Wearable for Mixed Indoor/Outdoor Localization

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***Abstract*—Dementia is the term used for diseases and conditions characterised by a decline in memory, language, problem-solving and other reasoning skills that affect a person's ability to perform everyday activities. These affect nearly 50 million people and is one of the major causes of disability and dependency among older people. One of the most worrisome problems dementia causes is to find them when there is no caretaker present. One solution to this problem, is restraining the movement to a safe confined space, where help is available. However, restraining their freedom puts in danger their well-being. Thus, it is presented a new approach to wearable tracking devices making it suitable for a person with dementia. The chosen tracking technology is Wi-Fi based geolocation, which, in an urban environment, can be used not only as an indoor positioning system but also as an outdoor positioning system. Moreover, the emerging Low Power Wide Area Network (LPWAN) are used to communicate with the cloud making it more affordable, when compared with devices with Global System for Mobile Communications (GSM), and independent from a smartphone. The proposed solution consists in a smartwatch-type device controlled with an ESP32 Micro Controller Unit (MCU) that has an embedded Wi-Fi module. The design, miniaturisation, power efficiency and the tracking software are the focus throughout this thesis.**

***Keywords*—Geolocation, Internet of Things, Low Power Wide Area Network, Wi-Fi.**

I. Introduction

In the ever growing elderly population, mental health disorders are getting more and more frequent. These diseases can cause loss of memory, panic attacks, loss of perception of time/space and even of reality/imagination, etc. Some of these symptoms can lead to dangerous situations when a caretaker is not present, raising concerns on the well-being of the patient. One solution is constraining the space where they can walk freely, but this can cause more psychological damage. This work proposes another viable solution, using a tracking device that has the capabilities to alert the caretakers if, at any time, they go outside the allowed area or if they enter a dangerous area.

The elderly population is already served by some trackers that are a solution to a certain extent. However, the requirements established by Liga dos Amigos da Terceira Idade (LATI), the elder care institution that exposed to us the problem, are not fully met. Three of this requirements are: the device should have a low cost, should give a rough indoor and outdoor location and it should be difficult to detach itself from the user. Plus, this thesis will use a Low Power Wide Area Network (LPWAN) bringing further cost reduction and battery life improvements, as these networks are suitable to devices that transmit low amounts of data.

The main objective of this project is to develop the service that provides a solution to the proposed problem. This service will include: (i) the wearable device, capable of transmitting the information to locate the user, and (ii) the cloud application that will provide a Graphical User Interface (GUI) where the caretakers can see the status of each of the users.

II. Technology Assessment

A. Positioning Technologies

There are many positioning technologies available to position people being the most relevant Global Navigation Satellite System (GNSS). It has revolutionised services that need real time positioning with high accuracy. This technology has the disadvantage that the power consumption is high and it is impossible to use it as an indoor localisation method. The other relevant technology is Wi-Fi a versatile universal technology used for wireless local area networking. There are obvious advantages on using Wi-Fi for indoor positioning systems such as a good signal coverage which significantly decreases the necessary infrastructure, when compared to other technologies. However, it is important to notice that a greater density of Access Points (APs) increases accuracy so investing in infrastructure may be necessary. Due to its widespread use it can also be used as an outdoor positioning technology, in an urban environment where Wi-Fi signals cover the majority of the area.

B. Low Power Wide Area Network

A LPWAN is a is a type of wireless telecommunication wide area network designed to allow long-range communications at a low bit rate for battery powered devices. Sigfox is at the moment the only LPWAN that covers the entire country and provides a low cost service. Sigfox operates in the Industrial Science Medical (ISM) (regional) band and uses Ultra Narrow Band (UNB) modulation, combined with simple modulation techniques, that grants it the advantage of transmitting signals over long distances. Sigfox only presents one big disadvantage the limited number of messages and its 12 byte size. Long Range (LoRa) Wide Area Network (LoRaWAN) is another LPWAN that is good for applications that do not need coverage beyond specific locations such as a farm. NarrowBand IoT (NB-IoT) is a LPWAN compatible with established wireless network providers it works in the licensed spectrum and is in early stages of launch.

III. State of The Art

A. Wi-Fi

The main approaches used in Wi-Fi based positioning, are based on the strongest Radio Signal Strength Indication (RSSI) method or on RSSI triangulation. Others, such as Angle of Arrival (AoA) or Time of Arrival (ToA), are not subject of further discussion since they require line-of-sight and the special hardware required to support them is expensive [1] [2].

The first method, Cell-Id, obtains the position by scanning the available Wi-Fi APs and the one with the strongest signal determines the device's position. The advantages of this method is that it only needs a database with the location of each AP. The disadvantage is the existence of high relative errors in the indoor environment. The approach based on the signal strength also relies on a Wi-Fi APs scan. However, instead of relying only on the strongest signal, it processes the data of more APs to give more accurate positioning. One method is based on a radio propagation model that, in an ideal situation, would only be affected by the signal path loss,

$$P(d) = P_0 - 10n \log_{10}\left(\frac{d}{d_0}\right) \tag{1}$$

where n is the path loss exponent, $P(d)$ is the received power in dBW at a d distance and P_0 is the received power in dBW at a reference distance d_0. This can be further improved, for indoor environments, by adding the effect of obstructions such as walls or doors,

$$P(d) = P_0 - 10n \log_{10}\left(\frac{d}{d_0}\right) - m \times WAF \tag{2}$$

where $P(d)$, P_0, n, d, d_0 have the same meaning as in equation (1) while m (the number of walls between transmitter and emitter) and WAF (the attenuation factor) can be derived empirically. Finally, using a trilateration with the extracted distances, is possible to position the user [3]. The work [4] applied these methods for indoor tracking in a hospital and results gave a 5 m accuracy.

Other method, Location Fingerprinting, is divided in two phases: offline training and online positioning. The offline phase consists in creating a radio map where the space is divided in cells, and each division is defined by Wi-Fi APs scan samples. The database will store the RSSI and Media Access Control (MAC) addresses and also the position where the sample was taken. A filtering technique is applied on the samples to decrease the number of APs RSSI that represent the fingerprint, that leads to a decrease in the computation time in the online phase [5] [6]. The process of collecting the samples can be difficult and time consuming. So, after an initial setup, it can be crowd-sourced through the development of an application that automatically logs the Wi-Fi scans and the user position, thus improving the database and the positioning accuracy [7]. The online positioning phase is the positioning system itself, assuming a database already exists. The device obtains its location by comparing the results from a Wi-fi RSSI scan with the samples in the database. However, there's still a need for a matching algorithm to achieve better positioning accuracy, such as the Nearest Neighbours method or a Neural Network method [5] [6] [8]. So far these studies have only used this method in an indoor environment. In [9] fingerprinting is used in outdoor environment. The algorithm accuracy is dependent on a high number of samples which is difficult in a high mobility environment.

Google owns one of the biggest Wi-Fi databases and it is dynamically updated with gathered data from Android phone users. Periodically, Android phones collect its Global Positioning System (GPS), Cell-ID and Wi-Fi location and send back the publicly broadcast Wi-Fi APs data, their Service Set Identifier (SSID) and MAC data. This is how the database knows the location of each AP. Figure 1, illustrates how the process unrolls to obtain the location. The device scans available Wi-Fi APs, uploads the RSSI and the MAC address and sends them to a remote server that has access to the database. This information is then transformed in latitude and longitude coordinates and displayed in some GUI. As such, the device never knows its own position, unless the GUI is accessible in the device (uncommon since these are battery powered devices).

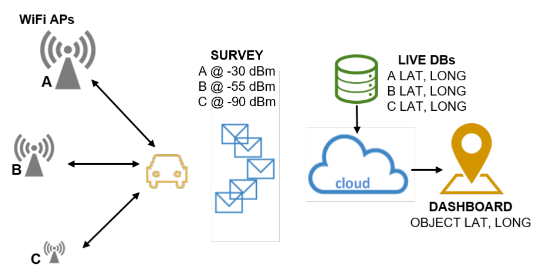


Fig. 1: Process of discovering the device location through Wi-Fi.

B. Other Technologies and Hybrid systems

A team from an engineering university in Malaysia developed a prototype that has a similar goal as this thesis i.e., tracking elderly people in an indoor environment. However, they do not consider the outdoors environment. This system consists in a Bluetooth Low Energy (BLE) wearable device with embedded sensors and BLE scanner nodes. The wearable device has a three-axis accelerometer and a three-axis gyroscope and with the data from these sensors they determine the motion type and broadcast it to the server. The BLE scanner nodes are used to scan the RSSI values of the beacons and broadcast them to the server. Once the values are received they are processed, with the trained model, to identify the location [10]. Similar to this study there is FIND an open-source framework that allows a client of this system to be able to pinpoint location in indoor environments with Wi-Fi and BLE sensor data. Since it is open source anyone can clone the system code and run it on its own server, it is also fully configurable to the specific use case. Once the service is running, it is accessible with an Hypertext Transfer Protocol

(HTTP) Application Programming Interface (API) that allows the user to train the algorithms that predict the locations and to make the estimations after the training. The accuracy of this system is dependent on Wi-Fi AP and BLE beacon density [11].

IV. System Development

The design process of this system begins with identifying what it must do and what the relevant inputs and outputs are. In principle, the system needs to continuously collect data and send it so it can be processed and give an approximate location of the patient to the caretaker. To simplify we can divide these in two subsystems one that is responsible for the data collection and a second where data is processed and displayed.

A overall view of the proposed system in this thesis shown in Figure 2. The first subsystem is a tracking device that will accompany the patients and its function will be to collect the data and send it. The key technologies that enable these functions are Wi-Fi, used to estimate the patient location and transmit data, and Sigfox used to transmit data when Wi-Fi is not available. To fast track part of the hardware development a module that contains a microcontroller and a radio transceiver (for sub-GHz) will be embedded in the first subsystem.

The second subsystem is where the collected data will be transformed into locations and displayed to the caretaker. The database stores all relevant data such as configurations of the device and the Wi-Fi scans that will be delivered to the localisation methods. The localisation methods are different for indoor and outdoor and the servers that compute these make the third block. Lastly there is the GUI, a smartphone application, that enables the caretaker to configure the device and track the patient.

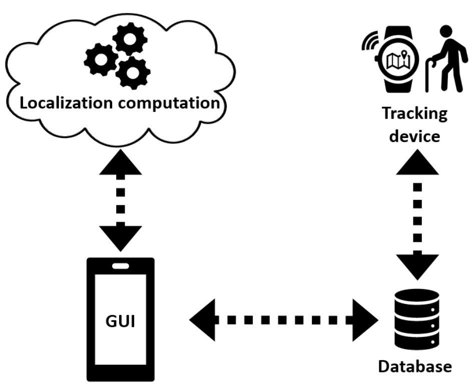


Fig. 2: System Architecture.

V. Hardware

The device architecture shown in Figure 3, is composed of two main blocks: (i) the connectivity module, that has the main components and will be the starting point and (ii) a Printed Circuit Board (PCB) that embeds the connectivity module and includes the peripherals(such as interface and battery) and the antennas.

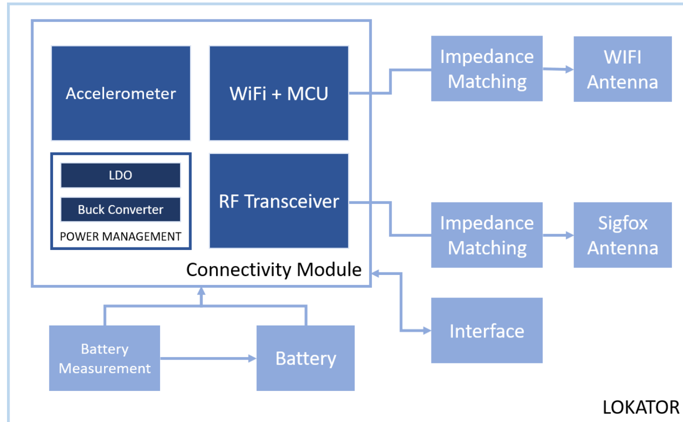


Fig. 3: Block diagram of the device components. The device itself has been named Lokator.

A. Connectivity Module

The connectivity module is the hearth of the device and its components are:

- The ESP32, is a system on a chip MCU with embedded Wi-Fi and Bluetooth/BLE connectivity.
- The subGHz-Transceiver, S2-LP, is what enables the communication with the Sigfox network.
- The accelerometer, LIS2DE, can be used to detect movement.
- The power management unit composed of two regulators, a Low-Dropout (LDO) (AP2138) and a buck converter (AP3428). The need for both is, once again, power consumption. In one hand, the LDO can consume less than a buck converter at lighter loads but, is more inefficient at higher loads which makes it a good choice to regulate voltage when the device is in sleep mode. On the other hand, the buck converter is more efficient when the device is awake.

The module dimensions are 19 mmx22 mm this makes it a really compact sized module with the sufficient IO needed to the application. The module has a Universal Asynchronous Receiver/Transmitter (UART) interface to program the ESP32 and control the internal peripherals such as the transceiver or the accelerometer. The only change that is possible to do regarding the power management is the internal power supply that can be changed between 2.5 V and 3.3 V. The internal power supply will power the other peripherals.

B. Antennas

The device has two antennas one for Sigfox that communicates at 868 MHz and Wi-Fi that communicates at 2.4 GHz.

There are three important considerations to have when designing or embedding antennas on wearable devices the efficiency of the antenna and the return loss (ratio between transmitted and reflected power).

The Sigfox antenna is the most complicated to embed in a small device because of its operating frequency, 868 MHz, meaning that a monopole should have a quarter of the wavelength, 8.6 cm. It is important to notice that in a monopole ground complements the antenna length so it should also have 8.6 cm. However, ground area is hard to come by in such small devices and reducing it also decreases significantly the operating frequency bandwidth. The best option to comply with this sizes would be to have an external wire antenna that would extend through the bracelet and also extending the ground to the other bracelet. This would increase costs as its a complicated manufacturing process. Having all this into consideration the chosen antenna falls over a wire coiled monopole, which biggest disadvantage is the low design freedom, chip antennas are excluded due to its reduced gain and take a considerable amount of PCB space. The chosen antenna is the SW868-TH13 [12].

At this stage the final PCB was already produced and antenna position was also defined, ideally the antenna would be perpendicular or pointing outward relative to the PCB however they are not compatible with a wearable device one would make it to thick and the other would extend the length. The chosen configuration is keeping the antenna at an angle relative to the board. One of the advantages of this configuration is that the antenna is substantially immune to the dielectric that is beneath the ground plane, meaning that it will radiate properly in the pulse, on the top of a table and even when it is charging.

Since the antenna is not in ideal conditions the load impedance (Z_{Load}) must be tuned to the source impedance ($Z_S = 50\,\Omega$) with a matching circuit, as represented in Figure 4. A matching network will maximise the power delivered to the load from the source, by minimising signal reflection. The PCB is ready for a double pi-matching circuit.

To calculate the values of the matching network components, Z_{Load} must be measured. In order to make this measurement, it is crucial, that the source (Connectivity Module) is detached, no components are between the measurement point and the antenna, the Vector Network Analyser (VNA) must be properly calibrated and, maintaining the measurement precision by minimising the variations between measurements. Additionally, the design of the device was also finalised so that the measurements are done as close as possible to the final environment since everything surrounding an antenna will influence its impedance. The measurement is done with a VNA, from mini Radio Solutions. This instrument is used to measure the reflection, insertion loss, S parameters, and transmission and return loss.

To minimise calculation and fine tuning complexity the matching circuit is a L-network, Figure 4, fine tuning is necessary because component values do not match exactly the calculated and because the first estimate of the antenna impedance has a low accuracy. The inductance L and capacitance C is calculated knowing that in a matched circuit,

$$Z_S = Z_{Load} = j\omega L + \cfrac{1}{j\omega C + \cfrac{1}{R_{Load} + X_{Load}}} \tag{3}$$

separating the real and imaginary part,

$$\begin{cases} \dfrac{\frac{R_{Load}}{R_{Load}^2+X_{Load}^2}}{\left(\frac{R_{Load}}{R_{Load}^2+X_{Load}^2}\right)^2+\left(\frac{X_{Load}}{R_{Load}^2+X_{Load}^2}+\omega C\right)^2} = 50\Omega \\ j\omega L + \dfrac{j\left(\frac{X_{Load}}{R_{Load}^2+X_{Load}^2}+\omega C\right)}{\left(\frac{R_{Load}}{R_{Load}^2+X_{Load}^2}\right)^2+\left(\frac{X_{Load}}{R_{Load}^2+X_{Load}^2}+\omega C\right)^2} = 0\Omega \end{cases} \tag{4}$$

it is obtained a equation that can be solved in order of L and C. The measured load impedance without matching needed for the calculation is in Table I, ergo the first iteration should have values near L=32.51 nH; C=2.78 pF. The various iterations of Z_{Load} and return loss can be observed in, Table I for the centre frequency, and in Figure 5 a sweep from 750 MHz to 1 GHz. It is possible to see that the iterations are converging to a matched circuit. Where the final result is an antenna that radiates well enough for our system to work.

TABLE I: Sigfox relevant VNA measurements.

	Return Loss [dB]	$R_{Load}[\omega]$	$X_{Load}[\omega]$
Without Matching	-1	14.5	98.2
1st - L=27 nH; C=2.7 pF	-6.6	117.1	-45.6
2nd - L=33 nH; C=2.7 pF	-9	91.8	-30.5
3rd - L=27 nH; C=3 pF	-15	48.1	18

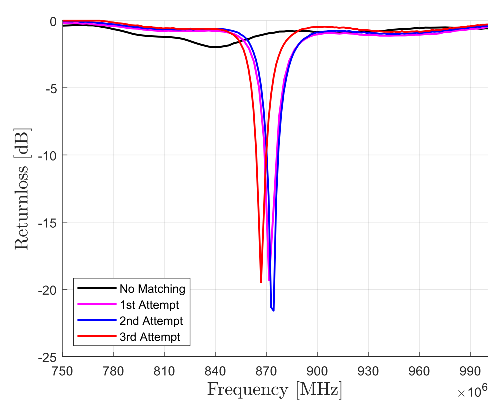


Fig. 5: Sigfox antenna return loss before and after matching.

Furthermore, the Wi-Fi uses a chip antenna [13]. This has a low efficiency compared to the first, but in close range communications the efficiency is less critical. Although there is an efficiency loss, there is gain with the reduction of the occupied space. The design is ready for a CLC (two capacitors in parallel with an inductor) impedance matching network.

This antenna will likely work without a matching circuit since it has fewer variables factoring in the load impedance. The variables were eliminated by strictly following the specifications provided by the chip antenna manufacturer, such as ground clearance and trace dimensions. However, the matching will follow the same rules as done with the Sigfox antenna because load impedance is still affected by the transmission

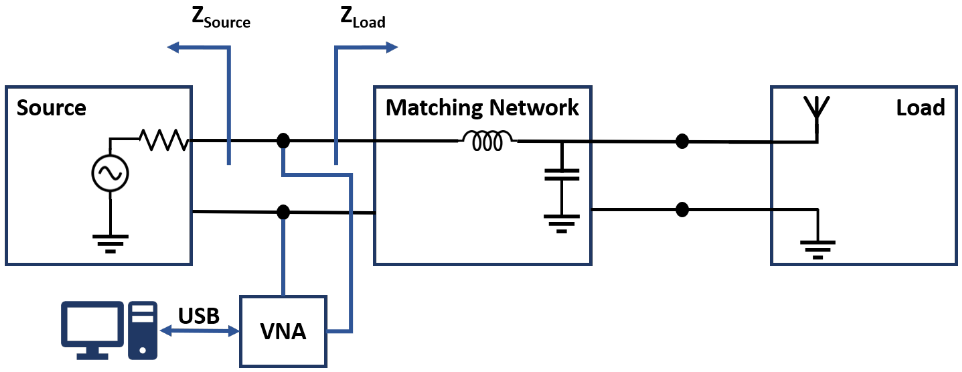


Fig. 4: Load impedance and return loss measurement.

line between the connectivity module and the antenna and other components such as the battery and plastic enclosure.

The matching circuit is the same as the used with Sigfox an L-network, shown in Figure 4. Thus, after measuring Z_{Load} without matching and replacing $R_{Load} = 16.4\,\Omega$ and $X_{Load} = 17.5\,\Omega$ in the equation (4) it is obtained L=10.16 nH; C=0.84 pF. The various iterations Z_{Load} and return loss can be observed in, Table II for the centre frequency, and in Figure 5 a sweep from 2 GHz to 3 GHz. It is possible to see that the iterations are converging to a matched circuit and the final result improves an already working antenna.

TABLE II: Wi-Fi relevant VNA measurements.

	Return Loss [dB]	$R_{Load}[\Omega]$	$X_{Load}[\Omega]$
No Matching	-5.2	16.4	17.5
1st - L=10 nH; C=0.75 pF	-6.1	105.9	61.1
2nd - L=7.5 nH; C=0.75 pF	-11.3	80.4	19.2
3rd - L=7.5 nH; C=1 pF	-2	33.7	109
4th - L=6.8 nH; C=0.75 pF	-22.4	50.7	7.6

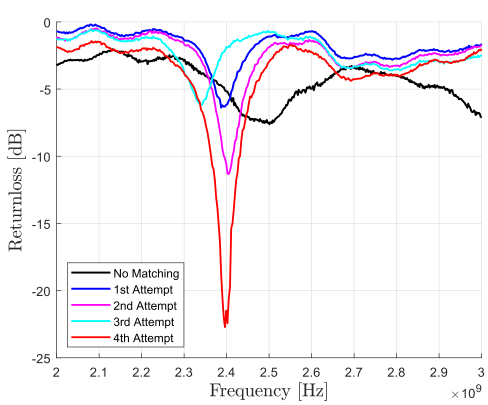


Fig. 6: Wi-Fi antenna return loss before and after matching iterations.

C. Interface

The interface is composed of a button and an Red, Green and Blue (RGB) Light Emitting Diode (LED). The button is used to wake up the device (to send an emergency message) and to reset the device to default configuration. The RGB LED is used to notify the user.

D. Battery measurement and charger

The battery used in the device is an LP502030, a lithium polymer battery, that has a 250 mA capacity at a nominal voltage of 3.7 V. The dimensions are20 mm x 30 mm approximately the same size as the connectivity module making it smaller than the PCB.

The battery voltage measurement circuit, Figure 7, is a simple voltage divider that can be controlled with an input. This circuit allows to have the Q2A transistor in the triode when the circuit is enabled and in the cutoff when is disabled. If Q2A would be in the saturation region the voltage read in the voltage divider would be inaccurate because the current is limited. The cutoff of Q2A is necessary to stop current draw in the voltage divider and current leakage to the ESP32 input when the device is sleeping. Alternating between these regions is possible because of transistor Q3A.

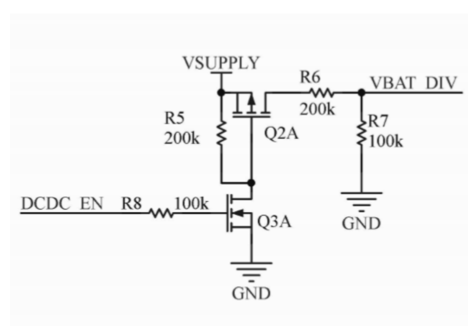


Fig. 7: Battery measurement circuit.

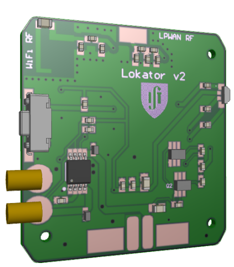
The battery charger, DIO5158 manufactured by DIOO Microcircuits, manages the battery charge voltage and current. The most important component connected to it, is a resistor that sets the charging current and is calculated by,

$$I_{CH} = 1218V/R_{10} \tag{5}$$

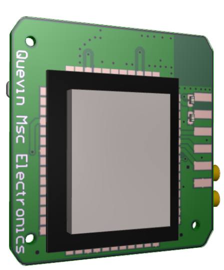
where the I_{CH} is the charging current in A and it is set to 0.25 A the maximum current charge of the battery, replacing it in the equation it solves to $R_{10} = 4.872\,\Omega$. The input supply voltage can be 3.8 V to 6.5 V so any common 5 V charger can be connected to the device. An eventual update in the battery with a higher capacity would only require a change in this resistor.

E. PCB Prototype

The first version of the PCB was essential to test the functionalities of the system and detect flaws in the designing process. Some of the critical design flaws were the battery pins needed to be exposed on the plastics for it to be charged, a problem that was solved by adding the charging circuit directly in the PCB, the button was connected to one ESP32 pin did not allow interruptions and there was no support to fix the PCB in the plastic enclosure. These and other small problems were solved and minor improvements were done to obtain the prototype displayed in Figure 8.



(a) Top Layer.



(b) Bottom Layer.

Fig. 8: Final PCB Prototype.

F. Design

The main objective at this point is to demonstrate a proof of concept, in other words demonstrating that the system works as idealised. To achieve this the hardware must be enclosed in something with similar shape however manufacturing a complex enclosure adds unnecessary costs at an early stage of the product development. As such various 3D models of plastic enclosure were developed and one printed. Figure 9 depicts how the chosen design looks with an exploded view to clarify how each component is placed. The costs to manufacture was low since the case was produced with a 3D printer available at Instituto de Sistemas e Robótica (ISR) and the watch straps attached to the 3D printed box is €2.

VI. Firmware

The Firmware of the device is simple as the only function of the device is sending Wi-Fi scan data to a database. The Wi-Fi scan data is composed by the MAC address and the RSSI of each available AP. Additionally, it is established that it can send the data in two ways via Wi-Fi or via Sigfox. Wi-Fi was added since it does not have data quantity nor message quantity restrictions.

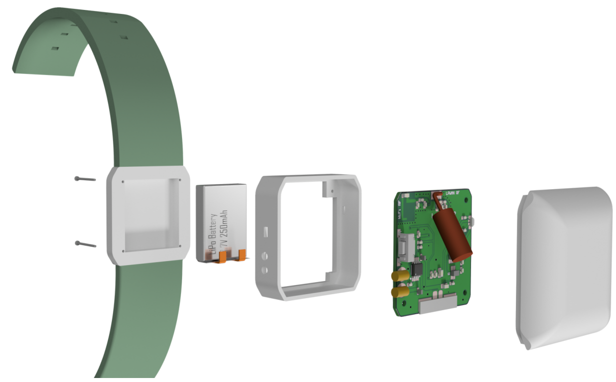


Fig. 9: Device concept.

Figure 10, is the first routine the device must do when its woke, it runs independently of the selected mode and it has two sources the button and the timer. The default mode is the tracking mode and can be set with a long button press. Also, this routine is responsible for triggering the low power mode. The low power mode is the selected mode without a timer wake-up the only way to wake-up is by pressing the button.

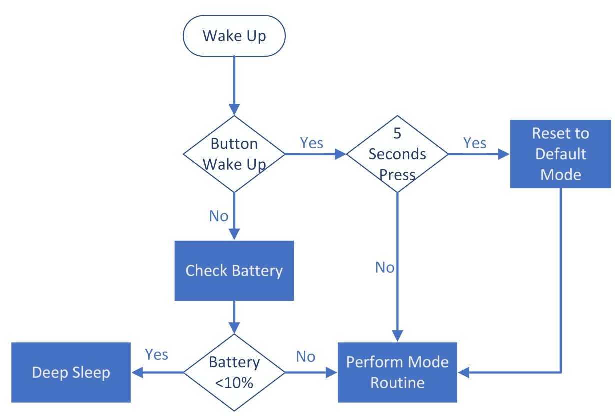


Fig. 10: Wake-up routine.

The default mode of the device is tracking mode, Figure 11. This routine attempts to send the scan data with Wi-Fi this is the preferred method since there is no size or message quantity limit. If WI-Fi is not available the firmware must decide if the scan is significantly different from the last to send with Sigfox. This mode also allows configurations to update although it is only possible with Wi-Fi.

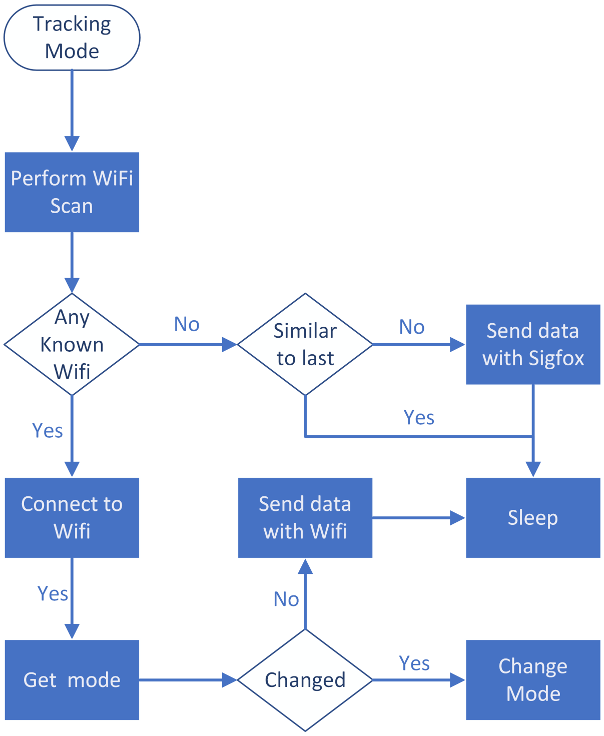


Fig. 11: Tracking mode routine.

There is also a mode that disables Wi-Fi uplink and downlink and a third mode that is used for training the FIND engine. This mode needs to be specific because it needs the location introduced by the user in the app and it is not viable to train it with Sigfox due to the message limit. Finally default configurations of the system are specified in Table III.

TABLE III: Device default configurations.

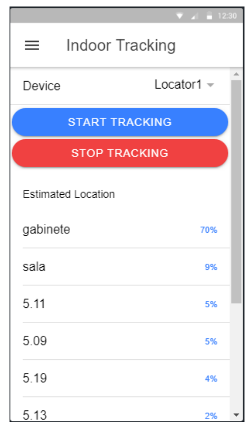
	Default Configuration
Mode	Tracking
Sleep Time	10 minutes
WiFi AP	SSID: Lokator
	Password: IST-Lokator

VII. Software

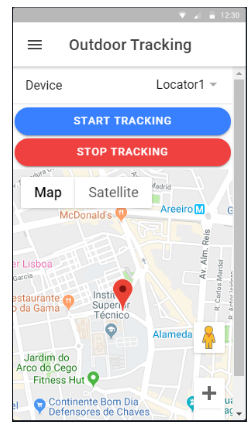
Software is what transforms this system and brings everything together. Besides the device that already has its part explained there is the database, GUI and the localisation methods. The database, used to store all the data coming from the device via Sigfox and Wi-Fi, is Firebase a service provided by Google that allows to store data in real-time. The GUI is the connection between localisation method and the stored data. It is also here that the user can change the configurations (see Table III) of a specific device and store them in the database. The reason why configurations are saved in the database and not immediately uploaded to the device is obviously because it is sleeping most of the time. The caretaker is also notified when the battery is low so that it can proceed to charge the battery. The indoor localisation method is FIND which uses Wi-Fi radio maps (fingerprinting) to estimate indoor locations. The outdoor localisation method is Google geolocation service.

A. Graphical User Interface (GUI)

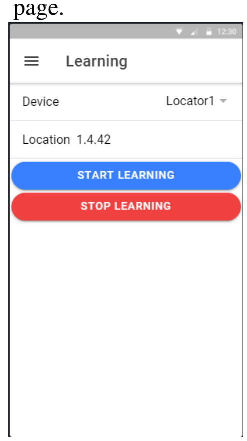
The GUI, Figure 12, is a smartphone application, developed with Ionic framework, an open source software development kit used to develop cross platform mobile applications. This framework is preferable over, building native applications, because the app is developed with Typescript and HTML, and then using a wrapper to run it as a native app. Consequently the application is compatible with both iOS and Android, although to compile the app to iOS a license of Xcode, Apple software development environment, is required.



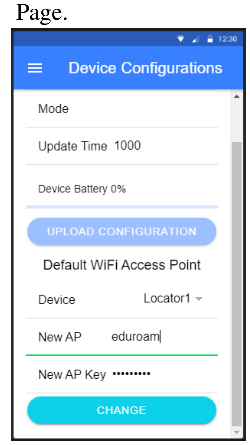
(a) Indoor tracking page.



(b) Outdoor Tracking Page.



(c) Learning Page.



(d) Configurations page.

Fig. 12: Smartphone application.

VIII. Results

A. Localisation Accuracy and Reliability

One of the initially posed problems was Sigfox's ability to maintain a reliable message delivery. To test the coverage and the ability to send messages, the system is tested in the institution and surrounding area and gathered data of how well it performed. None of the 50 messages sent were lost and the signal power of received messages gave us a perception of the worst locations to send messages, this data is compiled in Figure 13. This result confirms that the Sigfox antenna is working properly and reliably.

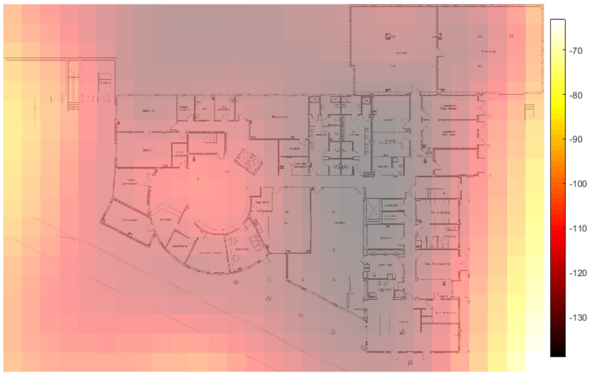


Fig. 13: Sigfox coverage inside institution.

Wi-Fi coverage in the institution posed a problem since using FIND as a positioning method requires a minimum of APs to construct the radio map which was not met, making the results obtained through this method unreliable. However, as Figure 14 indicates, testing Google geolocation API obtained results as intended. The average distance between real and estimated position was approximately 30 meters.

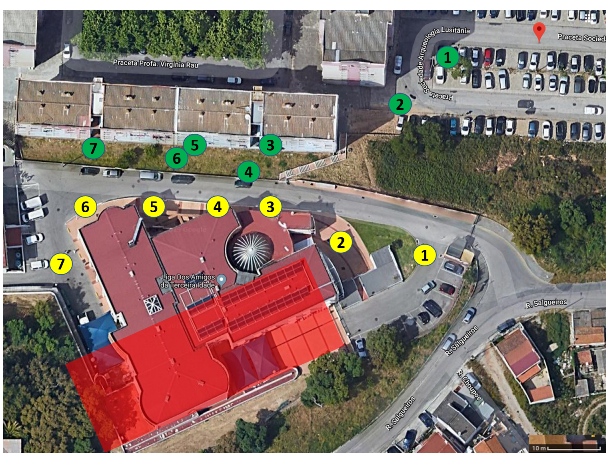


Fig. 14: Google geolocation API test in LATI. Yellow points real position; Green points Google estimated position; Red area represents area without Wi-Fi coverage.

To prove that FIND is a reliable positioning method for indoor environments the system was tested in Instituto Superior Técnico (IST) campus Alameda more precisely in the North tower. As a disclaimer, of the good results, it should be highlighted that the tower has 4 APs, in each floor, which combined with the simplicity of the blueprint make the testing conditions ideal. However the results point to a situation that even if the building was more complex and with less APs that the results could point to the correct location, with less accuracy, within the requirements. The locations where the samples are taken are presented in Figure 15 and the results of using FIND after training the engine are shown in Table IV. The results met the requirements as proof of concept even in other samples the engine estimated correctly the location. The total of probability is not 100% due to the fact that the remaining points have each less than 1% therefore are not significant and as such are not represented in the tables.

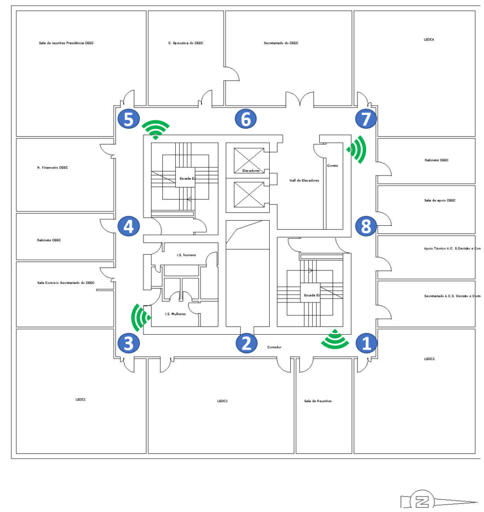


Fig. 15: 5th floor, samples and Wi-Fi APs locations. (each corridor is roughly 20 m)

TABLE IV: 5th floor positioning results.

		Sample Position							
		1	2	3	4	5	6	7	8
Estimated Location	1	68%	31%	5%	2%			1%	17%
	2	10%	64%	3%					
	3	4%	3%	85%	12%	12%		1%	2%
	4			5%	50%	2 %			
	5				28%	73%	29%	1%	2%
	6					6%	61%	3%	
	7						2%	83%	26%
	8	6%						4%	41%

B. Power Consumption and Battery

One of the mains requirements of the device is the time it should go without a charge. Thus it is important to choose an adequate battery size and capacity, there is a need to understand how much power the device consumes. To acquire the measurements, a virtual instrument was setup, as shown in Figure 16. The current is measured with a high-side shunt resistor placed in series between the supply voltage and the load (Lokator). Since the resistor is very small (0.25 Ω) and the consumed currents can be as low as 5 mA, in active mode, the voltage drop across the resistor needs to be amplified to usable levels. To this end, it is used the amplifier AD8211. A Rigol DP832 power supply was used to power both the amplifier and the load. The acquisition was done with a Rigol DS1054Z oscilloscope triggered by a General Purpose Input Output (GPIO) of Lokator. The data is sent to a computer, through

Universal Serial Bus (USB), with NIVisa drivers, the PyVisa library and a Python application. The raw data (current drawn at each instant, sampling frequency, power supply voltage) is then exported to an excel.

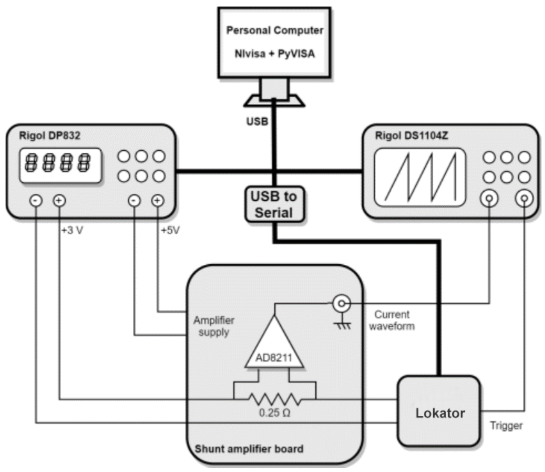


Fig. 16: Virtual instrument setup for power consumption measurement [14].

The main tasks are, Wi-Fi APs scans, Sigfox uplink messages, and Wi-Fi uplink and downlink messages. Computation time and its consequent power consumption is almost nonexistent, from the moment the device wakes up to the moment it will go back to sleep, any computation that takes place is accounted for in these tasks. As already stated before the only function of the device is upload sensor data and there is no information processing taking place. The acquisition of the measurements, is performed independently, and the results are presented in Table V

TABLE V: Task average power and time consumption.

	Wi-Fi Scan	Sigfox Uplink	Scan + Wi-Fi Uplink and Downlink
Average Power Consumption	0.199 W	0.126 W	0.207 05 W
Average Task Time	3.57 s	7.1 s	9.9 s

With this data it is possible to create three power consumption profiles. The first is a Wi-Fi AP survey which leads the device to infer that the location hasn't changed, going back to sleep mode. The second, is a Wi-Fi AP survey, followed by a Sigfox uplink message with the survey data, since the device infers that the current location has changed. A third power profile is the most recurrent if Wi-Fi is available where the device updates configurations and uploads via Wi-Fi.

To characterise how the lifetime of the battery changes with different amounts of sourced power to the load a power function was fitted from data of the datasheet. The chosen battery's datasheet provides the constant current discharge curve for five different rates [15]. When describing batteries, the discharge current is often expressed in C-rate. A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour. Each point, extracted from the datasheet, is the time it took the battery to completely discharge at the different rates (0.02C, 0.2C, 0.5C, 1C, 2C). A power function curve was fitted to this data resulting in,

$$BL(p)[h] = 0.9031 \times p^{-1.018} \tag{6}$$

where BL is the battery life in hours and p is the power drawn in W.

The battery drop, BD,

$$BD[\%] = \sum_{i=1}^{i=N} \frac{100 \times \frac{\Delta t}{3600}}{BL(p(i))} \tag{7}$$

where $p(i)$ is the power consumed at the instant at which the sample is taken, Δt is the the sampling period expressed in seconds(s) and N is the number of samples took during the power profile.

Now it is possible to estimate how much battery drop each task causes. The results are summarised in Table VI. The "Estimate Count" refers to the number of times each task can be done with a full battery.

TABLE VI: Model results and battery leakage.

Task	Battery Drop [%]	Estimate Count
Wifi Scan	0.021358017	4682
Sigfox Uplink Message	0.026455828	3780
Scan + Sigfox Uplink	0.047813845	2091
Scan + 2 Sigfox Uplink Messages	0,069171862	1446
Scan + Wifi (DownLink and Uplink)	0.061966	1614
Daily Leakage (assuming 15 µA current leakage)	0.144	694

Finally, based only on the described tasks it is possible to estimate how much time the battery can last until the device is charged again. Two scenarios are described:

- Worst case scenario: Where the device sends the maximum amount of messages. In this scenario the device wakes up every 10 minutes to make the Wi-Fi survey and sends the data.
- Estimated Normal use scenario: The device only sends uplink messages when it assumes its position hasn't changed, waking up every 10 minutes to verify it. It's assumed that the time it only does Wi-Fi surveys is 8 hours

Table VII, presents the battery life estimated in tracking and LPWAN mode. In tracking mode all of the messages were sent with Wi-Fi in a real scenario there it is possible that at some point of the day the user will be in an area that is not covered by a known Wi-Fi. The consequence of this will be a higher consumption since the required two messages consume more than a Wi-Fi uplink.

Certainly these estimates will vary widely depending on the behaviour of each user. Only after a wide test it will be

TABLE VII: Estimated battery life in different modes.

	LPWAN Mode	Tracking Mode
Worst Case Scenario	10 days	11 days
Estimated Scenario	14 days	16 days

possible to deliver more accurate estimates. The unexpected need of sending 2 messages to make the tracking methods work have affected significantly the power consumption this will also need to be improved.

IX. Conclusion

Developing an indoor and outdoor localisation wearable device is the most suitable option to ensure that elderly people with dementia can be found in case of emergency. The challenges arise when developing a device that must be small and contain technologies to track persons in both indoor and outdoor environment while at the same time having low power consumption. When designing such system a trade off analysis between the different technologies must be considered to make sure that requirements such as positioning accuracy, power consumption, cost and size are met avoiding compromises.

This thesis designed such system and demonstrated a proof of concept. The system was designed in such way that the device has only one function and that is to transmit sensor data leaving information processing and tracking capabilities to a server and a GUI. The chosen technologies were Sigfox to transmit data and Wi-Fi sensor data to track the device. Both of them are critical and as such a good antenna is designed to both making sure that Sigfox is capable to send messages without loss and Wi-Fi achieves a good coverage. This is achieved by choosing an antenna adequate to small devices and making sure the antenna path has its impedance matched. The device also has an LED for notifications and a button to send an emergency message. Finally, the device must have a functional and pleasant enclosure so a 3D piece was designed to house the hardware. The second part of the developed system is where the sensor data from the device is transformed in the localisation information. This system uses Google geolocation API to locate in outdoor environment and FIND to locate in indoor environment. Before using FIND each location must be previously mapped with Wi-Fi fingerprint data. The smartphone application is what agglomerates these services and uses them to display the estimated last known location in a map, of the selected device, and allows to change its configurations everything is simple and intuitive to the user. Ultimately what the development of this system has proven is that the concept works as imagined and it has real potential as a tracking device for elderly people. However, due to the lack of Wi-Fi coverage in the institution the system is not capable of pinpointing the location indoors. In the outdoor environment using the Google geolocation API the system can determinate if the user is outside and the relative direction being taken. Another important requirement is the battery lifetime which should not need to be daily charged and this is possible even if the usage varies. The estimation point to at least 10 days of usage without charging.

For future work rough edges of this development should be perfected such as producing a more refined and waterproof enclosure as this would allow further tests with patients. A third version of the hardware must include any changes needed to correct the flaws detected in real use and add a secondary functionality such as a low power display to show time or notifications to the senior citizen. In the software side improvements in indoor positioning are possible with an additional cost of Bluetooth beacons. Finally, a reassessment of the LPWAN should be done since network providers in Portugal are on the verge of releasing NB-IoT.

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