Towards a Fully Automated Bracelet for Health Emergency Solution

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Keywords: Bio Signal Monitoring Device, Arduino, Sensors, RF Communications, Emergency Scenarios Detection.

Abstract: Activity and health monitoring bracelets are currently a popular consumer electronic wearable, and several different manufacturers market several different versions, integrating a wide and diverse range of sensors. The several different types of bracelets often require the user to interact with the bracelet itself or with the help line attendant. However, this interaction is not suitable in many emergency scenarios. Thus, this paper presents a novel system to monitor, detect and communicate health critical situations, in a full automated manner. The system encompasses a bracelet capable for health abnormalities detection based on both vital signs, and accelerometer data collection from the user. This paper also describes the design and prototyping process of the bracelet, providing insight and solutions to observed problems. In spite of the early stage of this system, the observed results are promising and offer room for improvements on either complementary studies or different clinical emergence scenarios.

1 INTRODUCTION

According to (United Nations, 2015), by the year of 2015, Europe, Oceania and North America, had about 20 percent of elderly people (60 or more years old). By 2050, these numbers are expected to become higher than 30 percent. Authors of (Administration on Aging; Administration for Community Living; U.S. Department of Health and Human Services, 2012) indicate that, only in the United States of America, by 2011, the number of persons aged 65 years old or more was representing 41.4% of the total country's population, number expected to increase to about 56% in 2020. The authors also indicate that "about 28% (11.8 millions) of noninstitutionalized older persons live alone (8.4 million women, 3.5 million men)", where "almost half of older women (46%) age 75+ live alone".

As studied in ("Saúde Pública - Fatores associados a quedas em uma coorte de idosos residentes na comunidade Fatores associados a quedas em uma coorte de idosos residentes na comunidade," n.d.), the fact that an elderly is living alone contributes to the increase of the chance of occurring a fall, representing 28,5 percent in 1667 studied Brazilian elderly people, during two years. Living alone, described as "loneliness" in (Barg et al., 2006), is even "highly associated with depressive symptoms, anxiety, and hopelessness".

Depression being so present among people with more than 60 years old and taking into account that "high levels of depressive symptomatology are associated with increased risks of myocardial infarction (MI) and mortality" ((Barefoot and Schroll, 1996)), elderly living alone is a current and an expected future scenario for many families, which raises pertinent challenges due to the fact that accidents may occur with elderly and frail people, which may result in morbidity or eventually in death.

Only in the United States of America (USA), as presented in (Lloyd-Jones et al., 2010), from the total amount of deaths caused by Cardiovascular Disease (CVD) in all ages during 2006, the origin for 51 percent of the cases was Coronary Heart Disease (CHD) and Stroke for 17 percent. These same data show that approximately 677 thousand deaths were recorded due to CVD in people aged 65 years or older, and were also noted approximately 33 thousand deaths caused by Heart Failure (HF) in people 60 years of age or older, in the same year as the previous.

Matias, I., Pombo, N. and Garcia, N.
Towards a Fully Automated Bracelet for Health Emergency Solution.
DOI: 10.5220/0006800803070314
In *Proceedings of the 3rd International Conference on Internet of Things, Big Data and Security (IoTBDS 2018)*, pages 307-314
ISBN: 978-989-758-296-7

Notwithstanding every emergency solution is intended to be the fastest and easiest possible, the current solutions are merely based on emergency calls, wrist bracelets, or pendant devices with an emergency button. Therefore, its application in real life is limited to cases when the user is conscious and at the same time is susceptible to limitations due to the "human factor", in either the call duration or the difficult to press the button.

Although every created solution tried to decrease the time until the receipt for therapeutic strategies, delays such as "human factor", manual emergency buttons, people avoiding ambulance services when they really need it and others, "prevent the early application of life-saving procedures and contribute substantially to a diminished effectiveness of treatment" ((Luepker RV et al., 2000)).

Thus, this paper describes the design and the implementation of a fully automated device capable of recognizing several types of health conditions, as well as contacting the emergency services when needed, using the vital signals collected from the users' wrist.

The proposed system also provides a personal database of collected vital signals, which will then be used by a doctor to detect any abnormalities in an early stage, also as providing other ways to decrease the emergency response time.

In summary, the main contribution of this study is to define a fully automated system architecture to measure vital signals, in order to detect movement abnormalities or hearth related diseases and, therefore, to alert physicians and/or informal health care providers on alarm episodes, while using mostly open access electronics. The ultimate goal is to provide an intelligent and autonomous solution to help persons living alone or being monitored due to a chronical disease.

2 BACKGROUND

As presented in Table 1, there are already on the market several solutions for the simple "emergency button" option, such as (Bay Alarm Medical, n.d.; Rescue Alert, n.d.; LifeStation Inc., n.d.; Alert1, n.d.; Philips N.V., n.d.; ADT LLC, n.d.; Life Fone, n.d.; Medical Guardian LLC, n.d.; Solodev, n.d.; Samsung, n.d.; FitBit, n.d.; Mi, n.d.), some having an extra feature like Global Position System tracking or fall-detection and others being able to collect some important health data used in this new approach, such as heart rate and body temperature (smart bands and smart watches).

However, none offers a way to interlink the collected data to detect health conditions and/or immediate emergency situations, this is, some of the current solutions already have some of the same sensors this new approach uses, but they are not using its data to recognize health conditions/emergencies.

For example, by using a pulse monitor (capable of reading heart rate variability and others), it is possible to detect arrhythmia ((Patel et al., 2012; Tsipouras and Fotiadis, 2004)), CVD (("HEART RATE AS A PROGNOSTIC FACTOR FOR CORONARY HEART DISEASE AND MORTALITY: FINDINGS IN THREE CHICAGO EPIDEMIOLOGIC STUDIES | American Journal of Epidemiology | Oxford Academic," n.d.)), Coronary Artery Disease (CAD) ((Kligfield et al., 1989)), HF ((Nolan et al., 1998)) or even a stroke ((Glotzer et al., 2003; Ritter et al., 2011)). Using a body temperature sensor, it is still possible to establish a relation between hypothermia/hyperthermia and longevity after a stroke happen ((Kammersgaard et al., 2002)). Finally, by using an accelerometer to monitor the user's sleep, it's possible to detect certain episodes and/or disorders, described in (Hjorth et al., 2012).

Thus, to decrease the lack of assistance in emergency situations, it is necessary to create a device capable of, using mainly already existing sensors, detect and automatically react to health abnormalities, being anyway portable and easy to use.

Table 1: List of Features of Each Device.

	Features						
Name of solution	**Fall detection/accelerometer**	**GPS locator**	**Heart rate monitor**	**Body temperature**	**Skin detection**	**Health record**	**Emergency button/contact**
Bay Alarm Medical ((Bay Alarm Medical, n.d.))						**X**	**X**
Rescue Alert ((Rescue Alert, n.d.))							**X**

Table 1: List of Features of Each Device. (cont.)

LifeStation ((LifeStation Inc., n.d.))		X					X
Alert1 ((Alert1, n.d., p. 1))	X	X					X
Philips LifeLine ((Philips N.V., n.d.))	X	X					X
ADT Medical Alert ((ADT LLC, n.d.))	X	X					X
LifeFone ((Life Fone, n.d.))	X	X					X
Medical Guardian ((Medical Guardian LLC, n.d.))		X					X
MobileHelp ((Solodev, n.d.))	X	X					X
Samsung Gear S3 ((Samsung, n.d.))	X	X	X				
FitBit alta HR ((FitBit, n.d.))	X		X				
Mi Band 2 ((Mi, n.d.))	X		X				
Proposed system	X	X	X	X	X	X	X

3 METHODS

This section describes the proposed system, including its components, and decision workflow. In this study, a prototyping platform, known as Arduino, was used. In fact, two units were used, one to collect data from the sensors and other to collect data sent from the first, which is stored and interpreted, combined with the following sensors:

- 3-axis accelerometer ((Analog Devices Inc., 2009));
- GPS antenna ((Sparkfun Eletronics, n.d.));
- Pulse sensor ((Sparkfun Electronics, n.d.));
- Body temperature sensor ((Sparkfun Electronics, n.d.));
- Skin contact detection sensor;
- Waterproof speaker ((VISATON GmbH & Co. KG, n.d.));
- 434 MHz radio frequency transmitter and receiver ((Sparkfun Electronics, n.d.));

All these sensors, excluding the skin contact detection, are off-the-shelf components, and available on the market, not from medical grade. The skin contact detector was designed and built for this specific study. It is composed by two electrical pins (wires) and one 1 kilo ohm resistor (similar to the human skin resistance, as studied and concluded in (Ho et al., 2012)), as illustrated in Fig. 1, referring the output power of the Arduino board.

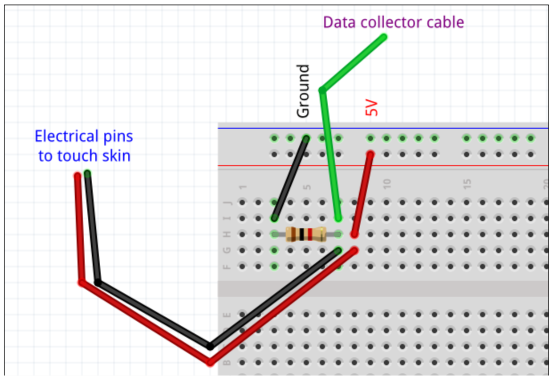

Figure 1: Skin contact detection sensor scheme.

The data collector cable was connected to an analogue input port, which receives 10 bits' data, and the electrical pins are designed to touch the skin of the user (placed on his/her arm).

All the boards' ports used to connect all the sensors are listed in Table 2.

Table 2: Ports and Sensors.

Input/output	Sensor(s) connected
GND	Accelerometer, GPS antenna, Pulse sensor, Body temperature sensor, RF transmitter, RF receiver, Speaker, Skin contact detection sensor
3.3V	Accelerometer
5V	GPS antenna, Pulse sensor, Body temperature sensor, RF transmitter, RF receiver, Skin contact detection sensor
A5	Accelerometer
A4	Accelerometer
A3	Accelerometer
A1	Skin contact detection sensor
A0	Pulse sensor
8	GPS antenna
9	GPS antenna
10	Body temperature sensor
3	RF transmitter (part of the device for the user to wear), RF receiver (part of the device to collect data to store)
11	Speaker

This project is composed by two distinct parts, assembled in two Arduino boards.

On the collector and transmitter board we assembled all the sensors to collect data, the speaker and the RF transmitter. This part was responsible to be on the users' wrist, powered by a 7.0 volts' battery, to read all the sensors and send the information collected, each 10 seconds, to the other board.

On the other hand, the receiver and interpreter board was connected to a computer and, by reading the data received from the RF receiver, checked if any emergency scenario (described below) were detected and, if necessary, sounded an alarm, contacting the emergency services automatically, also sending the recorded vital signals data of the last 24 hours.

By combining these two concepts and running the scenarios described below, the device can produce alarms, that can be deactivated in case of a false alarm, establish the automated contact with the emergency services, send sensors data from the moment and the last hours to that crew and guide them to the victim, using sound.

Some of the already designed scenarios need to be improved and tested in real cases, being then interpreted by an Artificial Intelligence.

Besides very basic yet, they are the following:

- Detect if the device is placed on the user's wrist:
    - If the data collected from the skin contact detection sensor is higher than "200" (skin detected), proceed to the next scenarios. Else, repeat this scenario.

- Pulse abnormalities detection:
    - If the pulse is below 30 beats per minute (BPM) or higher than 140 BPM, check temperature;
    - If the body temperature is under 38ºC and higher than 36ºC, check the pulse during the next 20 seconds;
    - If, during the next 20 seconds, the pulse average is lower than 35 BPM or higher than 135 BPM, start "emergency procedure";
    - (the BPM and body temperature values will be adapted to each user of the prototype, regarding his/her previous recorded data and known health condition);

- Body temperature abnormalities detection:
    - If the body temperature is lower than 36ºC or higher than 39ºC, repeat this scenario during the next 30 seconds;
    - If in the next 30 seconds the temperature average is lower than 34ºC or higher than 40ºC, start "emergency procedure".

- Movement abnormalities detection (falls or abrupt movements originated by some type of injury):
    - If there are "G-force" readings higher than 3.55 G (fall peaks studied in (Bourke et al., 2007)), check data from the accelerometer during the next 10 seconds;
    - If, in the next seconds, another positive of the first point is detected or the "G-force" average is lower than 1.2 G, start "emergency procedure" (it was detected a fall and the user isn't moving anymore);
    - (the movement values will be studied more closely in the next phase of this research).

- Emergency procedure:
    - The alarm is sounded by the speaker on the collector and transmitter device;
    - If, during the next 30 seconds, a "false alarm" button in the collector device is not pressed (to implement on the next phase of this research), start the automated call to the emergency services, sending the location of the person (detected by the GPS antenna) and the data collected 30 seconds before the scenario was detected;
    - When it's confirmed that an emergency crew is on the way to the user's location to help, start sending the data collected every 30 seconds, preceded by the sending of the records of the last 24 hours.

Moreover, all the collected data are stored during 24 hours on the collector and then sent to a remote database, which can be accessed and used by a physician to detect some health issue not causing an emergency.

4 RESULTS

By assembling the two concept parts, it was possible to collect and interpret the "normal" vital signals data from a person on a non-controlled environment or state.

Making an automated device capable of detecting health issues means it needs to have sensors capable of measuring certain vital signals. In line with this, the presented project is designed to be able to recognize patient's behavioural abnormality, based on heartbeat, body temperature and body movements.

Related to the heart, this type of device would have to be capable of detecting, for example, a stroke. According to (Ritter et al., 2011), a stroke can be diagnosed and evaluated using the pulse BPM collected data and, as studied in (Glotzer et al., 2003), it can also be detected thru Atrial High Rate. Other important heart disease is arrhythmia which, as tested in (Patel et al., 2012), is possible to detect through the “R-R interval” (also known as “Inter Beat Interval”). With Heart Rate Variability, it is even possible to detect a Heart Failure case ((Nolan et al., 1998)) and, as concluded in (Kligfield et al., 1989), a Coronary Artery Disease can also be assumed using data collected from heart rate. Finally, it is also possible to establish a connection between the heart rate and the probability of having Cardiovascular Diseases, thus being an important way of diagnose. To solve and be able to detect these five studied types of heart diseases we used a pulse sensor (Sparkfun Electronics, n.d.), measuring BPM, ST segment and IBI of the patient.

About body temperature, it is needed to measure the users’ one, allowing the device to detect any abnormalities as described in (Lu and Dai, 2009) (more specific to people above 65 years old) and recognize patterns for diagnose after a stroke has occur, as concluded in (Kammersgaard et al., 2002). For that, the solution was using a body temperature sensor found in (Sparkfun Electronics, n.d.).

Finally, using a 3-axis accelerometer ((Analog Devices Inc., 2009)) the device can detect falls, false-alarms and sleep monitoring the user, as detailed in (Hjorth et al., 2012).

The only scenario coded so far was a small part of the movement abnormalities detection one. Because there were only tested the average signals, it is not possible to present any significant results of this at this stage of the project.

The Fig. 4 shows the current prototype of the receiver and interpreter board, as well as the current prototype of the collector and transmitter (“Intelligent Health Monitoring Bracelet” – adapted to a real-life bracelet – Fig.5). The current prototype of the collector is yet in a large scale, which will be reduced to a simple and discrete bracelet, replacing the Arduino board with a smaller version for wearable prototypes, also removing the extra amount of wires and replacing some sensors with other smaller and equivalent versions of them.

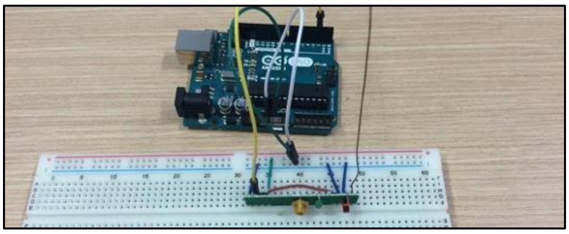

Figure 2: Current prototype of the receiver and interpreter.

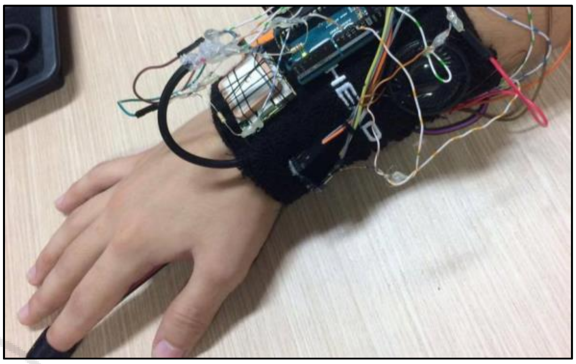

Figure 3: Current prototype of the collector and transmitter.

After assembling these two parts of the device, we found some issues on working with all the sensors together:

- Receiver and interpreter:
  - The length of the antenna had to be calculated depending on the frequency of the transmissions (0,17 metres as calculated in (1)), the same that was applied to the collector and transmitter. If lower or higher than 17 centimetres, the communication efficiency was lower in distance (the average was around 15 metres).

$$\frac{speed\ of\ light}{frequency} = \frac{300\,000\,000\ m/s}{434\,000\,000\ Hz} \approx 0{,}691244$$
$$\text{¼ of antenna wavelength} = \frac{0{,}691244}{4} \approx 0{,}17 \text{ metres} \quad (1)$$

- Collector and transmitter:
  - The GPS antenna had to be tested separately to the remaining sensors, because when all were plugged to the “5V” port, the GPS antenna didn’t receive the minimal amount of current and wouldn’t start seeking a satellite signal;
  - The accelerometer sometimes presented some values over 7 G-forces, due to bad connections of the sensors’ pins;

The skin contact detection sensor works best in non-fully dry skin, i.e. with some humidity in the human tissue (because the resistance is lower – more similar to the resistor used). To solve this, we forced the sensor against the user skin, working as expected.

5 DISCUSSION AND CONCLUSIONS

By crossing data from three sensors, namely, GPS, accelerometer, pulse sensor, body temperature and skin contact detection sensor, on the presented scenarios and implementing the two devices communication system, it is now possible to create a new e-health and intelligent emergency solution, with new features, complementing the ones described in the Introduction section. The proposed solution may solve several limitations observed on the literature:

- By removing the "human factor" during a routine or an emergency call this is a quicker solution;
- By sending the collected data from the 30 seconds before an emergency scenario detection and every 30 seconds after, it allows the medical crew to have real-time vital signals from the user, decreasing the "first medical exam" duration, done when arriving to the patients' home, also decreasing the helping time, increasing the chances of a good recovery of the person;
- By having an intelligent and advanced emergency scenarios software detector, it is avoided having an "emergency button" present on the current devices, this way reducing the chance of a "false alarm" or a false press of the button;
- With the data being stored and sent to a database, it allows a doctor to constantly remotely monitor the health of the user, being possible to detect several health issues in an early stage.

The skin contact detection sensor had to be implemented due to the non-exact values readied from the pulse sensor (when not placed on the user's finger the values derivate from below 20 BPM and higher than 200 BPM often) – this sensor has to be on the users' finger because it was designed for that and when tested on the arm the values were not correct (average of 20 BPM of difference to the real ones). This same sensor was built by us, because we didn't find any identical on the market.

After testing the reading process of the sensors data, we realize the storage capability of the Arduino board was not enough and preferred to send them to the receiver and interpreter device, being then stored in a computer. The same was applied to the scenarios recognition, offering a decrease of power consume of the battery.

Regarding the frequency on which the data must be collected, it is needed to study more deeply the ideal of collections in one minute (the minimum that won't affect the emergency solution efficiency), due to the high power consumption of the current one, which is constantly reading new values.

For the communicators antenna length, it will be sought a better antenna architecture, being then possible to implement it more easily on a real life wrist bracelet.

The list of the three sensors used were chosen due to the data collected and described in the Results section.

Related to the radio frequency communicators, they were chosen instead of "Wi-Fi" or "Bluetooth" due to the lower power consumption.

6 FUTURE WORK

Because this is an early stage of this project, it's only possible to us to present the work done so far.

On its next stage, there will be presented:

- The results of the tests, involving the scenarios detection (improve of the current ones and addition of new ones);
- The result of implementing an Artificial Intelligence algorithm for analysing the health data;
- The power consumption of each sensor used;
- The battery power management efficiency (turning on and off the sensors to economize it);
- Detailed success rates for the current communication process and its efficiency affected by distance, amount of data and environment;
- Possible communications alternatives, to prevent data loss when in rooms with many objects;
- A new and more easy to use version of the bracelet, using smaller and more efficient sensors;
- The results of the tests of the overall system (synchronization, success rate of

the communications and alarm generation and success rate for the health issue recognition).

ACKNOWLEDGEMENTS

Contributing to this research, the authors affiliated with the Instituto de Telecomunicações also acknowledge the funding for the research by means of the program FCT project UID/EEA/50008/2013.

The authors would also like to acknowledge the contribution of the COST Action IC1303 – AAPELE – Architectures, Algorithms and Protocols for Enhanced Living Environments.

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