Wearable devices for Health Remote Monitor System

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***Abstract*—It is feasible to see how communication and information technology have advanced at a rapid pace in today's world. The introduction of wearable technology is one aspect contributing to this progress and has the potential to be an innovative solution to healthcare challenges since it may be utilized for illness prevention and maintenance, such as physical monitoring, as well as patient management. In order to solve some of the healthcare challenges, this paper proposes the development of an intelligent health monitoring system with alerts and continuous monitoring using wearable devices capable of collecting biometric data on human health. The concept was then proven by the development of a prototype using sensors connected to a micro-controller which transmits its information via MQTT to a Node-RED powered dashboard that handles the health metrics monitoring. The designed prototype has proven satisfactory to provide evidences that support the developed research questions.**

***Index Terms*—Iot, Healthcare, Intelligent monitoring systems, Wearable devices, Data monitoring, Alerts**

I. Introduction

This paper presents the result of my research in the field of Internet of Things (IoT) and Medicine conducted between September 2021 and October 2022 at ISCTE-IUL. This document covers themes such as Wearable Technology, E-health and monitoring systems.

A. Motivation

When it comes to the elderly and people with chronic diseases or physical disabilities, there are certain challenges in terms of their healthcare because this individuals are frailer and have a weakened immune system, making them more susceptible to diseases. As a result, they require more care to maintain their health making it is necessary to find ways to improve their quality of life, such as encouraging the practice of physical exercise, regular medical monitoring and also physical and emotional support.

Wearable technology has the potential to be an innovative solution to healthcare challenges since it may be utilized for illness prevention and maintenance, such as physical monitoring, as well as patient management [1]. It makes use of wearable devices [2] that can monitor the health of specific individuals in a more convenient, quick, and secure manner [3], these may contain similar technological functionalities, however, they may be located in different parts of the body, constituting the Head-mounted wearable, Body-worn devices and Wrist-worn and handheld wearables, which are among the best known and widely used for healthcare purposes. These devices are small and simple to use, allowing for the collection of health data in real time and immediate transmission to doctors [4].

Due to the problems mentioned above regarding the older population and/or those with chronic difficulties, it is necessary to develop some kind of health monitoring system capable of overcoming these inconveniences, in which the health of certain individuals can be monitored, promoting the ways mentioned above to ensure their quality of life , something that is possible to accomplish due to the appearance and development of the wearable technology mentioned above.

B. Context

Healthcare monitoring systems are associated with communication and information technologies, particularly with the Internet of Things (IoT) and electronic health (e-health). IoT devices and technologies are widely recognized as critical enablers for a range of new applications, including remote health monitoring and play a critical role in making these applications more accessible and affordable to everyone [5]. E-health, according to Eysenbach [6], is a field that depends essentially on the junction of medical informatics, public health and business referring to health services. There have been certain studies that used these terms in different contexts, such as R. Miramontes, R. Aquino, *et al.* [7], a study that used a platform called "PlaIMoS" to monitor cardiovascular and respiratory variables, which consists of several wearable sensors, a network infrastructure to allow the transmission of data with security mechanisms, a server to analyze all collected data and apps for real-time measurements. A. Yunusova, J. Lai, *et al.* [8] examined the mental health of emerging adults as measured by a mental health app. This study's major purpose was to employ event mining to anticipate changes in mental health. To do so, with the use of wearable sensors they monitored the contextual aspects of daily affect changes, such as sleep, physiology, and activity.

This paper connects all the previous ideas (IoT, e-health, monitoring systems, wearable sensors), and shows a new methodology for collecting biometric data and integrating it into an intelligent system with alerts and continuous monitoring using wearable devices. In addition to these ideas, this paper and its project seek to contribute so that its users can access follow-up and medical support without having to travel to hospitals, allowing them to remain in the comfort and safety of their homes and carrying on with their daily lives.

C. Research questions

There are a few research questions that need to be answered with this paper. These questions are primarily concerned with the development of an intelligent system for monitoring biometric data via wearable devices, as well as determining the benefits and drawbacks of using this system and these devices.

- How can the tracking of personal health contribute to improve the quality of life of the target person?
- How to efficiently automate the transmission of personal health data?
- Can we reduce the number of alerts sent to healthcare professionals without jeopardising the patient support?

D. Hypotheses

The main goal of this dissertation is to develop an intelligent health monitoring system with alerts and continuous monitoring using wearable devices capable of collecting biometric data relating to human health, and to apply this system not only in a home environment so that people can be in the comfort of their homes while still monitoring their health, but also in their day-to-day lives. To achieve this and to answer the previously mentioned research questions, some hypotheses must be addressed and completed:

1) It's necessary to use a wearable device that can track a person's health;
2) Extract data from the wearable device;
3) Send the data to a server where it can be monitored using some type of protocol or/and a platform;
4) Monitoring all collected data within the server so alerts can be generated;
5) Saving all monitored data using a data base;

Primarily, to be able to answer the first research question, it is then necessary to perform the hypotheses 1 and 2 . Then to efficiently automate the transmission of personal health data, which is related to the second research question, is necessary to perform hypotheses 3. In relation to the third research question, hypotheses 4 and 5 need to be done.

II. State of the Art

This section will address the various types of sensors and data processing and techniques used in existing remote healthcare monitoring systems.

A. Literature Review

1) Data Processing used in remote health monitoring systems:

Data from wearable devices is analyzed and gathered in vast volumes, depending on the unique product [9]. Nowadays, there are multiple sorts of wearable devices that employ various types of sensors, therefore there are several specific ways to gather and analyze data. M. Vahabi, H. Fotouhi, *et al.* [5] evaluate the use of Shimmer sensors to monitor the ECG signal and the movement of a human gathering via Bluetooth with a Master node. In this study, the whole process of gathering and transferring data was done using only the shimmer sensors, a Raspberry Pi B+ (Master node) and a local database.

In more detail, a Python script was used to communicate the shimmer sensors and the raspberry pi, allowing data to be sent and stored on the raspberry pi local database.

F. Ullah, A. Iqbal, *et al.* [10] built a framework for physical activities and health monitoring for pregnant women. Their framework consisted of only three sensors, a three-axis accelerometer, a three-axis gyroscope, and a temperature sensor, creating a single wearable sensor module, connected to a Raspberry Pi via Bluetooth using Python-based *BlueZ* , same to [5], and a mobile phone.

The main goal of [11] was to create a Wearable Wireless Body Area Network (WWBAN) to monitor the health of elderly and disabled people using a pulse oximeter, heart rate, temperature, hydration, glucose level and fall detection sensors, Arduino, a LCD and GSM modem. To collect all the data from the sensors, they were connected to the Arduino and displayed on the LCD. The data was analyzed and processed sending alerts by SMS to a doctor using GSM modem via GSM network, if the data fall below or exceed the typical interval. The Things Speak platform was used to store the patient's data enabling health professionals to see it.

Through literature review, it was possible to determine that there are various types of wearable devices and their application is widely used for the creation of health monitoring systems. It was possible to discover that the equipment and sensors used were the same or slightly different, being that the most used sensors were those that monitored temperature, oxygen, and heart rate, the equipment utilized included the Arduino, Raspberry Pi and the most used platform used was Things Speak.

III. Intelligent Monitoring System - Monitoring Biometric Data via Wearable Devices

This intelligent monitoring system consists on demonstrating how it is possible to monitor biometric data in a secure and efficient manner through the use of wearable devices, therefore the following methodology was used, System Architecture and Structure and System development.

A. System Architecture and Structure

To better understand the system architecture, its structure was designed to include multiple layers, Figure III-A:

1) ***Hardware Layer: Wearable Device and Microcontroller***
   The equipment used for the realization of this system was a wearable device and a microcontroller, connected via Bluetooth. Regarding to the wearable device, a wrist-worn wearable, more specifically a smartwatch, for the purpose of this system, was chosen due to its ease of use and small size, as well as its ability to continuously collect biometric data such as,BPM (Beats per minute) and activity values(steps, calories, distance, and fat burned). In section II-A, the majority of the projects described used Raspberry Pi as their chosen microcontroller which is also the favored choice for the development of this system because it's a low-cost, credit-card-sized computer, who functions as a computer with its own operating system (Raspbian GNU/Linux version 11, in this case) that allows internet access and the installation of specific applications, libraries, and so on. To extract the values collected by the smartwatch this raspberry pi uses a Python-based program retrieved and adapted from GitHub [12], capable of establishing a connection with a MQTT platform, through which the collected data is transferred and then collected by the server.
2) ***Network Layer: MQTT Protocol and Platform***
   In terms of data transfer, the protocol used was the MQTT (Message Queuing Telemetry Transport Protocol),which is a binary data communication protocol that allows for a variety of communication patterns in an IoT environment [13] and makes use of a client-server system with publish/subscribe approach. In this protocol, all messages have a topic to which clients can subscribe or publish (procedure used inside of the Python-based program); messages published by clients are received by a broker, who subsequently sends the messages to all clients who have subscribed to the specified topic [13]. This protocol was applied using the HiveMQ Cloud Platform, which is a fully managed cloud-native IoT messaging platform that makes IoT device connectivity reliable and scalable [14] and allows users to create a free MQTT broker cluster with 100 subscriptions per connection and a capacity of roughly 10 GB, allowing to connect to various IoT devices (System's Raspberry pi) and store information (System's biometric data).
3) ***Data Layer: Server and DataBase***
   The server that was chosen to monitor all the transfer data and generate alerts was the Node-RED. This programming software is a free JavaScript-based tool, built on Node.js platform and has a flow editor for building JavaScript functions in a web browser, making it simple to connect flows using the palette's various nodes. The primary goal of using this software consisted in establishing a connection with a MQTT platform, gather all of the data to be monitored sending email alerts if the data doesn't meet the predetermined thresholds and store the data to a MongoDB data base. This database accepts larger data, with a maximum value size of roughly 16 MB and provides consistency, durability, and conditional atomicity [15] and in this system contains several collections, "Sensores_User1, Sensores_User2 , ... ", which are linked to different users and respective biometric data. Their structure consists of "User Details"(id and user's age), "HR"(BPM value and respective time and date) and "Activity"(steps, calories, distance and fat burned).
4) ***Application Layer: Dashboard Node-RED***
   This layer represent the Node-RED Dashboard making it possible to visualize the biometric data collected by the Node-RED in a more appealing and easy way into two tabs, "Biometric_Data" tab (displays all the user details, biometric data, alerts and current average velocity to see if he is performing any type of activity) and "Alerts" tab (includes a table that stores all of the alerts generated throughout the day.)

B. System development

In this section, the data monitoring methods employed in this system and the alerts generated will be discussed in more detail existing in total five monitoring methods in order to provide a good data monitoring:

1) Maximum and Minimum limitations for the Heart Rate value have been established, which According to [16], the normal Heart Rate values over the age of 10 years old ranges between 50/60 BPM and 90/100 BPM. This monitoring system, if violated, generates the "Heart Rate Alerta" alert which, when handled, generates the "Heart Rate Controlado" alert.
2) Taking into account the possible presence of cardiac arrhythmias, tachycardia (BPM$>$100, which generates the "Heart Rate elevado" alert) and bradycardia (BPM$<$50, which generates the "Heart Rate baixo" alert), more limits were created.
3) The heart rate values can reach higher levels when an individual engages a physical activity, potentially exceeding the previously specified limits, resulting in the generation of "false" alerts. To solve this, the equation 1 was used.
   $$\overline{v} = \frac{\Delta x}{\Delta t} \tag{1}$$
   According to L. L. Long and M. Srinivasan's research [17] the average velocity of a person when performing a walk-run mixture or fast pace is between 2 and 3 m/s, and when mostly running can vary between 3.5 and 4 m/s approximately.With this information a limit was created and whenever the user's average speed exceeds the predefined limit, the user is performing a physical activity and the "Atividade fisica" alert is generated.
4) When engaging in a physical activity three's also a maximum heart rate limit which is calculated, according to [18], with the following equation 2.

$$BPM_{max} = (220 - Age) * Percentage_{max} \quad (2)$$

This equation consists of subtracting 220 by the individual's Age and then multiplying by the $Percentage_{max}$, which value is 0.76 (76%), according to [18]. Whenever the BPM>BPM_{max} the alert "Alerta Atividade fisica Heart Rate elevado" is generated.

5) The value of the heart rate changes over time, which can be rather quick, depending on the person. In order to know if the heart rate has a concerning increase, the equations 3 and 4 were used.

$$\sum_{k=1}^{n} Diff\_HR_{K...n} = |HR_{K+1} - HR_K| \quad (3)$$

$$Average_{HR} = \frac{\sum_{k=1}^{n} Diff\_HR_{K...n}}{Number_{Diff\_HR}} \quad (4)$$

The 3 equation consists in calculating the summation of the difference between the five received heart rate values (these values are received every one second), i.e. $HR2$ subtract by $HR1$, $HR3$ subtract by $HR2$, and so on. After obtaining this summation, it is possible to use the 4 equation, which consists in dividing this summation by the $Number_{Diff\_HR}$ and obtaining the average heart rate value. For example, if the value of $Average_{HR}$ is equal to 3.5, the Heart Rate value would have increased by exactly 14 values in 5 seconds, which generates the alert "Alerta Variacao de Heart Rate". Besides theses alerts, when the heart rate value equals zero the alert "Heart Rate Nulo" is generated. All alerts generated during the respective day will be shown on the node-RED Dashboard under the "Alertas" tab and could be viewed in a collection called "Alertas" in the MongoDB Database.

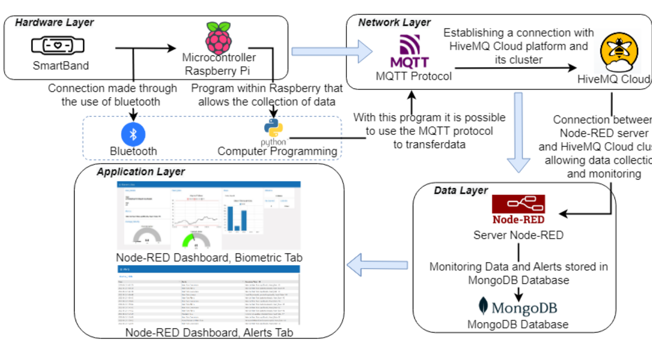

Fig. 1: Diagram of the system's development

IV. Implementation, Results and Discussion

This section will examine and discuss the requirements for a good connection between the system's hardware and the results gained by employing the monitoring methods of the system.

A. The requirements for a good connection between the system's hardware

When using the hardware for possible biometric data collection and transfer, it was necessary to perform some tests to verify the maximum distance that the smartwatch could be from the raspberry pi in order to maintain the connection. Through these tests, it was feasible to determine that the maximum distance possible to retain a good connection and/or not failing is approximately a radius of 16 meters, concluding that the distance is a little short in comparison to bluetooth 4.1 (around 100 meters [19]), due to the usage of the Python-based program, which reduces Bluetooth's potential and the presence of numerous physical obstacles.

B. Monitoring Methods and results

To obtain the results, this system was tested using two different users, user 1 and user 2. The user 1 is 24 years old and does not have any type of illness nor does he take any type of medication and the user 2 is 54 years old and has high blood pressure, necessitating medication. user 1 and user 2 monitoring, more precisely their heart rate values can be respectively visualized through the figures 2 and 3.

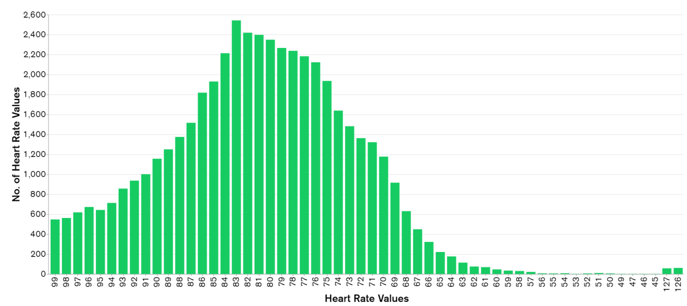

Fig. 2: User 1's heart rate values

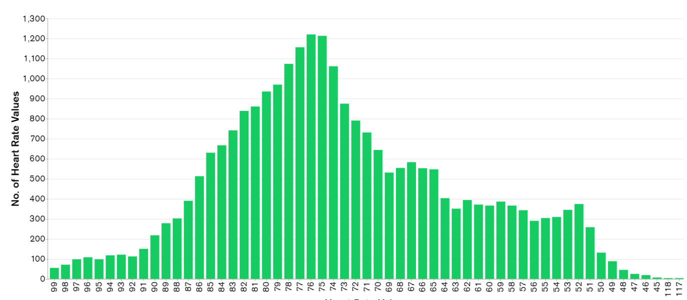

Fig. 3: User 2's heart rate values

As shown in the figures above, when comparing the two users their heart rate values behaved similarly with an interval for user 1 between 71 and 87 BPM and for user 2 between 84 and 70 BPM, which are reasonable heart rate values according to [16]. However, it is possible to conclude that the user 1 had more records of elevated values, between 89 and 99 BPM, than low values, between 65 and 51 BPM and user 2 had more records of values between 65 and 50 BPM and less between 90 and 99 BPM, which is quite interesting because its the opposite of the user 1, which implied that user 1 had a higher heart rate and user 2 a lower heart rate. Concerning alerts, the figure 4 can be used to locate the intersection of some alerts generated by both users.

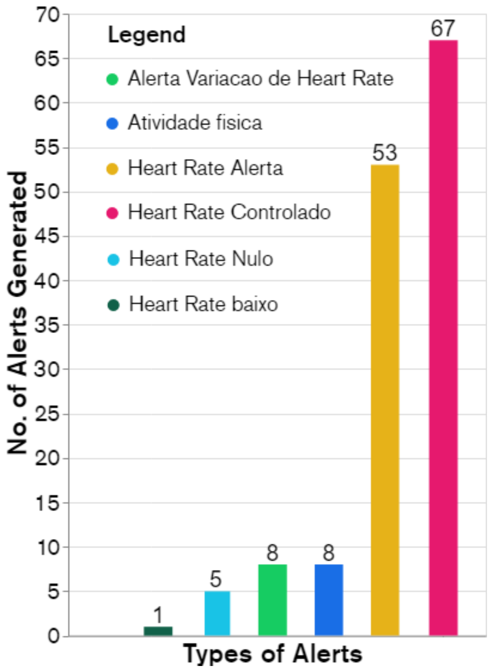

Fig. 4: Some alerts generated by both users

The system is functioning properly, since all possible alarms were generated. Both users' monitoring was pretty good, because the most frequently registered alert was "Heart Rate Controlado". On the other hand, it is possible to confirm the presence of the "Heart rate Alerta" alert (heart rate measurements above or below the predefined limits) and that this alert was generated unnecessarily, i.e., these alerts have predefined values, and due to the tests performed on the two users, it was possible to conclude that the maximum and minimum defined values, 95 and 55 BPM respectively, were not the most adequate, despite the fact that these were the default values found in [16]. user 1's heart rate behaves in a faster manner, exceeding the maximum limit of 95 BPM and user 2's heart rate behaves in a slower manner, with readings lower than the minimum limit of 55 BPM. The same holds true for other monitoring methods, for example, the "Alerta Variacao de Heart Rate" which requires different values for both users due to their different heart rate behaviors.

As a result, it was possible to conclude that before the limits incorporated into the monitoring methods can be defined, it is first necessary to understand the person's health history, as to the possible existence of diseases and/or taking any kind of medication, in order to create a more accurate monitoring system without generating so-called "false alarms".

V. Conclusion and Future Work

A. Conclusion

According to the results achieved in the previous section the authors conclude that it was possible to execute efficient monitoring of two users without the need for users to go to a hospital establishment and the physical intervention of a doctor. However, this method only works at home in medium/short distances, because the distance to maintain connection between the system's hardware is limited, as stated in IV-A, and that the raspberry pi is not a portable device; it requires an electric current to function, making it impossible to verify a person's typical day-to-day life outside of home, which represents a limitation. This nevertheless is reasonable evidence to answer the first research question stated in section I-C.

Additionally, we may conclude that this system can provide a favorable result because it's possible to transmit all acquired data in a very efficient and automatic manner due to the use of a python-based program, the MQTT protocol, and the node-RED server, which ensure the automation of this system and the monitoring of the users' health, which answers the second research question.

Finally, this system is also capable of sending alerts only when monitoring methods are violated, sending another alert only when another monitoring method is violated, preventing the generation of duplicate unneeded alerts, which is sufficient to provide a response to the third research question.

B. Future Work

This section primarily consists of offering future suggestions and innovations for improving this system and making it more efficient for future use. This future work consists in overcoming the limitations of this system and the most critical concerns is the establishment and maintenance of the connection between the two devices by increasing the distance between them, allowing for more accurate and effective monitoring. With this monitoring, it is possible to assess an individual's health more accurately because they can move more freely in their houses and travel greater distances without jeopardize the system. Related to this limitation, is to employ a portable and easy-to-move device instead of the raspberry pi for better monitoring, allowing a more precise analysis of the user's health, since it could be done during the user's normal daily life without having to worry about exceeding the maximum distance between the two devices and the need of an electric current.

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