Wearable with integrated piezoelectric energy harvester for geolocation of people with Alzheimer's

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ABSTRACT

Alzheimer's is a progressive disease that affects memory, causing disorientation in the patient, which causes them to lose themselves, generating anguish in families who have to resort to expensive searches. The objective of this research was to implement a device that can remotely provide the location of the Alzheimer's patient over a long period to relatives for greater security. For this, in this research, a mobile application was developed that receives information from a wearable that applies the internet of things using long-range wide area technology to show the patient's real-time location and uses piezoelectrics for greater battery autonomy. The real-time location of the person and the radius of the safe zone in the application were obtained as results, the received signal strength indicator value where the signal was excellent or good had a value of -30 to -89 dB between 0 to 400 meters and the battery discharge time was 11 hours and 44 minutes. It was concluded that the application is interactive, that the piezoelectric system increased the autonomy of the wearable, and that the long-range wide area (LoRa) technology allowed monitoring of the patient's location with great precision at 400 meters.

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1. INTRODUCTION

Dementia currently affects 46.8 million people worldwide [1]. People with dementia are generally dependent on caregivers, as they require specialized care and constant monitoring as wandering is a particular problem [2]. Of the cases of dementia, Alzheimer's disease is one of the most outstanding that affects neurological functions and is still incurable, it is characterized by being a syndrome generally of a chronic or progressive nature [3] that causes the person to be disoriented and have problems to remember your address and location [4]. For families, paying for the service of a nurse to monitor a patient with Alzheimer's is high. However, due to the accessibility of the internet of things (IoT), monitoring of patients can be carried out remotely and in real-time, so that action can be taken on time if there is any problem with the patient [5]. These IoT monitoring solutions can increase security by establishing a safe zone for a person with dementia to move around [6]. The monitoring range of the safe zone will vary according to the wireless communication technology which can be short or long-range. Within long-range networks, we have low power wide area networks (LPWAN) such as SigFox which is a narrow band technology, or long range wide area (LoRa) which is based on spread spectrum technology [7]. LoRa is a wireless technology that provides IoT applications with secure, low-power, and long-range data transmission [8]. LoRa technology interacts with systems such as microcontrollers, Smartphones with mobile networks, Bluetooth, wireless networks, and sensors, which generates an integrated and automated environment for users [9]. Appearing completely new classes of portable devices that, although low consumption, lack autonomy because their use time is limited by current battery technology, which results in higher costs due to the inability to store enough energy for biomedical detection in the long term [10]. investigations that focus on increasing the durability of the battery through energy harvesting to be able to self-feed the system [11]. Harvesting mechanical energy from the human body, particularly from the feet, is an alternative process for acquiring potential electricity. The pressure of the weight of the human body produces mechanical energy when walking and running [12].

In this article, an IoT-based shoe has been designed and developed with a LoRa technology SX1276 transceiver that overcomes the existing limitations regarding the monitoring range and is connected to an Espressif system module (ESP32) that will send the position to a mobile application that it will show in real-time the location of the patient and the battery charge of the monitoring system inside the footwear that contains piezoelectrics to reduce the battery discharge time. In addition, the footwear has a subscriber identity module (SIM800L) global positioning system (GPS)/general packet radio services (GPRS) module that will send a text message with the patient's location if it leaves the LoRa monitoring range.

2. MATERIALS AND METHODS

2.1. Materials

A TTGO T-Call ESP32 SIM800L with GSM/GPRS communication, it has a Chipset ESPRESSIF-ESP32 240 MHz Xtensa single-/dual-core 32-bit LX6 microprocessor, with 4 MB quad serial peripheral interface (QSPI) flash, 520 kB static random access memory (SRAM), module interface universal asynchronous receiver transmitter (UART), serial peripheral interface (SPI), secure digital input output (SDIO), inter-integrated circuit (I2C), pulse width modulation (PWM), TV PWM, inter-IC sound (I2S), general purpose input/output (GPIO), this module comes from Shanghai, China [13]. An ESP32 microcontroller featuring a low-cost, low-power 32-bit system on chip (SoC), with 4 MB QSPI flash, 520 kB SRAM, Bluetooth v4.2, and wireless fidelity (Wi-Fi) connectivity, this microcontroller is of Chinese origin [14]. Two modules RYLR896 which include an 868-915 MHz transceiver module, a simple processor for data transfer and reception that uses little power and a 127 dB dynamic range received signal strength indicator (RSSI) that enables controlling different appliances from 3 to 12 km distance, these modules come from China [15]. A TP4056 battery charger module that not only allows to charge the battery but also maintains a stable current, this module is from China. Two lithium-ion NCR18650B batteries with a capacity of 1,500 mAh from Japan [16]. Four piezoelectric sensors are made of lead zirconate titanate and polyvinylidene difluoride, these sensors come from the United States [17]. A 2W10 full bridge rectifier with, an AC input voltage of 1,000 V (max), DC output voltage of 1,000 V (max), DC output current of 2 A (max), and peak forward voltage of 1,000 V, this rectifier comes from China [18]. An LM7805 voltage regulator with an input voltage range is 7–35 V output current of up to 1 A and an operating temperature of 0±125 °C, this voltage regulator comes from Neubiberg, Germany [19]. A web development tool called MIT APP inventor, created by the Massachusetts Institute of Technology, in which simple and complex applications can be created through mobile devices.

2.2. Description of system operation

The system starts with the graphical interface of the mobile phone of the patient's family member. The patient's data and two important parameters are entered. The first is the point of origin with its respective latitude and longitude that was obtained by clicking on a point on the map and the second parameter is the value in meters of the radius that is the maximum distance from the point of origin in which the patient is monitored. This system is often used to monitor in real-time and alert family members that the Alzheimer's patient has left a “safe zone” [20]. Then these data are sent to the wearable which performs the calculations of the limiting region to send an alert in case the patient has left the safe zone, for this the current position of the patient must first be captured (latitude and longitude in movement), then it is subtracted with the initial position, the difference module is found, this module is converted to meters by multiplying it by 111.2 Km/1° [21] to compare with the radius entered in the graphical interface. A variable is generated that conditions the alarm system in the mobile application. The system also captures the battery charge level using percentages. If the patient manages to leave the safe zone, the wearable sends an alert to the mobile application every 2 minutes at an interval of 10 minutes. The information of the patient's data, the position and the condition of whether he is outside or inside the safe zone will be saved in a database every minute. The process flowchart can be seen in Figure 1.

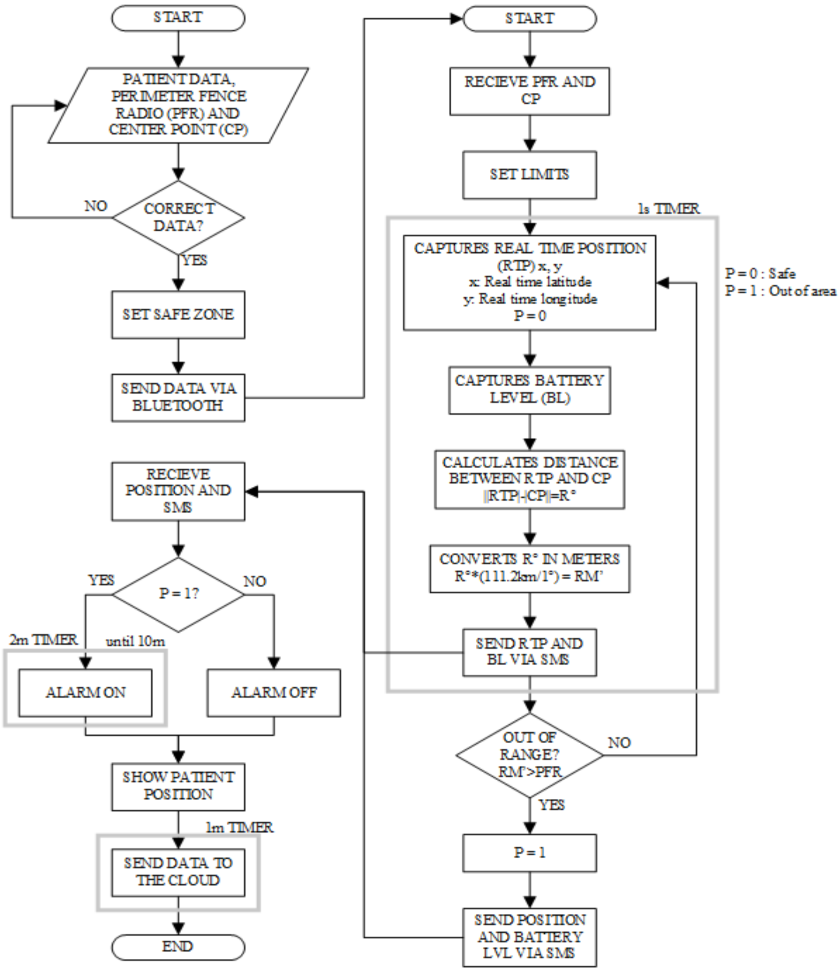

Figure 1. System operation flowchart

2.3. System architecture

The system has been divided into three parts. The first part is the receiving base which is made up of an ESP32 and a LoRa transceiver module which is an LPWAN technology used for IoT applications [22]. The receiver receives information from the sender Wearable and sends the information to the cloud. The second part is the wearable transmitter, which consists of a LoRa module that connects to the TTGO T-Call ESP32 SIM800L, the SIM800L is integrated and was used for the location of the Alzheimer's patient [23]. The wearable transmitter installed a set of piezoelectrics as an energy source since it can transform the mechanical tension produced when walking into electrical energy to charge the battery [24]. The emitter is inside the shoe so that the position of the person can be monitored, integrating into daily life as part of a garment [25]. The third stage is the mobile application of the users that will obtain the data stored in the Google Firebase database to show through the graphical interface the position and the percentage of battery charge of the emitting wearable [15]. The general system architecture is presented in Figure 2.

2.4. Description of the system parts

2.4.1. Wearable emitter

Figure 3 shows the connections of the components of the emitting wearable. The TTGO ESP32 SIM800L microcontroller in Figure 3(a) is capable of connecting to the internet via Wi-Fi or GSM and transmitting the captured geographic coordinates [26], to later send this data to a receiving base through the SX1276 transceiver in Figure 3(b). This LoRa technology transceiver is connected from its RXD (3) and TXD (4) pins to the TXD/GOIO01 and RXD/GOIO02 pins of the TTGO ESP32 SIM800L respectively. The battery with the capacity of 1500 mAh was used to supply energy to the system, as seen in Figure 3(c), and a TP4056 charging circuit to connect to the lithium battery that is charged through a universal micro USB connector [27] as shown in Figure 3(d), this module will be connected to the positive and negative pin of the battery through its pins B+ and B- respectively. The charge supplied by the battery is measured by the analog input

ADC12/GPIO12 of the ESP32 which is connected by a 1 MΩ resistor to the Output+ pin of the TP4056 module and by a 100 kΩ resistor to the Output- pin of the TP4056 module. Piezoelectric sensors were implemented, shown in Figure 3(e), so that when the patient begins to walk, energy is generated that can be used to increase the discharge time of the battery. To take advantage of this energy source, the current generated by the piezoelectric sensors was rectified through a full wave rectifier diode bridge module called 2W10 that can be seen in Figure 3(f) that charges the capacitor up to a predefined voltage [28] and a 7,805 voltage regulator to keep the voltage output constant this module can be seen in Figure 3(g) that will finally be connected to the battery. The emitting wearable contains a switch to turn the device on and off, as shown in Figure 3(h).

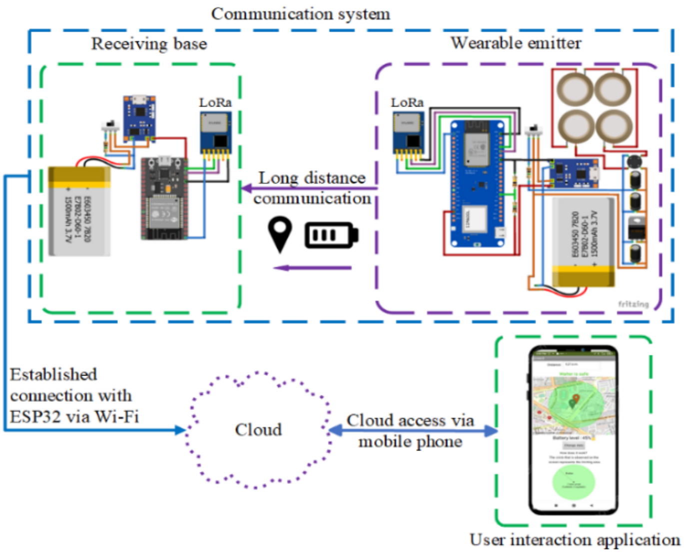

Figure 2. General system architecture

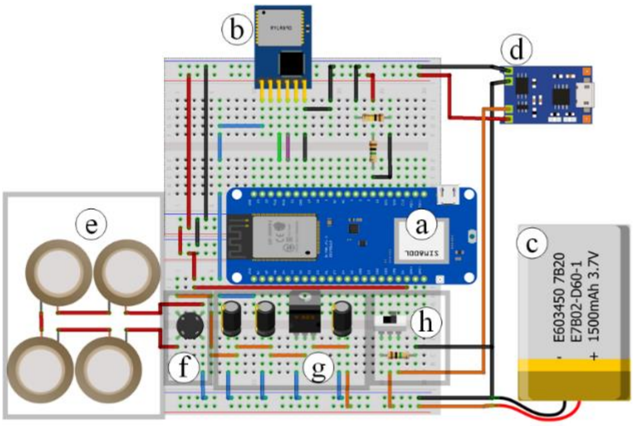

Figure 3. Circuit of the emitter wearable (a) TTGO ESP32 SIM800L, (b) SX1276 transceiver, (c) Battery, (d) TP4056 battery charger module, (e) Piezoelectric sensors, (f) 2W10 full-wave rectifier diode bridge, (g) 7805 voltage regulator, and (h) switch of on and off

The emitter circuit must be placed inside the shoe, for this reason a cavity was made in the sole, specifically in the upper part where the heel rests, in such a way that the circuit components are inserted easily and safely without short circuits, as shown in Figure 4. By placing the emitter circuit in this cavity, the mechanical damage that can be caused to the circuit by the weight of the person is avoided [12]. In addition, damage or discomfort to the user's foot is avoided when carrying out their activities, because the circuit is not in direct contact with the skin and the components of the circuit are light, having a total weight of 52.4 g which makes it almost imperceptible.

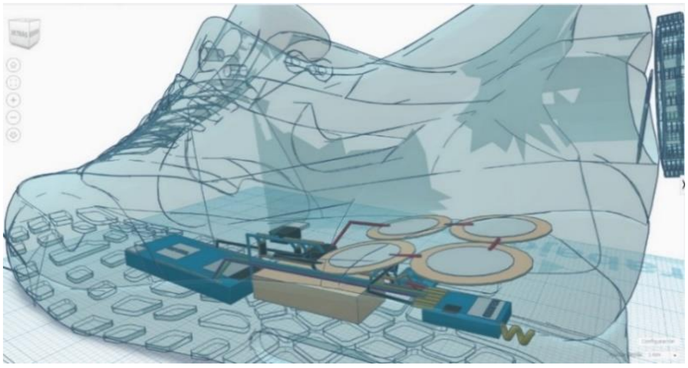

Figure 4. Design of the emitter wearable with its respective circuit

2.4.2. Base receiver

Figure 5 shows the connections of the components of the receiver base. The ESP32 board as see in Figure 5(a) is connected to the LoRa transceiver in Figure 5(b) to read the positioning data of the emitting wearable [29]. This LoRa technology transceiver connects with its RXD (3) and TXD (4) pins to the TX1/GPIO10 and RX1/GPIO9 pins of the ESP32 respectively. The battery with the capacity of 1,500 mAh was used to supply energy to the system, as seen in Figure 5(c) and a TP4056 module that will allow charging the battery through a universal micro-USB connector as seen in Figure 5(d), this module will be connected to the positive and negative pin of the battery through its pins B+ and B- respectively. The receiving base contains a switch to turn the box on and off, as shown in Figure 5(e). The Receiver will send the values received from its Wi-Fi module to Google Firebase as a database server in real time so that these data can then be extracted by the application [30].

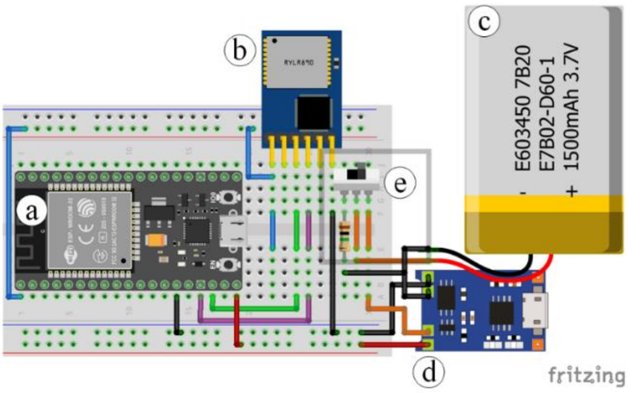

Figure 5. Circuit of the receiving base (a) ESP32, (b) SX1276 transceiver, (c) battery, (d)TP4056 battery charger module, and (e) on/off switch

2.4.3. APP description

Figure 6 shows all the configurations of the entry of the patient's data and the secure circular zone. When starting the monitoring application, the graphical interface (screen 1) shows three list selection buttons. The first button "select Bluetooth device" will display a selection list of Bluetooth devices, in this case, the wearable of this article (it should be noted that only Bluetooth is used to enter patient data since long-distance communications are used for monitoring). The second button "select center point" opens another screen (screen 2) that will allow to select a location on the map by pointing to this point using markers, the red marker represents the current location of the user that is extracted from Google Firebase [31] to the phone mobile and the blue marker represents the selected center of the safe circular zone, while this center is selected, the latitude and longitude of said point is observed, which with the "Confirm Location" button saves this data and returns to screen 1. The third "select radius" button will display another selection list of four numbers (100, 200, 500, and 1,000) these numbers being the radius in meters of the safe circular zone. In the "enter patient data" section, it allows to enter text that is interpreted as names, surnames, ID numbers, and ages of the patient respectively in each textbox. This screen 1 allows to view all the data that will be sent to google firebase as a database server [32] and to the wearable by pressing the “send” button that will open another screen where the current location will be monitored of the patient in real-time.

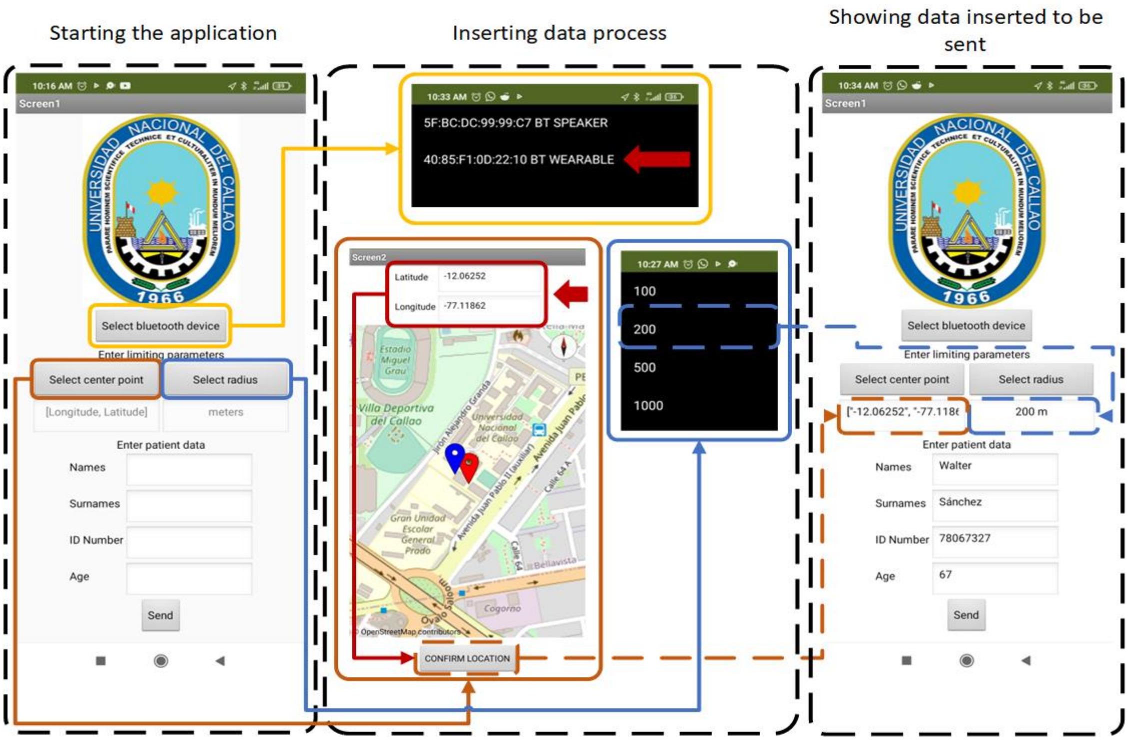

Figure 6. The graphical interface when starting the application on the mobile phone for its configuration

3. RESULTS AND DISCUSSION

3.1. Mobile phone application

When sending the patient's data and the parameters to establish the circular safe zone (CSZ), another screen (screen 3) seen in Figure 7 will open. In Figure 7(a), two markers are observed, the red marker represents the current location of the user of the mobile application and the dark marker represents the current location of the patient measured by the wearable, the safe circular zone configured by the user is also observed of the mobile phone, the distance between the current position of the patient and the center of the safe circular zone is also observed next to the label “Distance” being in this figure 34.2 m for a selected radius of 200 m, therefore a text of green color written, “Walter is safe”. Figure 7(b) shows the current charge of the wearable battery. Figure 7(c) shows a button that will return to the initial configuration shown in Figure 6, where the patient's data will be entered again if the data has been entered incorrectly. Figure 7(d) shows a small guide to interpret the monitoring and the configuration entered at the start of the application. In this experiment, the values of the radius have been modified to observe the effect of the CSZ in the application, resulting in a greater CSZ, being in Figure 7(e) of only 100 m, Figure 7(f) of 500 m, Figure 7(g) for 1,000 m.

By monitoring the current position of the patient, a 100 m radius of the circular safe zone was selected as shown in Figure 8. Figure 8(a) shows the initial position of the patient being a distance of 43 m towards the center of the circular safe zone. In Figure 8(b), movement of the patient is observed and an increase in this distance is perceived, being 85.2 m. Figure 8(c) shows that the distance of 102.1 m between the patient and the center exceeded the radius of 100 m initially programmed, therefore the text of “Walter is safe” changes to “Walter is out of range!” in addition to changing red color that represents an alert to the user. Immediately a notification is manifested that can be seen in Figure 8(d) that will play an alert sound.

In the application developed by Balasubramanian [33] it can only be used to monitor the position within the facilities of an apartment and with Bluetooth, however, it does not establish a safe zone as is done in this research. This area allows decisions to be made in different scenarios to support the patient when moving at home and outside of it. Another advantage of this application is that it can be used from any point on the internet, since all the information displayed is extracted from the cloud.

Figure 7. Real-time patient position monitoring interface (a) CSZ of 200 m radius, user and patient positions and the distance of the patient to the center of the CSZ, (b) current charge of the wearable battery, (c) button to change patient's data; d- Guide to interpret the monitoring, (e) 100 m radius of the CSZ, (f) 500 m radius of the CSZ, and (g) 1,000 m radius of the CSZ

Figure 8. Monitoring of patient's position in real time for a 100 m radius of the circular safe zone (a) distance of 43 m, (b) distance of 85.2 m, (c) distance of 102.1 m, and (d) alert notification

3.2. Signal power

During the connectivity tests, the emitting wearable containing the LoRa device was moved to take ten samples at each distance. When using the LoRa transceivers to send the positioning of the patient, some small disturbances were detected in the received signal as the patient moved away from the center point, the power of the received signal in dB was measured at the receiving base as shown in Figure 9. Between 0 and

400 meters, a power between -30 and -89 decibels is perceived, which means that an excellent or good signal was perceived at this range. Between 400 and 800 meters, a power between -90 and -110 decibels is perceived, which means that at these distances the signal received by the receiving base does not have as much quality as in the first range, but the received signal is still acceptable. Between 800 and 1,200 meters, a power of -110 to -120 decibels is perceived, which means that the received signal is of poor quality, and disturbances are perceived in the receiving base. At distances greater than 1,200 meters, communication with the wearable is lost as shown in Figure 10.

In the research conducted by Rendeiro *et al.* [34], the minimum RSSI value achieved was -89, measured at a distance of 300 meters when using AP Action RF 1,200 with line of sight. When these results are compared with those obtained in the current study, it can be noted that there is better data reception when using LoRA equipment, since -89 RSSI was obtained, but at a distance of 400 meters without line of sight. Furthermore, when comparing these studies, it is observed that the RSSI tends to decrease slowly as the hardware moves further away from the access point. Although, in this research it is observed that this is also due to the appearance of obstacles.

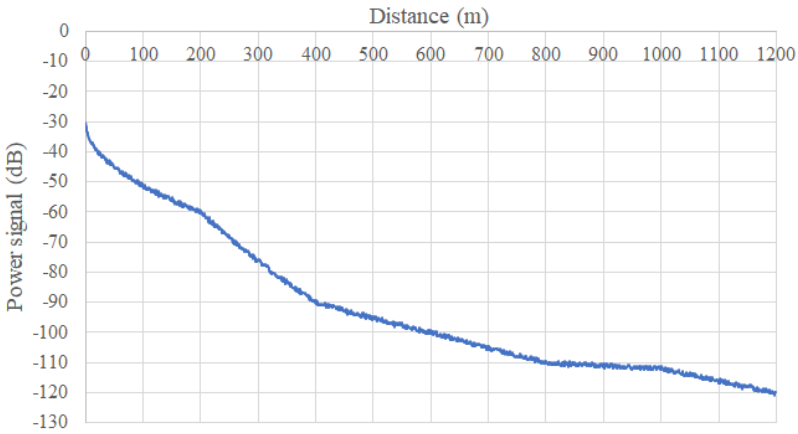

Figure 9. Signal power from the emitting wearable to the receiving base

Figure 10. Distance displayed on the map and the strength of the received signal for distances of 0, 400, and 1,200 meters

3.3. Battery level

The average consumption of the components with the highest energy demand per hour has been measured, with the TTGO ESP32 v1.3 being 171,462 mA and the LoRa SX1276 component being 75.113 mA. The sum of these two components theoretically results in a consumption of 246.575 mA, as can be seen in Table 1. The calculation of the discharge of the battery level was made with (1).

$$Battery\ duration\ (h) = \frac{Battery\ capacity\ (mAh)}{Wearable\ total\ consumption\ (mA)} \quad (1)$$

Table 1. Consumes and theoretical wearable time duration

Component	Consume per hour (mA)	Battery capacity (mAh)	Theoric wearable duration (h, m)
TTGO ESP32 v1.3	171.462	1500	6h 5m
SX 1276	75.113		

The battery level was collected by taking the values delivered wirelessly by the cell phone to calculate the real discharge time, which was then compared with the theoretical discharge time of the wearable that was calculated in Table 1 and with the time of discharge using the piezoelectrics, each one of them is shown in Figure 11 and they are presented in green, blue and orange respectively. The graph was made by collecting the battery level every ten minutes.

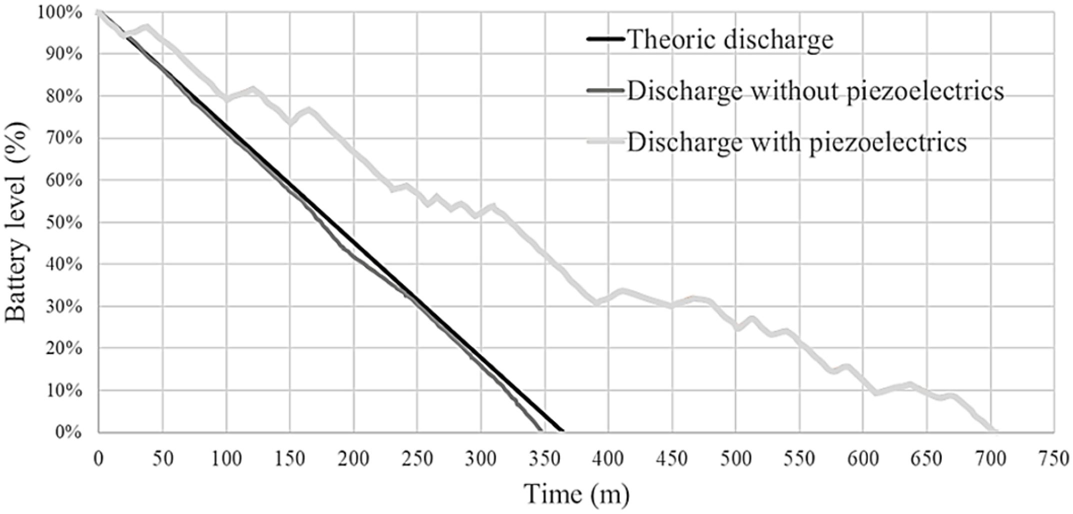

Figure 11. Wearable battery level

The theoretical value of the discharge time was 5 hours with 47 minutes. In the test stage of the real discharge time of the battery, two cases were analyzed, the first analyzed the discharge time of the battery without the use of piezoelectric, and the second the discharge time of the battery with the use of piezoelectric. The battery without piezoelectrics had a discharge time of 6 hours and 5 minutes; with piezoelectrics, it had a discharge time of 11 hours and 44 minutes. During this test, the person performs their activities during the day normally. The power of the batteries with a capacity of 2,000 mAh and 3.7 V is enough to run the device for about 10 continuous hours [35]. This investigation with a battery of 1,500 mAh and 3.7 V it has been possible to maintain the system activated for 11 hours and 44 minutes with the support of the piezoelectrics, which shows an advantage in the performance of the wearable when using piezoelectrics.

4. CONCLUSION

The location of the patient with Alzheimer's can be easily visualized through the application and the alert message can be displayed on the cell phone when the person leaves the range of the safe zone that appears red on the map and that is configurable from the mobile application where the central monitoring point and the safe zone radius are selected, which makes it interactive. It is concluded that the energy harvesting carried out with the 4 piezoelectrics placed in the shoe produces enough electrical energy during the patient's usual activities to extend the autonomy time in the battery, which went from 5 hours and 47 minutes to 11 hours with 44 minutes with a 1,500 mAh LiPo battery. The LoRa technology in conjunction with the ESP32 microcontroller as a receiver and the TTGO T-Call ESP32 SIM800L development board as a transmitter allows a greater distance of wireless monitoring and is suitable for sending data, since the signal is excellent or good at a distance of 400 meters without a line of sight, being useful for ambulatory monitoring.

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