of a graphical interface that allows to manage the data of the patients, their clinical histories as well as the data related to the respiratory rate. The graphical interfaces of the application are created through different forms. Each form represents one of the screens that can be accessed in the application. These screens are designed using the graphical components which are provided by Visual Studio.

Figure 2 shows the graphical interface developed for the analysis of the respiratory rate. As shown, a plot is depicted according to data which is being obtained from the device.

When the stipulated time for the test expires, the physician can save the generate plot which is assigned to the patient and contains the date and time when the plot was performed. The peaks of the plot correspond to the expirations that the patient performs throughout the respiratory cycle.

Related to the communication of the application, in the one hand, it maintains a bluetooth communication with the device to obtain the data that the sensor captures and to paint a plot with them. In the other hand, the application communicates with a database developed with Microsoft Access.

To summarize, the development of this software comprises 9 forms with 18 C# classes which contain 4500 lines of code in total. In addition, the prototype was developed by one undergraduate student in 820 h.

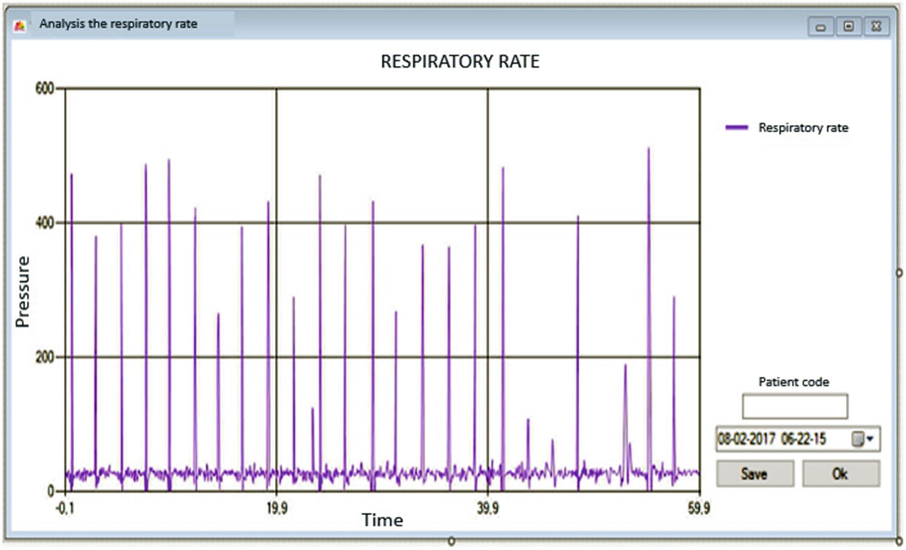

Fig. 2. Part of the graphical interface

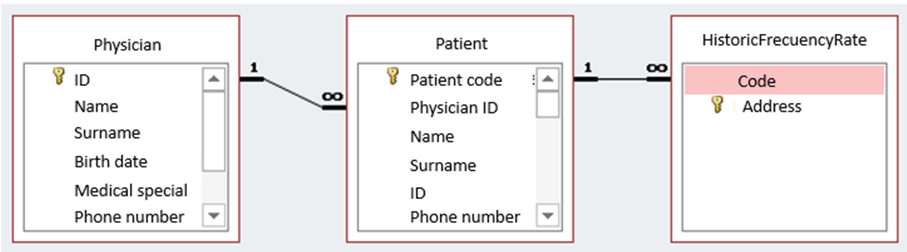

Fig. 3. Medical table design

Design of the Data Base. For the process of designing the database (cf. Fig. 3) the steps proposed in the book "El nuevo PHP. Conceptos avanzados" by Vicente Javier Eslava Muñoz have been followed [16].

The design is divided into three stages:

- **Conceptual Design**
  At this stage an information schema is constructed which is known as a conceptual schema.
  The conceptual schema is constructed using the information that is collected in stage 1 of the development. When constructing this scheme, one understands the meaning of the data that are necessary and the entities, attributes and relationships are found.

The objective of this scheme is to understand the perspective that the user has of the data, i.e., the nature of it. In addition, this design has been used to convey to the users what has been understood about the information that this one wants to handle.

- **Logical Design**
  At this stage the conceptual schema is transformed into a logical schema. In this case, the relational model has been used.
  Normalization is a technique that is used to verify the validity of logical schemes based on the relational model, since it ensures that the relations (i.e., tables) obtained do not have redundant data. In this case the third normal form is reached.
- **Physical Design**
  The physical design is the process of producing the description of the implementation of the database in the database management system that has been chosen, in this case Microsoft Access.

3 Evaluation

After the development of the proposed technology, the system passed to the testing phase. Then, a set of tests were performed to a group of real users, consisting of the use of this technology. Specifically, 20 users participated, of which 10 were doctors and 10 patients.

These users are told the traditional methods that exist for the taking of the respiratory rate so that they are put into situation.

Once everything was understood regarding what is currently used, some enveloped were delivered with two satisfaction surveys. The first survey was intended to measure the satisfaction of the existing methods and the second to measure the satisfaction of the proposed method. These surveys were anonymous, so there was no kind of conditioning when expressing what they really thought.

After the first surveys were filled, the operation of the technology was explained in order to be tested. They had about half an hour to test the proposed technology. During the tests, the group of users were observed and analyzed in order to know how they use the application and the device. As a result, on the one hand, any change in functional requirements was required and, on the other hand, a set of non-functional requirements was detected.

Finally, once the test is finished, users were asked to fill in the second survey, i.e., related to the satisfaction of the proposed method. And once completed, both surveys were inserted in the envelope and delivered.

Surveys were used to measure the reactions of users to this proposal in some way. This is done by looking at user responses and comparing the means of the results. After comparing the means of medical users, interesting results were obtained as shown in Fig. 4. In this figure, Serie 1 corresponds to the means obtained before performing the field work and the Serie 2 corresponds to the means obtained after performing the field work.

Additionally, a comparison of the means of the patient users has been made, which can be seen in Fig. 5. In this case the Serie 1 corresponds to the means obtained before

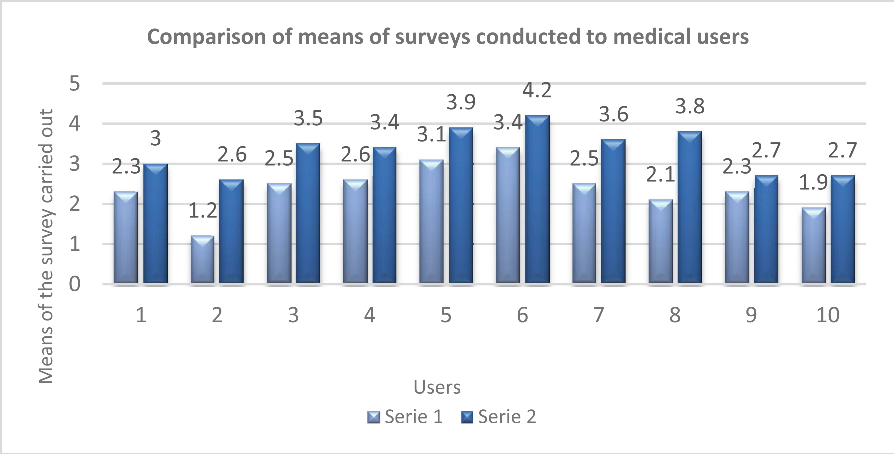

Fig. 4. Comparison of means of the surveys made to medical users.

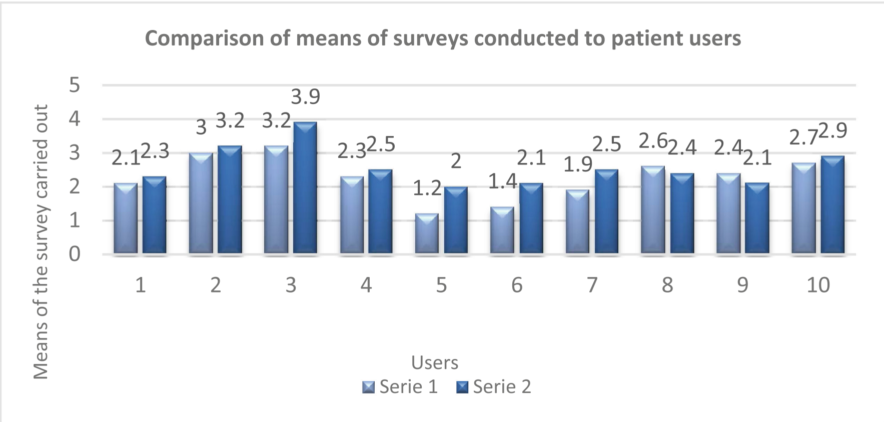

Fig. 5. Comparison of means of the surveys made to patient users.

performing the field work and the Serie 2 corresponds to the means Obtained after the field work.

4 Related Work

As far as we know, there no exist any specialized device to measure and monitor the respiratory rate in a non-invasive way that was reliable in terms of measurement. Although some related research is being conducted (e.g., [17, 18]) only few device are being manufactured (cf. Fig. 6).

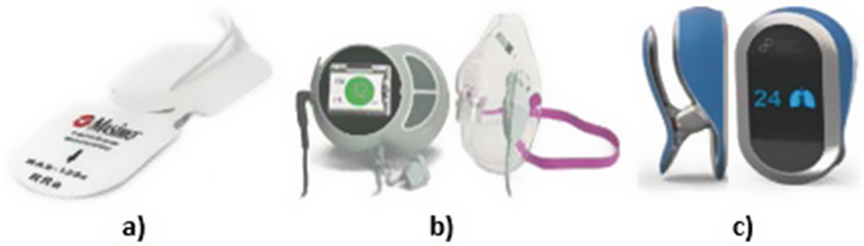

Fig. 6. Existing devices for respiratory rate monitoring. (a) Rainbow Acoustic Monitoring, (b) RespiR8 and (c) First Response Monitor

4.1 Rainbow Acoustic Monitoring™

Masimo, a global leader in innovative non-invasive control technologies, introduced Rainbow Acoustic Monitoring in 2005™ (Fig. 6 - a). It is an acoustic sensor for continuous monitoring of respiratory rate, this sensor has an integrated acoustic transducer and is easy and convenient to apply. It is placed on the surface of the neck to detect acoustic vibrations of the upper respiratory tract on the skin surface during the respiratory cycle.

This device was presented at the American Association of Respiratory Care conference on December 5–7, 2009 in San Antonio, Texas.

The data collected by this sensor are transmitted to one of the platforms also manufactured by Masimo by means of a cable connection. In this platform one can see the values of the respiratory rate collected along with other data if additional Masimo sensors are used.

One of the disadvantages of this product is that it is necessary to purchase a specific monitor from Masimo to see the information that it collects. That is an unnecessary expense for the product carrier center. The technology proposed in this paper removes this inconvenience since it can be installed in any computer that the center owns.

Another disadvantage is that Rainbow Acoustic Monitoring™ requires a cable to transmit the data collected by the sensor to the Masimo monitor, which is uncomfortable for the patient. With the technology proposed here, this problem is overcome by using a bluetooth connection to transmit the sensor information to the computer where the user application is installed.

Finally, unlike Rainbow Acoustic Monitoring™, the technology proposed in this work allows the physician to operate the device through a user application where she can obtain the respiratory rate data of the patient, store data and learn relevant information for diagnosis.

4.2 RespiR8

Anaxsys, a British medical device company that develops and markets respiratory devices, announced on 13 October 2010 the availability of respiR8 (Fig. 6 - b). RespiR8 is a device to continuously monitor respiratory rate through a face mask that uses its own technology through a patented sensor that responds quickly and reliably to differences in the degree of humidity of the inhaled air with respect to exhaled one.

The data collected by the sensor can be read by a screen arranged on a small monitor. The mask and the monitor are connected by cable.

Similarly to Rainbow Acoustic Monitoring™, one needs her own monitor to view the data that the mask collects from the respiratory rate. As stated above, this drawback does not exist with the technology proposed here.

Also, the connection between the monitor and the RespiR8 device is wired which is uncomfortable for patients. As discussed above, the proposed device transmits the data wirelessly.

Another thing worth noting is that the price of the consumables of the proposed technology (i.e., a nasal cannula) is much lower than that of RespiR8.

4.3 First Response Monitor

Finally, Cambridge Design Partnership, a leader in technology and product design, announces on August 6, 2015 that they have created a vital sign monitor for reliable, fast measurement and for real-time display of respiratory rate (Fig. 6 - c). This monitor is shaped like a clip to be placed on the nose. Once placed, the control of the breathing rate begins immediately.

The collected data can be visualized through a screen that is already incorporated or transmitted in real time to a Smartphone or Tablet via Bluetooth.

This technology is not yet in the market so its pros and cons cannot be known accurately. Nonetheless, one of its cons would be that it cannot save relevant information about the patient who the test is being performed to, or store the respiratory rate data information that is obtained.

5 Conclusions and Future Work

This work presents the development of a device from a microcontroller and a respiratory rate detection system with microphone which obtains statistics of the respiratory rate and reflect them in a user application on the computer. The information that is captured by the device is packaged and sent wirelessly using a bluetooth device.

Therefore, the developed technology speeds up obtaining vital parameters and can carry out early diagnosis of diseases in an easier way. To do this, the plots that are generated with the information regarding the respiratory rate that is captured by the sensor are stored the medical equipment. This information includes relevant data of the patient to whom the monitoring of the respiratory rate will be carried out. This information is what has been considered necessary according to the requirements of the doctors.

In short, all the objectives that had been set at the beginning of the work were fulfilled.

Based on the results obtained in the testing part of the system, the development of the technology proposed here is feasible, thus enabling to obtain more information on the evolution of the patient.

Due to the simplicity to the developed system is more comfortable for the patient. In addition the patient will have more confidence in the results of his test, because the proposed technology provides more reliable results compared to the current technology.

Probably, the proposed technology is feasible since the requirements and reactions of end users have been taken into account, i.e., their needs, objectives, motivations, limitations and behavior. Therefore, a greater satisfaction and experience of use is obtained with the minimum effort of the users.

In summary, this technology would achieve, among other things, economic savings, greater reliability in the results and therefore more reliable diagnostics.

Throughout the work have been proposed ideas to improve this technology and the information that is obtained, but lack for time and material, among other things, has not been possible. Some of them correspond to the following:

- Use of sensor with greater accuracy for a better quality and accuracy of the obtained data.
- Extension of the application and graphic interface with the objective of obtaining more information from both the health professional and the patient.
- Implementation of new sensors to be able to measure other vital signs and thus obtaining a more exhaustive examination.
- Optimize the code in order to reduce the software execution time.
- The use of Wi-Fi technology instead of Bluetooth technology in order to reduce the time spent when transferring large files.
- Expansion of the database to store more information.
- Database in the cloud.
- Local storage in the microcontroller.
- Activity alarms.
- For the images that are generated from the respiratory rate, use of the DICOM standard (Digital Imaging and Communication in Medicine) [19].

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