Wearable Monitoring System

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Abstract

As people get older, both the body and mind suffer from it, making them more vulnerable, dependent and prone to various types of age-related illnesses. This means that the need for more regular monitoring increases. With the advancement of technology, it is now possible to remotely assess a person's health 24 hours a day. This leads to more accurate monitoring which leads to better diagnosis and improved quality of life as the patient does not need to travel unnecessarily to a hospital or health clinic, resulting in lower costs to the patient and hospitals. In this work, several technologies and projects address this problem are presented and compared. Next, a low-cost solution for a wearable device that combines health monitoring and indoor localization using a network of nodes is proposed. This solution is intended to be used in a person's house or in a nursing home, it is easy to install, and its main goal is to improve the autonomy and safety of its users with the lowest cost possible, allowing them to age in their home and thus promoting a better quality of life. The developed solution was evaluated and proved to be effective in locating and monitoring the activity level of the person, and in analyzing and forwarding data from the sensors. The solution is modular and can easily be expanded in the future to incorporate more biomedical sensors.

Keywords: Wearable, health, monitoring, low-cost

1. Introduction

Human aging is inevitable. A person's body and mind will also age and this leads to a large number of people who are more debilitated, dependent and with age-related illnesses. This creates a growing need for constant monitoring and care. Older people tend to forget about taking medication, are more likely to fall, have difficulty moving, have health problems that need to be checked regularly and dementia is also a problem in this age group. These people are often unable to live by themselves and therefore, must live in a nursing home or with their family.

With the advances in technology, there are now many systems that can perform telemedicine and health monitoring. These intelligent systems are capable of monitoring a person at home with quality and reliability, which helps prevent frailty and the worsening of diseases. If a person is being monitored while doing their daily life, the results are more accurate, and the patient does not have to waste a day going to the hospital and to stay in an uncomfortable environment. With the *Internet of Things* (IoT), the patient's information can be quickly sent to a doctor to evaluate the data. With this type of systems, the need for hospitalization can be lessened by the right diagnosis, and time and money are saved for both the patient and the medical facilities.

However, the existing solutions have some negative characteristics. Usually, these systems have a high cost, the autonomy is not the best and are closed products. This means that these systems do not allow to modify or add new sensors and features.

This work proposes a low-cost system that uses a wearable device that can monitor the vital signs of one or more users in an indoor environment. The device uses sensors such as heart rate and an accelerometer to detect abnormal situations and generate alarms related to falls and inactivity. Combined to health monitoring, the system also performs room-level localization by having a network of nodes that communicate by radio frequency inside the desired indoor facility. All the information about the users is sent wirelessly through the network until it reaches the central node that processes and stores the data for later consultation on a web application created for that purpose. All the network and user information can be configured through the web application and all the alerts are configurable for each user. This combination of indoor localization and health monitoring is expected to have a good impact on the user's health diagnosis. It is intended to be used at the user's house or in nursing homes, and it is capable of monitoring several users at the same time. The main goal is to demonstrate that the low-cost solution proposed in this work, has the potential to be used as a real life health monitoring and indoor localization system. The total system cost must be as low as possible without losing the main features required. The system will monitor the users every day without restricting their daily life, which makes them feel more comfortable by knowing that their health and physical status is constantly being monitored, contributing to their wellbeing and increasing their quality of life.

The rest of this document is organized as follows: chapter 2 includes related work about communication protocols, indoor localization, fall detection and health monitoring. Chapter 3 presents the proposed health monitoring and localization system. And finally, the conclusions are presented in chapter 4.

2. Background

2.1. Indoor Localization Techniques

Indoor localization [1] can be defined as any system that can determine the position of something or someone inside of a closed structure continuously and in real time. In order to achieve a reasonably good accuracy, the system needs to be able to handle several problems such as smaller dimensions, high non line of sight (NLOS), interference of obstacles like walls, objects and movement of human beings and the multipath effect. The multipath effect occurs when the radio signals are reflected by obstacles and reach the receiving radio by two or more different paths. The performance of a localization system can be evaluated according to the accuracy, responsiveness, coverage, adaptiveness, scalability, cost and complexity of that system. Indoor localization techniques can be divided into three categories: proximity, triangulation and scene analysis.

2.2. Communication Protocols and Radios

There are many different types of RF protocols available with various advantages and disadvantages. Three important characteristics to consider when choosing a wireless communication method are data rate, range and power consumption.

The communication protocols and radios compared in this work are:

Wi-Fi - WiFi [2] has a very high data rate but also has high power consumption. A popular Wi-Fi module is ESP8266 [3] and costs around 6 euros.

ZigBee - This protocol [1] is based on IEEE 802.15.4 and it is one of the standards in terms of wireless sensor networks. The XBee [4] module is a low power radio that allows a microcontroller like an Arduino to communicate wirelessly using Zigbee and costs around 20 euros.

Bluetooth – Bluetooth [1, 2] is a wireless standard for wireless personal area networks (WPANs). Almost every Wi-Fi enabled mobile device, such as mobile phone or computer, also has an embedded Bluetooth module.

Bluetooth Low Energy – BLE [5] is a wireless personal area network technology. Compared to classic Bluetooth, is intended to maintain a similar communication range while providing a reduced power consumption and cost. HM-10 [6] is a popular BLE module to work with Arduino.

GSM – The Global System for Mobile communications [7, 8] is the standard for digital mobile communications. It is necessary to have a SIM card and the messages or data that is transmitted have a cost associated. SIM900A [9] is a popular GSM module and costs around 10 euros.

CC1101 radio module - CC1101 [10] is a low-cost transceiver designed for low-power wireless applications and the cost of this radio module is around 4 euros.

nRF24L01+ radio module - The nRf24L01+ [11] is a single chip designed to operate in 2.4 GHz worldwide ISM frequency band and uses GFSK modulation for data transmission. This radio is one of the most inexpensive data communication options that can be found. It costs less than 1 euro.

Table 1 displays a comparison between all the devices discussed above regarding consumption power, data rate, range and average price:

	Consumption	Data Rate	Range	Price
ESP8266	170mA	54 Mbps	100m	6€
XBEE	45mA	250 kbps	20m-30m	20€
HM-10	50mA	2 Mbps	10m	3€
SIM900A	500mA	9.6 Mbps	Global	10€
CC1101	14.7mA	600kbps	40m-50m	4€
NRF24L01+	13.5mA	2 Mbps	30m	0.8€

Table 1: Comparison of different radio modules regarding consumption, data rate, range and price

2.3. Fall Detection

According to the World Health Organization [12], approximately 28-35% of people aged of 65 and over fall each year and the frequency of those falls increases exponentially with age and frailty level.

There are basically two types of fall detection systems: context-aware systems and wearable devices (including smartphones) [13]. The context-aware systems are based on cameras, floor sensors, infrared sensors, microphones, and pressure sensors. Wearable-based solutions can combine different sensors such as accelerometers, gyroscopes, inertial sensors and barometers. But the accelerometers are the most used option within the literature [14]. Most of the fall detection techniques based on wearable devices are machine learning (pattern matching) techniques or fixed thresholds techniques [13].

2.3.1 Dynamics of a fall

In order to detect a fall based on acceleration, the magnitude of acceleration needs to be calculated using the 3 axis accelerometer values (equation 1).

$$\hat{a} = \sqrt{\alpha x^2 + \alpha y^2 + \alpha z^2} \tag{1}$$

A Fall event can occur in different directions but usually the acceleration pattern is the same. A typical fall can be divided into 3 sections: the free fall period, the impact period and the inactivity period:

Free fall period - In this period, the subject starts descending towards the ground and the acceleration is less than 1g and tending to 0g.

Impact period – After descending, the subject eventually impacts the ground or other objects and the acceleration rapidly increases to values usually greater than 3g.

Inactivity period – After the impact, the subject usually remains almost motionless for a very short amount of time. This happens even if the fall event does not have any serious consequences. After the fall, the subject may become unconscious or start moving and trying to get up.

2.3.2 Fall detection solutions

In [15], an easy to use wrist-worn fall detector called Speedy was developed. After a heavy fall, the device detects it and alerts a call center. It can emit an alert even if the user is unconscious or too agitated to ask for help by himself. The system has an accelerometer and uses 3 thresholds to detect a fall. Those thresholds are the acceleration magnitude, the current speed and the vertical speed. The system does not measure the orientation of the user and this is the main problem with this solution. If the user rotates during a fall, there could be many errors in the threshold calculations, and this can result in a poor fall detection.

[16] proposed a solution also based on fixed thresholds but it also adds a threshold for orientation change retrieved from the gyroscope. There is a trigger that activates if the magnitude of acceleration is lower than the lower threshold. After that, If the acceleration goes higher than the upper threshold, another trigger is activated. If the person's orientation changes within 0.5 seconds of activation of trigger 2, and the orientation change remains for 10 seconds (indicating the person is immobilized), a fall is detected. If any of those triggers fails to occur, all the triggers are reset, and the acceleration readings are taken as normal. It was also implemented a false alarm button that can be pressed within 5 seconds after a fall is detected and a button to ask for help. This solution has also a GPS module that sends the location of the user when an alert is emitted.

[17] proposes several features that can be calculated trough the analysis of the acceleration magnitude measurements. After calculating those features, they are used as input to a neural network. Despite the good results, the neural network was trained with data from simulated falls. Real falls data is needed in order to validate the solution.

Apple Watch [18] is a smart watch produced by Apple and it has the capability of detecting falls. When a hard fall is detected by the Apple Watch, an alert appears and allows the user to easily call emergency services or dismiss the alert. If the user is unresponsive for about a minute, a 30-second countdown will begin, and a sounding alarm will start. When the countdown ends, an emergency call will be placed automatically, and a message will be sent to the user's emergency contacts. The falls are automatically recorded, and the fall history of the user can be checked. This feature is automatically enabled for users that are 55 years and older and can be turned on for anyone in the Apple Watch app.

2.4. Health Monitoring Systems

2.4.1 AMON

AMON [19] is a wearable medical computer for high risk patients. The system is a watch-like housing mounted on a wrist blood pressure cuff. It continuously monitors and logs, pulse, blood oxygen saturation and the patient's temperature. The level of physical activity is measured by an acceleration sensor. When necessary, blood pressure and electrocardiogram (ECG) can also be taken. The system performs an online analysis of the user's health status and if the results are reasonably different from a predefined user specific range, additional measurements such as ECG and blood pressure are required. If those additional measurements confirm the deviations, the system automatically alerts a doctor. A manual alert can be triggered whenever the patient feels that he needs assistance. All the data logged in the previous hours is sent to the medical center.

The medical personnel can communicate with the patient using the simple LCD display of the device and then can instruct it to perform new measurements.

2.4.2 MySignals

MySignals [20] is a development platform for medical devices and eHealth applications. It allows more than 20 biometric sensors such as pulse, breath rate, oxygen in blood, electrocardiogram signals, blood pressure, muscle electromyography signals, glucose levels, galvanic skin response, lung capacity, snore waves, patient position, airflow and body scale parameters (weight, bone, mass, body fat, muscle mass, body water, visceral fat, Basal Metabolic Rate and Body Mass Index). This makes MySignals one of the most complete eHealth platforms in the market. All the data gathered by MySignals is encrypted and sent to the user's private account in a Cloud API. The information can be sent using Wi-Fi or Bluetooth Low Energy 4.0. The data can be visualized in a tablet or smartphone with Android or iPhone Apps and in a TFT screen incorporated on the platform. It also features an alarm/emergency button that provides immediate assistance by just pressing the button.

2.4.3 HealthBand

HealthBand [21] is a project that detects and locates a person whose health status is in danger. It is designed as a remote rescue system for people who are at risk of having a stroke, cardiac arrest and heart attack. A smartphone is synced with a wearable health monitoring bracelet that can read the user's vital signs such as pulse rate and body temperature. If the bracelet detects life threatening vital readings, the phone synced to the bracelet will automatically call the family to prompt the person's health status. The wearable device contains an ATmega328 chip acting as a standalone Arduino that is connected to a body temperature sensor, a pulse rate sensor and a blood pressure sensor. The device communicates with a mobile app that shows the information gathered by the sensors and the data is refreshed every 30 seconds.

2.4.4 FrailSafe

The FrailSafe Project [22] consists of an integrated assessment system that can estimate the patient's frailty level, provides health monitoring, indoor and outdoor localization, games for cognitive stimulation and generates notifications in case of adverse events.

The indoor localization system of this project is based in Bluetooth beacons. Several of those beacons are positioned in the older person's home and constantly emit a unique identifier (ID). The device that receives that information is a smartphone or a smartwatch that must be carried by the patient all the time. The mobile device receives the signal from the beacons and estimates the person's current room by calculating the distance between itself and the beacon.

Regarding health monitoring, the system is composed of a sensorized garment, an electronic device and a software tool for visualization of streaming data or downloading the recorded data from the electronic device to a PC and then uploaded to a cloud service. The sensorized garment is a shirt with short sleeves that has two fabric electrodes for electrocardiogram (ECG) monitoring, a fabric piezoresistive sensor for respiration monitoring on the chest, and two small boxes with a 9-Degrees of Freedom (DoF) IMU sensor that is placed in each sleeve. All sensors are connected via cables to the device and collects the data from them. After that, a microprocessor elaborates several parameters, and all the raw and processed data are saved on a microSD card. That data can be transmitted by Bluetooth to a computer or an Android device for real time data analysis.

2.4.5 Other health monitoring solutions

Two very similar projects are now presented. These two systems are not products, they are smart health monitoring system prototypes, and both use an Arduino as microcontroller. The project "Smart health monitoring system" described in [23] proposes a system where several biomedical sensors are interfaced with Arduino UNO microcontroller and get the information from the sensors. The sensors used in this project are temperature and heartbeat sensors. After that, the data is saved in SD card and then, is sent to a server and to a mobile app wirelessly. The android application developed has a medicine reminder, shows nearby hospitals, shows health care tips and home remedies, shows the sensor data, and has a BMI (Body Max Index) calculator. The medicine reminder feature reminds patients of their dosage timings through an alarm ringing system.

The project "Health Monitoring System using internet of things" presented in [24], is a similar solution where an Arduino Mega with more sensors monitors not only the body temperature and heartbeat, but also respiration, blood pressure and performs ECG. The data is then automatically uploaded to a website by a cloud server where the patient's health status can be monitored easily. The system has also an LCD display implemented that shows the same information. For communication it uses a WIFI module (ESP8266).

2.4.6 Existing solutions comparison

MySignals is the only solution that is a finished product and is one of the most complete products in the market, the other solutions are still prototypes that are under development. FrailSafe is a big project funded by the European Union and is the only solution that also has a system that can perform room-level indoor localization. HealthBand, AMON and FrailSafe present solutions for a wearable device. Both HealthBand and AMON projects propose a wearable device to be used on the wrist, instead, FrailSafe project proposes a shirt as a wearable device (SmartVest). In terms of cost, HealthBand, [23] and [24] projects are the cheapest solutions. Both FrailSafe and MySignals are the most expensive ones. Table 2 presents a comparison of the existing solutions regarding the communication method, whether the solution has a localization system, whether it proposes a wearable device and the total cost of the system.

	Communication	Localization	Wearable	Cost
AMON	GMS	No	Yes	Medium
MySignals	BLE, Wi-Fi	No	No	High
HealthBand	BLE	No	Yes	Low
FrailSafe	BLE	Yes	Yes	High
[32], [33]	Wi-Fi	No	No	Low

Table 2: Comparison between the existing solutions

3. Implementation

The proposed solution can be divided in two different segments that work together: indoor localization and health monitoring. The goal is to develop a wearable device and a system where one or more people can be localized inside an indoor space and be able to monitor those people regarding basic health characteristics with the lowest cost possible.

3.1. Architecture

The architecture of the proposed solution is composed by several components that interact with each other. It includes a network of fixed and mobile nodes based on the Arduino Nano microcontroller. The mobile nodes are attached to the users and periodically send all the information gathered by their incorporated sensors to the network. The fixed nodes send the data received from the mobile nodes through the network until it reaches the central node. The central node collects all that data and sends it through a serial channel to the local server, which is a device with higher memory and processing power such as a computer or a Raspberry Pi. The local server runs a server that reads the data sent by the central node, processes it and stores the relevant information in a MySQL database. The local server also runs a web application that gather information from the database and displays the user data in real time. Before starting to use the system, a setup procedure must be performed in the web application. This procedure consists of inserting all the information that the local server needs to start running. That information helps the server to associate the fixed nodes with their corresponding divisions and the mobile nodes with their corresponding users. The web application can also set specific configurations for each user. These configurations are also sent to the database and the local server forwards the message through the reverse path until it reaches the specific mobile node.

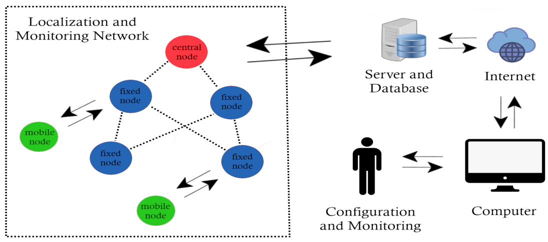

Figure 1: Overall architecture of the proposed system

3.2. Radio selection for the node network

In order to choose the communication method for the localization and monitoring network, and taking into account the related work and that the project's objective is to be low cost, 4 radio modules were selected for evaluation: XBee, HM-10, nRF24L01+ and CC1101. The Xbee is the most expensive and the nRF24L01+ is the cheapest alternative. HM-10 uses Bluetooth Low Energy which can be a problem, since all the nodes in the network will need to pair with each other and with every new mobile node. This could result in latency issues and connection problems. Also, regarding cost and power consumption, the nRF24L01+ seems a better choice compared to HM-10. A performance comparison was made between XBee and nRF24L01+ [25] and the results showed that the nRF24L01+ can compete with the xBee module in almost every metric evaluated. Therefore, since one of the main objectives of this project is to be relatively cheap, the nRF24L01+ seems to be the right choice. It costs no more than 1 euro and has the capability to handle the communication between the nodes and to create the network. The major issue with this module relates to how it measures signal strength. This radio does not have Received Signal Strength Indication (RSSI).This feature measures the power of a present radio signal and is very useful for indoor localization because it detects if a mobile node is getting closer or far away from a receiver. The nRF24L01+ only has 1 bit called Received Power Detector (RPD) that returns true if the power of any radio signal detected is equal or greater than -64dbm and returns false otherwise.

3.3. Network topology

The nRF24L01+ radio module [11] has the capacity to create a network with several nodes that can act as transmitters and receivers. The radio's firmware handles all network procedures, which simplifies the node's software, as not everything is implemented in the Arduino. The network is arranged in a tree topology using the RF24 [26] and RF24Network libraries [27] that were created by TMRh20 to explore the capacities of the radio. The radio can actively listen up to 6 other modules at the same time. One node is the base, and all other nodes are children of either that node or another. Each node can have up to 5 children, and this can go 5 levels deep. This means that it is possible to create a network with a total of 3125 nodes. Since this project is intended to use in a house or nursing home, this limitation will not be a problem. The libraries provide an efficient acknowledgement of network-wide transmissions, using dynamic radio and network protocol acknowledgements. Each node has a logical address on the local network and the nodes can join the network without any changes to any existent nodes. The administrator of the network must assign a 15-bit address to each node. The address describes exactly the position of the node within the network tree. It is an octal number, and each digit represents a position in the tree further from the base. When a message is sent, a header needs to be created with the node address of the receiving node. The network finds the right path to reach that node and sends the message. In order to localize a person inside a house, a network with fixed nodes in every division must be implemented. Those fixed nodes will receive information from a mobile node that is attached to a user and will send that information to another fixed node until it reaches the central node that can process the information.

3.4. Indoor localization

The indoor detection is one of the main features of this system. Knowing the location of a person inside an indoor space can be very helpful when a person falls, faints or in other several types of situations where the location of people is useful. Developing this type of system with low price components is a great advantage but those components can have some limitations that might affect the reliability of the system. The indoor localization does not need to be very accurate because the objective of this system is to just detect which division the mobile node is at the moment. To achieve this, it is only necessary one fixed node per division. If a division is bigger than usual and there is interest in identifying different areas in it, more than one fixed node will be probably needed. As previous said in chapter 3.2, most radios have the RSSI feature but the nRF24L01+ radio have only the RPD bit as a way to measure signal strength. This is an important limitation that needs to be known when developing a localization system. Systems that use radios with RSSI usually compare the strength of all the received signals and assume that the closest node has the highest signal strength, and can determine the distance between the nodes with some accuracy. Because the radio used on this system only have the RPD bit as a way to evaluate the signals received, the common indoor localization methods will not work with this radio due to that limitation. The developed approach consists of a system based on points using the 2 possible RPD values.

The mobile nodes move inside the network and periodically broadcast their ID along with sensors data. The fixed nodes that receive the message from the mobile nodes, add the value of the RPD bit to the message and send that information to the central node or to another fixed node that can send the data to the central node. The central node also works as a fixed node, but it is connected to the local server and sends to it all the information received through a serial channel. The local server runs a python script (server script) that receives the network information and starts processing it. This is where all the localization is performed, which simplifies the software of the nodes.

First, the server script associates all the fixed nodes of the network with their corresponding division. Every mobile node has an array with the size of all the fixed nodes that exist on the network. Each value inside this array is associated with a certain fixed node. These values, or confidence points, are the system's confidence that the mobile node is located at a certain fixed node's division. The higher the confidence points for a division, the more confident the system is that the mobile node's location is at that division. When a fixed node is detecting the presence of a mobile node and the RPD value is "0" (low strength), 1 confidence point is attributed to that division. If the RPD value is "1" (high strength), 5 confidence points are attributed to that division. The other divisions that had no messages received have 0 confidence points attributed. This is performed for every mobile node every second within 4 iterations (4 seconds). After the detection, all the confidence points are set to zero and the iterations start over again. If all the divisions have 0 confidence points, the system declares an unknown position for that mobile node.

However, there can still exist blind spots and ambiguities where a mobile node apparently seems to be in two different divisions at the same time. To solve this, if a division has the highest confidence points at two detections in a row, the mobile node starts the next detection with already 2 confidence points on that division. This is to create a certain resistance to leave the division and solves several ambiguities. That resistance is removed as soon as a different division is assumed as the location of the mobile node. If the mobile node is in a position where there is no detection of the same division two times in a row, the resistance is not created, and the ambiguity cannot be resolved until the mobile node moves or a certain fixed node is changed to a better position. Another implementation that tries to solve the ambiguities is by using the concept of neighbors. All the divisions that have a direct passage to a certain division are its neighbors. Before finishing the detection procedure, the server script checks if the division that now has the highest confidence points can be directly accessed from the mobile node's last division. This automatically ignores the divisions that might be getting confidence points attributed but cannot be accessed from the last division.

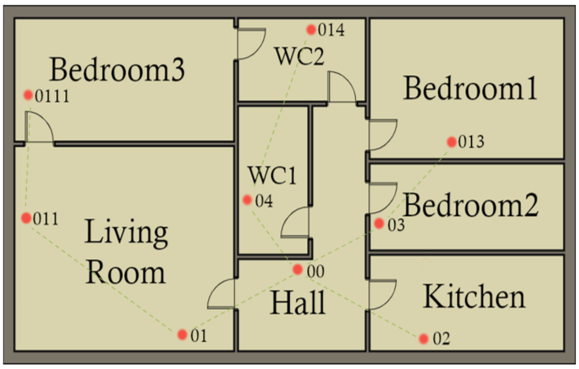

Figure 2: Example of a network implementation inside a house

Figure 2 shows an example of a 9 nodes network implementation inside a house with the central node placed on the hall. The living room on the figure can be an example of a division that needs 2 nodes because its size might be too big or there is a need to identify certain areas inside it. There are several ways to create a network inside an indoor space. Having very few connections can be a problem because the nodes could be too far away for a message to be received. Lots of connections and levels within the network means that more fixed nodes can receive messages from the mobile nodes and those messages need to take longer paths to reach the central node. This increases the network traffic and the number of ambiguities, and also decreases the probability of a message reaching the central node. The goal is to find a balance between the node's distance and the number of connections.

3.5. Fixed and mobile nodes

Both mobile and fixed nodes are made of the same components, but with the difference of the mobile nodes having sensors incorporated. The nodes are built on top of a PCB board that helps with the connection and support of the node's components. It was designed by Professor Renato Nunes from Instituto Superior Técnico and it was created for other projects but can be used on this project as well. Attached to the board are the nRF24L01+ module for radio communications and an Arduino Nano to control everything. There is also 5 leds and 3 buttons attached to the PCB board that are used for testing, alerts and to simulate actuators and sensors.

The mobile nodes are equal to the fixed nodes but have more modules attached. In order to detect falls and inactivity, an MPU6050 [28] accelerometer was attached to the board. And for heart rate measuring, an MAX30102 [29] module was connected. These two modules communicate by the I2C protocol but had no connections made for them inside the PCB, so some wiring and soldering had to be made. A better prototype can be made with a new PCB designed to have connections to all the modules and with a considerable smaller size.

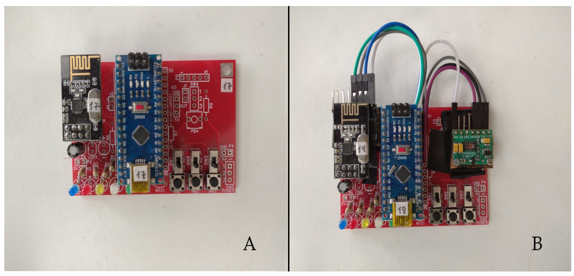

Figure 3: A – Fixed Node, B – Mobile Node

3.6. Health monitoring

Through localization it is possible to identify if a person is active and moving around regularly, which already gives some information about the person's health status. If a person goes to the toilet many times throughout the day or stays in a division for a long time, it may indicate that there is a problem. The patient also might have difficulty to move or have fallen. Combining that with sensor information leads to a more correct and detailed diagnosis of the user's health status. The mobile node is carried by the person being monitored. This device periodically monitors the sensors data and sends that information to the base node to be processed and stored.

3.6.1 Fall detection

The fall detection algorithm of this solution uses fixed thresholds that are based on [16, 18].

The node is continuously calculating the magnitude of acceleration (equation 1) and based on the magnitude, the system uses triggers that activate or deactivate according to those values. If all the triggers activate, a fall is detected. The first trigger is activated when the magnitude of acceleration goes below the lower threshold, which indicates that the user is falling. After that, if the magnitude of acceleration goes higher than the upper threshold within the next 500ms, the second trigger is activated (impact period). If during the next 500ms after the second trigger being activated, the system detects an orientation change greater than 200 $^{\circ}$/s, the third trigger activates. OC is calculated using equation 1 but replacing the 3 accelerometer values with the gyroscope values. After waiting for 3 seconds, a blue LED turns on indicating that the system is suspicious of a fall event. Next, for 10 seconds, the system checks once again the orientation change of the user. If there is a movement greater than 100 $^{\circ}$/s, the system assumes that the user is conscious and moving freely. However, if there is no movement detected from the user during the 10 seconds period, the system now is certain that a fall has occurred. A white LED that simulating an actuator such as a buzzer turns on and the user's emergency contact automatically receives an SMS message with information about the time and the location of the fall event.

3.6.2 Inactivity detection

Detecting inactivity can be important to monitor on some people because even if a fall was not detected, the person could have fainted or there is an unusual loss of mobility that needs to be evaluated.

The inactivity detection starts by calculating the orientation change. If for a predefined amount of minutes (60 seconds by default) the orientation change remains below 10 $^{\circ}$/s, an inactivity event is detected, an alert is sent to the system the same way as the fall detection alert and a white LED turns on that could simulate an actuator such as a buzzer. Pressing a button, cancels the alarm and turns off the LED. If there is an orientation change higher than 10°/s during the predefined period, the timer is reset, and it starts counting from the beginning.

3.6.3 Heart rate measuring

In this solution, the MAX30102 sensor is always on standby mode to avoid abnormal readings and to save battery. If a user presses button1, the sensor wakes and is waiting for a finger to be placed within the next 5 seconds. If no finger is placed, the sensor returns to standby mode. If there is a finger placed on the sensor, it starts measuring the heart rate of the user for 20 seconds. It senses the heartbeats and performs some calculations to get the bpm value. After gathering several of those values, an average is calculated and updated along the 20 seconds measuring period. After the measuring procedure, a red or green LED turn on depending if the value measured belongs within the acceptable bpm range, which is 40-160 bpm by default (the range can be predefined and adjusted to the user). After 5 seconds the feedback LED will turn off and the sensor returns to the standby mode.

3.7. Web Application

3.7.1 Web application architecture

The web application offers access to every element of the system and allows the analysis and management of the network and user data. Django is a python web framework that runs as a backend server creating and managing all the database models. Django was selected as the backend framework for this solution due to previous experience in developing web applications with it, and because Python has libraries and tools that help to read the serial data from the central node very easily. In order for the frontend to access the database, a RESTful API was created using a framework called Django REST framework. That data can be read, updated, created and deleted using the methods GET, PUT, POST and DELETE. The Django REST framework serializes the data and allows access and updates via the RESTful API. The frontend of the web application is created by the React framework inside the Django project. React is a frontend JavaScript library that handles user interfaces. Django loads a single HTML template and let React manage all the frontend. It gets and posts data via the Django API and uses the static files from Django when a user visits the URL.

3.7.2 Web application GUI

The web application gives access to all the information processed by the system. It has a simple and intuitive design that helps the user to analyze the data with ease. It has 3 different pages: Dashboard, user, setup.

The dashboard displays a table with the name of all the users stored on the database and their current location. There is a search bar that filters the users on the table. A radio button allows to choose whether users are filtered by name or by the current division. Finally, it is possible to get more information about each user by clicking on their name.

After clicking on a user, the app redirects to a user page where it shows more detailed information about the user such as the current location, the history of divisions that the user already went, the history of falls, the previous heart rate readings and the last heart rate measurement. There is also a section to manage the alarms related to the user. A switch button can be turned on or off for each of 4 configurable alarms (inactivity, fall, heart rate and emergency button). Regarding the inactivity detection alarm, there are two input boxes that indicate the time range for a detection to be activated. The default range is 09:00h - 23:00h.

The purpose of the setup page is to setup the network before running the server script. The setup is divided in two sections: the mobile nodes and the fixed nodes. At the mobile nodes section, users are created by inserting their corresponding mobile node ID, username and the emergency phone number. At the fixed nodes section, it is required to insert the fixed node ID, its corresponding division, and the ID's of all its neighbors. For both sections there are buttons to add or delete users and fixed nodes. It is also possible to setup the network by providing a JSON file with all the network information.

3.8. Alerts

A system that generates lots of alerts all the time will not be usable because people will tend to ignore them after a while. That is why the alerts of this system are configurable for every user and are only emitted when there is an urgent event. Besides the falls, inactivity and heart rate alerts, the user can also press the SOS button of the mobile node, which automatically sends an alert to the system. The alerts have two ways to be emitted. The first one is on the mobile node itself, where leds turn on simulating actuators such as a buzzer. The second one is an SMS message that is sent to the user's defined emergency phone number. The SMS alert works by using a web platform called "IFTTT" [30]. IFTTT is a web service that allows users to create chains of conditional statements that are triggered by changes on other web services. After creating an account on the platform, it is possible to access an URL with a personal key that will be used to emit an alert. When an alarm event is detected, the server script sends a post request to the URL gathered before and adds to it the details of the event. A predefined phone that must be connected to the internet and has the IFTTT application installed, receives the notification from the platform and automatically sends an SMS message to the user's emergency phone number.

4. Conclusions

Currently, more and more people are getting older and need more medical care and to be monitored more often. The human body suffers a lot with age, making it more prone to various problems and illnesses. But it is not just the body that suffers with age, the mind also becomes more fragile. Older people tend to get lost and to forget many things such as not taking medication, for example. Nowadays it is possible to monitor the elderly at home or in a nursing home 24 hours a day, and in a non-intrusive way. The person's health condition can then be sent remotely to a medical professional for evaluation. This saves a lot of time and money for both the users and medical facilities and could provide better diagnosis because the user is being monitored in a comfortable environment and doing his daily life.

In this work, several existing solutions and technologies that approach the health monitoring and indoor localization areas were studied and compared. After studying the positive and negative aspects of these solutions, and taking into account existing technologies, a low-cost solution that consists of a wearable device was developed, which can be used in a house or nursing home. The solution implemented performs room-level localization, allows to monitor the heart rate of the user, has an SOS button, and detects falls and inactivity. It then sends alerts that can be received via SMS message to the user's emergency contact. Combining the localization with the health analysis, will help to perform a better and more reliable diagnosis. Suggestions for future improvements to this system were proposed, such as designing a new PCB board, replacing certain components, improving the mobile node's power consumption, and calibrating certain parameters within the indoor localization and health monitoring algorithms.

The results show that even with some limitations and accuracy problems, the proposed system have an acceptable performance and proves that this low-cost approach on wearable health monitoring and indoor localization can be achieved. In the end, by performing some improvements and calibrations, a real life system that has a lower cost compared to other existing solutions could be implemented in the future based on the proposed solution in this work. This type of equipment is very relevant because it allows people to be safer, allowing them to age at home, enjoying greater comfort and better quality of life.

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