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LoRa based Search and Rescue system for people with special needs

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“Cuando la vida se vuelve lunática, ¿Quién sabe donde la muerte descansa? Tal vez ser demasiado práctico es una locura. El rendirse a los sueños – eso es posiblmente locura. Demasiado cordura puede ser locura – y lo más loco de todo: ¡Ver la vida como es, y no como debería ser !”

Miguel de Cervantes Saavedra, Don Quixote de la Mancha

Prologue

This dissertation thesis constitutes the end of my postgraduate studies in the Department of Electrical and Computer Engineering (ECE) of the University of Patras. The title of this dissertation is *"LoRa based Search and Rescue system for people with special needs"*.

However, before I present the theoretical background for the topic we discussed and the conclusions we reached, I would like to express my heartfelt gratitude to my tutor, Prof. Nicolas Karacapilidis. His advice was definitive, and his recommendations and helpful comments were unquestionably useful supplies during the writing of this dissertation thesis.

Moreover, I feel the need to warmly thank Mr. Christos Bouras, and Michael Xenos, both Professors in the Computer Engineering and Informatics Department (CEID) at the University of Patras, and Mr. Apostolos Gkamas, Professor in the University Ecclesiastical Academy of Vella. Their guidance and experience were crucial to the elaboration of this dissertation.

Finally, I would like to thank my parents and my brother for the support they have given me over the years, as if I did not have their substantial support in this endeavor, then I would not have successfully completed of my postgraduate studies.

Περίληψη

Το αντικείμενο αυτής της διατριβής είναι η μελέτη και η εφαρμογή ενός συστήματος αναζήτησης και διάσωσης με βάση το LoRa που μπορεί να βοηθήσει στον εντοπισμό των ατόμων που έχουν υψηλό κίνδυνο να χαθούν. Αυτοί οι άνθρωποι μπορεί να υποφέρουν από άνοια, διαταραχή της προσοχής και απόσπαση της προσοχής και είναι πολύ σημαντικό να βρεθούν σε ένα συγκεκριμένο χρονικό πλαίσιο, καθώς η ζωή τους μπορεί να κινδυνεύει. Το σύστημα βασίζεται στην αρχιτεκτονική δικτύου LoRa που επιτρέπει την επικοινωνία μεγάλης εμβέλειας και τη χαμηλή κατανάλωση ενέργειας. Η μελέτη ξεκινά με μια σύντομη εισαγωγή στο Διαδίκτυο των πραγμάτων, τις ασύρματες επικοινωνίες και τα συστήματα LoRa, ενώ παρουσιάζει επίσης το σύστημα αναζήτησης και διάσωσης, τις προσεγγίσεις του και τις απαιτήσεις που το συνόδευσαν. Αυτό ακολουθείται από μια ενότητα αφιερωμένη στο πεδίο αλληλεπίδρασης ανθρώπου-υπολογιστή, τις κύριες μεθόδους και αρχές που χρησιμοποιεί για την αξιολόγηση μιας εφαρμογής ή συστήματος και τα διάφορα στάδια σχεδίασης που προηγούνται αυτής της διαδικασίας, όπως η δημιουργία ενδεικτικών χαρακτήρων και σεναρίων χρήσης. Στη συνέχεια, η μελέτη συνεχίζεται με το τεχνικό μέρος όπου περιγράφονται όλες τις τεχνολογίες και οι αλγόριθμοι που χρησιμοποιήθηκαν στα πλαίσια της διπλωματικής εργασίας. Η προτελευταία ενότητα περιλαμβάνει την αξιολόγηση των πρωτοτύπων της εφαρμογής, τον τρόπο που έγινε, την παρουσίαση των παρατηρήσεων από τους αξιολογητές και τα κύρια συμπεράσματα. Επιπλέον, παρουσιάζεται η τελική μορφή της αίτησης. Τέλος, το έργο ολοκληρώνεται με τη συζήτηση και τα συμπεράσματα που προέκυψαν από τη μελέτη και την κατασκευή του συστήματος, καθώς και προτάσεις για μελλοντικές επεκτάσεις του θέματος στους τομείς των συστημάτων LoRa σε συνεργασία με τον τομέα της αλληλεπίδρασης ανθρώπου-υπολογιστή.

Abstract

The subject of this dissertation is the study and implementation of a LoRa based Search and Rescue system that can help in the localization of people having a high risk of going missing. These people may suffer from dementia, attention disturbance and distraction, and it is of great importance to be found in a specific time frame, as their life can be in danger. The system is based on LoRa network architecture that enables both long-range communication and low energy consumption. The study begins with a brief introduction to the Internet of Things, wireless communications, and LoRa systems while also presenting the Search and Rescue system, its approaches, and requirements that accompanied it. This is followed by a section dedicated to the Human-Computer Interaction field, the main methods and principles used by it in order to evaluate an application or system, and the various design steps that precede this process, like the creation of indicative personas and scenarios of use. Then the study continues with the practical and technical part where it lists all the technology and algorithms on which it was based to create the application with emphasis on geolocation technologies. The penultimate section includes the evaluation of the prototypes of the application, the way it was done, the presentation of the observations by the evaluators, and the main conclusions. In addition, the final form of the application is presented. Finally, the work concludes with the discussion and conclusions that emerged from the study and construction of the system, as well as proposals for future extensions of the topic in the fields of LoRa systems in collaboration with the field of Human-Computer Interaction.

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Introduction

A large percentage of individuals with dementia are at risk of wandering and go missing. These people may be injured, causing trauma to themselves and their families and caregivers, and necessitate the use of costly Search and Rescue (SAR) operations. Approximately 60% of dementia patients may become disoriented and go missing. Furthermore, according to a study, about half of children with autism spectrum disorder have attempted to elude parental control at least once and eventually go missing while walking, having similar repercussions to themselves and to their caregivers too. But even healthy people may get lost as well in different scenarios. A scenario could be the disorientation of children in large parks such as amusement parks, where the parents are easier to lose their children in the crowds. Another scenario could be the accidents that occur in mountainous sports, e.g. skiing, as the athletes can go missing usually due to an accident. All the above scenarios indicate the importance of the existence of a system that can help rescuers and in the case of the supervisors of people suffering diseases such as dementia in locating and rescuing these people in case they go missing.

In this context Internet of Things (IoT) can benefit vastly the SAR operations. The widespread use of fitness trackers, Global Positioning System (GPS) devices, smartwatches, and other portable IoT technology opens up new avenues for improving protection and caring for people with a high probability to go missing. These devices' intent, role, and technologies differ, and range from gait and behavior analysis to determine physical activity, to warning systems that monitor slips, to GPS trackers that assist in the location of the missing. Such systems thus have some requirements that should be met in order to effective. The core requirements are a) the communication technology and protocols, b) the localization accuracy, c) the energy consumption and d) Human-Computer Interaction (HCI).

As far as the communication technologies are concerned different wireless technologies can facilitate such systems each technology posing different advantages and disadvantages. For outdoor monitoring systems, a new class of wireless technologies has been created called Low Power Wide Area Networks (LPWAN) with the main characteristics the low energy consumption the long-range communication, and low cost. The de-facto technology is the Long Range (LoRa) technology. As far as the localization process is concerned the GPS technology is widely used, because it provides high localization accuracy, but this accuracy comes with a price in terms of energy consumption. Thus, a combination of LoRa use and a localization process based on LoRa instead of the GPS may enable a new potential for the SAR systems.

From an HCI standing point, such systems have a lot of parameters that affect the user experience, due to the fact that there are many stakeholders, for example, the person that wears the portable device, the supervisor that uses the interactive interface through which the location is monitored. HCI is a multidisciplinary area of research that focuses on the architecture of computer technology, specifically the interaction between humans (users) and computers. HCI, which was originally concerned with computers, has since grown to include nearly all aspects of information technology architecture, and in our case IoT systems.

Having said the above, the subject of this thesis is to create a LoRa based SAR system for people with special needs. Particularly, the main objectives are a) to create an online platform for location monitoring of people with special needs, b) study and solve specific requirements of a SAR system, namely the energy efficiency in LoRa networks through user-based mechanisms and with the use of Machine Learning algorithms, and the localization algorithms

Thus, in the next chapter many definitions about the IoT concept will be presented, highlighting the change of concept over time as a result of technological innovations in computer hardware but also

the establishment of the internet. Also, we will focus on wireless technologies that support IoT. More specifically, there will be an overview of the available ways in which all these devices are interconnected. Here are a few protocols for connecting small devices such as Bluetooth, Wireless Fidelity (Wi-Fi), up to larger networks such as cellular networks. One category of such technologies is the so-called LPWAN that focus on transmissions in long ranges. LoRa will be discussed thoroughly, as the main representative of LWPAN category and will be the basis of this thesis. Finally, the SAR operations in the context of IoT are presented. The definition, different approaches for the SAR operations, and the requirements of the SAR operations using a wearable-based system are presented. Notably, the requirements are the basis of the problems that are coped in this thesis in the later chapters.

Chapter 2 is a dive into HCI world. As the problem of this thesis has to deal with the population at risk and mechanisms that can save it through monitoring processes, the HCI field offers the theoretical background that supports the study and help in the right evaluation process of the proposed website platform "Search and Rescue". The chapter starts with an overview of the HCI field and its history. Then it continues with the most popular and useful models, the interaction model from D. Norman and the one of Adowd and Beale which both explain the relationship between the system and the user, as well as how the proposed system is based on those models. The next section mentions the usability heuristics of Norman, the seven principles that an application must have as well as the requirements and misconceptions that are a common field in the daily life of a designer. The concept of personas, scenarios, and the general design phase is presented at well. The chapter concludes with the quoting of two interviews: one with an expert in the domain and one supervisor from Child's Smile organization.

Chapter 3 deals with the presentation of algorithms for energy saving in IoT-based networks, emphasizing providing solutions concerning the LoRa networks that exist in the literature. Also, two energy efficiency mechanisms are proposed in order to tackle the SAR operation problem of the high GPS energy consumption. The first mechanism makes decisions about the frequency of the sensor measurements and the LoRa transmissions according to the user's state (e.g. emergency state). The second one is a Machine Learning based mechanism for network resource allocation that aims to reduce collisions and the reduction of energy consumption. Lastly, a review of the localization algorithms for LoRa networks is presented and the implementation and the algorithm selection in the context of this thesis are presented as well.

The evaluation process on the website prototype with the recommendations of the users and the final version of the website is presented in Chapter 4. It is the most important part of the dissertation as gives the reader insights about the first ideas of the designer and the system and how it finally took its final form under the guidelines of the HCI field. More specifically, the evaluation process is presented step by step with the description of the area and the way in which it took place. One by one all the problems that evaluators pointed out, the heuristics that were violated as well as the recommendation for a better design implementation contained in this chapter. Furthermore, a usability questionnaire frames and closes the chapter with the answer of the evaluators.

Chapter 5 is the last of the thesis. It is a conclusion of the whole thesis and a recommendation for future works. It starts with a summary of the 4 chapters, discussing how the HCI domain was connected with the world of LoRa networks in order to save lives. Then, it presents the main challenges that a system like the proposed one of Search and Rescue will deal with in the world of HCI and LoRa in terms of evaluation and practical implementation. The next unit presents the main assumptions of the thesis in a conclusion form. The end of the thesis comes with a paragraph that is about future work in the domain of machine learning and other applications that can be based on the system that this study proposed.

1

Internet of Things

"If you think that the internet has changed your life, think again. The Internet of Things is about to change it all over again!"

— Brendan O'Brien

1.1 Definition

There are a lot of talks nowadays about various innovations that take place in the field of computer engineering and informatics, one of these being the Internet of Things (IoT). The goal of IoT is to create a smarter world and a simpler way of life by conserving time, energy, and money. Expenses in various industries can be minimized using this technology. IoT has become an increasing trend in recent years as a result of massive investments and numerous studies. However, what exactly does the term IoT mean? As is usually the case with any new concept, there is no clear and absolute definition of IoT, as different groups of IoT "creators", such as researchers, academics, companies, have proposed different definitions. One definition suggested by Somayya Madakam, R. Ramaswamy, Siddharth Tripathi [1] *is an open network of intelligent objects that have the ability to self-organize, share information, data, and resources, reacting to changes in the environment*. Atzori et al. define IoT as *a combination of embedded technologies including wired and wireless communications, sensor and actuator devices, and the physical objects connected to the Internet* [2]*[1]*. Alternatively, we can define IoT as *the communication network of a series of devices, home appliances, cars as well as any kind of object that incorporates electronic means, software, sensors, and network connectivity to allow the connection and exchange of data*. Otherwise, we can say that the philosophy of the IoT is *to connect all electronic devices to each other through a local network or to provide the electronic devices with the ability to connect to the Internet*.

From the above definitions it is understood that the main components of such a system are the following: 1) sensors, 2) processing networks, 3) data analysis unit, and 4) system monitoring [3]. The idea of the IoT is oriented towards the greatest use of all existing interconnection technologies, hence the internet. The creation of more and more efficient, economical microcontrollers and sensors, the reduction of costs has contributed to the wider use of these devices, thus increasing the number of the use cases. Some of these use cases may need even the incorporation of micro-controllers in clothes. Also, the availability of many wireless technologies (each of which has different advantages and disadvantages) pushes the rapid development of IoT applications. All these sensors are transmitting data, and this data is aggregated and analyzed in remote servers extracting valuable information, hence IoT has been benefited vastly of the development of cloud solutions. In this point, it is important to introduce

one important aspect of IoT application the “Computing Framework”: that is the data processing architecture, the most well-known of which are fog and cloud computing. Depending on the device’s and process’s place, IoT implementations use both frameworks. In some applications, data should be processed right after it is generated, while in others, it is not appropriate or necessary to process the generated data right away. Fog computing refers to the real-time data processing and the network architecture that enables the real-time data processing.

Three main computing frameworks are used in modern systems: a) edge computing, b) cloud computing, and c) fog computing. In edge computing, the data processing is carried out at a distance from the hub, near the network's edge. This method of processing allows data to be processed at the edge devices of the network. Since devices at the edge may not be connected to the network continuously, a copy of the master data/reference data is required for offline processing. Edge devices have a variety of functions, including 1) enhanced security, 2) data filtering and cleaning, and 3) storing local data for local use. On the other hand, in cloud computing, the data to be processed is sent to data centers, where it is analyzed and processed before being made usable. Since in many IoT applications the data processing needs to run at high speeds, this architecture has high latency and load balancing, suggesting that it is insufficient for processing IoT data. The amount of data is high, and big data processing would increase the cloud servers' Central Processing Unit (CPU) consumption [4]. Cloud computing comes in a number of varieties, e.g. Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

After this expansion of IoT applications, the "liquidation" of the concept of the Internet has begun. From its strict description to the interconnection of computers and the design of various protocols that mainly concerned personal computers, in a broader sense of interconnecting more devices. This is how the concepts of pervasive programming and ubiquitous computing are born. It is the idea in computer science and software technology, where computing happens "everywhere". The term ubiquitous computing was introduced by Mark Weiser in 1988, head of Xerox PARC, creating the first publications on the subject. Particularly, the IoT has enabled the visions of Mark Weiser about ubiquitous computing, who has stated (before the emergence of IoT) that:

“For 30 years, most interface design, and most computer design, has been headed down the path of the “dramatic” machine. Its highest ideal is to make a computer so exciting, so wonderful, so interesting, that we never want to be without it. A less-traveled path I call the “invisible”: its highest ideal is to make a computer so imbedded, so fitting, so natural, that we use it without even thinking about it. (I have also called this notion “ubiquitous computing,” and have placed its origins in postmodernism.) I believe that, in the next 20 years, the second path will come to dominate. But this will not be easy; very little of our current system’s infrastructure will survive.”

It is the vast availability of IoT infrastructure that has enabled the use of ubiquitous computing nowadays.

1.2 Wireless Technologies

As pointed out in the previous paragraph IoT depending on the perspective studied, different definitions have been given for this concept. But in general, we can say that IoT aims at the cooperation of different devices. This collaboration, however, is a very general idea, but mainly multi-parametric, with the result that there is a plethora of technologies, protocols, and prototypes depending on the various specifications of the problem they are trying to solve. Some features with which categorization of the wireless technologies can be done are the communication range, the energy consumption, etc. Thus, wireless technologies can be categorized into technologies of short-range communication, cellular technologies, and Low Power Wide Area Networks (LPWAN).

The most notable and widely used short-range technologies are Bluetooth, the IEEE 802.11/Wireless Fidelity (Wi-Fi), and the Zigbee technology. Bluetooth is a short-range technology created in the '90s and is a standard for wireless personal networks. It operates in the free 2.4 GHz band, thus the devices that support Bluetooth can operate in all parts of the world. Bluetooth connects two devices directly (device to device communication). This technology allows you to connect without wiring to objects such as mice on a computer, connecting mobile/wearable devices to a mobile phone when they are within walking distance. Multimedia transmission such as images, songs between two devices. The IEEE 802.11 standard is a set of standards for wireless LANs used for a range of applications. Some of them are internet access, internet telephony, and the interconnection of various objects such as televisions, digital cameras, and computers. The first version of Wi-Fi was made in 1997 and has been widely used ever since. As far as the IoT part is concerned, this technology is mainly used for interconnection within a building and can often be used in addition to other technologies, such as LoRa. The main characteristics of these technologies are the short-range transmission, and the low cost, in the case of Wi-Fi can be power consuming. For this reason, these kinds of technologies face important limitations for the IoT scalability and IoT deployments in large areas.

Another type of device interconnection is the Cellular wireless technology networks which have given a great opportunity to send data from machine to machine, and with the advent of Fifth Generation networks (5G) are predicted to give a great impetus to the establishment of IoT in our lives. 5G is expected to offer increased speeds compared to previous generations while at the same time it will be able to support multiple users of the same network by increasing the available bandwidth with the minimum possible response time while using techniques to reduce energy consumption within the network. The main characteristics of cellular technologies are long-range communication and high speeds. Nonetheless, cellular networks are limited by high energy consumption and high cost. Lastly, an emerging type of technologies are emerging called LPWAN and will be presented in subsection 3.3

1.3 Low Power Wide Area Networks

As explained above, the two categories of wireless technologies are limited either by the energy consumption cost, the financial cost, or the communication range, showing a gap between those two categories. The LPWAN technologies come to fulfill this gap, as their main features are the energy-efficiency, long-range communication, and low cost, usually compromising the latency and throughput. LPWANs are designed to co-operate with existing short-range radio and cellular IoT networks; though, the user or application must decide which network(s) to use, according to the application's needs and requirements. In the remaining of this subsection, a more thorough answer to the question "Why LPWAN ? " will be provided.

Firstly, it is necessary to investigate the application requirements. IoT systems must be installed in remote or nomadic areas in many applications, e.g. agriculture. As a result, most micro-computers run on batteries and are unlikely to have access to a constant power supply. Battery replacement requires time and energy, and when extended to large networks, it becomes an unaffordable cost. In [5] estimated a node's battery life in decades, while a more cautious calculation [6] set it at *"10 years or more"*. Based on these assertions, the target battery life for End Devices (ED)s is set at ten years in this paper. LPWANs must communicate over long distances since they are wide-area networks. LPWANs are usually accepted to have a target range of a few kilometers in urban areas and tens of kilometers in rural areas around 10 km in Line of Sight (LoS) conditions [7]. Obstacles, infrastructure, moving artifacts, and other types of signal deterioration cause path loss, shadowing, multipath fading, and other types of signal deterioration when LPWAN signals are deployed in urban environments.

Many IoT applications need the use of a large number of EDs, thus in order to deploy massive numbers of IoT devices a low cost should be achieved as it would be impractical if EDs are costly to produce and maintain. Due to the fact that many companies and organizations have a budget available,

cheaper EDs often result in a larger system. If a public network provides an LPWAN, each node is likely to be charged an annual subscription fee. On the other hand, if an organization has its private LPWAN, ongoing maintenance and service expenses would be incurred on an annual basis. Furthermore, taking into account that e.g. Bluetooth technology transmits in free bands, whereas the cellular networks use the licensed spectrum, LPWAN should cope with the interferences. Many LPWAN technologies use the unlicensed Industrial, Scientific, and Medical (ISM) bands due to the high cost of licensing a frequency band that belongs to the Licensed spectrum. While using the ISM band may save money, it may compromise efficiency and reliability.

Some LPWAN technologies are the Narrowband IoT (NB-IoT), Sigfox, LoRa, Weightless, etc. While in this thesis, the technology used is the LoRa technology and a thorough description will be provided, a brief presentation of other notable LPWAN technologies should be made. Starting with the main rival of LoRa, the NB-IoT technology is developed by the 3rd Generation Partnership Project (3GPP) and is part of Long-term Evolution (LTE), and with the advent of 5G, it will be integrated into it as well. So far it coexists with Global System for Mobile Communications (GSM), Universal Mobile Telecommunications Service (UMTS), and LTE and is an evolution of Machine-Type Communications (MTC). 3GPP is the organization that sets the standards for LTE GSM, UMTS, and these standards are referred to as Releases [12] [15]. NB-IoT operates in the licensed frequency bands as LTE, which are divided into 12 sub-carriers of 15 kHz each in the downlink transmissions (DL) using Orthogonal frequency-division multiple access (OFDM) and 3.75 or 15 kHz in the uplink (UL) using the single-carrier FDMA (SC-FDMA) access scheme. It's also worth noting that NB-IoT uses a Phase Shift Keying (PSK) modulation technique, which is the same as that used in LTE. NB-IoT uses a frequency band with a bandwidth of 180 kHz, which is equal to one resource block in LTE transmission. In order for the NB-IoT to coexist with the LTE using the same infrastructure, three operation modes have been introduced in the NB-IoT specifications: 1) In-band service using resource blocks within an LTE carrier is one of the three operating modes. 2) Guard-band service, which makes use of any unused resource blocks in an LTE carrier's guard-band. 3) Stand-alone operation: Using currently used GSM frequencies is one potential scenario. On both sides of the 200 kHz spectrum, a guard interval of 10 kHz remains.

Another LPWAN technology that is widely used is called Sigfox. SigFox uses the Differential Binary Phase-Shift Keying (D-BPSK) modulation, with a fixed bandwidth of 100Hz and a speed of 100bps (for Europe) or 600bps (for the US), within an unlicensed frequency, for Europe, the bandwidth is 868MHz and 915MHz for the US region. This modulation technique belongs to the Ultra-Narrow Band (UNB) modulation class, which, like Chirp Spreading Spectrum (CSS) (used by LoRaWAN systems) and NarrowBand (used by NB-IoT), requires low-power consumption to maintain connections between EDs and BS. SigFox's network is divided into two layers, the Network Equipment and the SigFox Support System. Both base stations and their attached antennae make up the Network Equipment, which is arranged in a star network topology to deliver energy-efficient endpoints and high spectral efficiency. Devices transmit messages to the nearest base station via a radio interface, which receives the message and forwards it to the SigFox Support System via the public Internet. This backhaul is typically focused on Digital Subscriber Line (DSL), with LTE and satellite as backup media [16].

1.4 LoRa

LoRa technology is a broader term that consists of two main parts. The first one is called LoRa that defines the physical layer of the technology and the modulation technique. The other part called Long Range Wide Area Network (LoRaWAN) refers to the open specification protocol developed by the LoRa Alliance which is an inclusive community in which any person or organization is welcome to participate [17]. LoRa is predominantly a manufacturing-driven business model, with Semtech transceivers being the only ones available, in contrast to Sigfox that follows a subscriber business model or the NB-IoT that operates in the licensed spectrum. While only Semtech can make actual transceivers,

any hardware manufacturer can incorporate them into their products as long as LoRa's specifications are followed. The organization that is responsible for the certification of LoRa complied products is the LoRa Alliance. The main parts of a typical LoRa network are the: End Device (ED): a peripheral node that can be an actuator or micro-controller, the Network Server (NS) that is a central unit that controls the LoRa network parameters, forwards messages to applications, and sends replies to the EDs through the LoRa gateway(s), and the Gateway (GW) that is an intermediate node that translates the LoRa packets to Internet-compatible packets that will be transmitted via a backhaul network, usually a Wi-Fi or ethernet.

The physical layer of LoRa allows the communication between a node to the LoRa GW in an energy-efficient manner and is ideal for battery-constrained devices over long distances. It can cover over 15 km in LoS conditions and is similar to CSS modulation allowing a trade-off between the data rate for sensitivity within a channel bandwidth. Moreover, from Frequency Shifting Keying (FSK), LoRa provides low power features, while having increased coverage. One interesting capability of LoRa is that a GW can receive a lot of signals at the same time since the signals have different SF. The physical layer of the LoRa is proprietary by Semtech, so there is not a lot of knowledge accessible and the scientific community cannot access the documentation [17][18].

LoRAWAN defines the open-access communication protocol of the network and is the Medium Access Control (MAC) layer protocol. LoRaWAN uses a star network topology. The EDs are broadcasting their messages directly to the GWs, as the LoRa uses a star of stars topology. The packets are encrypted, and only the appropriate GW can process each packet. Then, the packets are sent via a backhaul technology over the Internet to the Network Server and then to the Application Server. If the Network Server receives copies of the same message from the same node through different GWs, it is up to it to decide which copy to transmit to the Application Server. Also, LoRaWAN describes three Classes, which categorize the nodes in classes A, B, C. Each class has a different energy consumption impact, with the A class consuming the least energy [17][18]. Specifically, after sending an uplink packet, Class A devices only open two temporary receive windows. The only downlink packets that are sent from the GW to the EDs are for acknowledging purposes. Class B devices have the same acknowledgment features as class A devices, but they open receive windows at fixed times that the network server knows about as well, and not only after the uplink transmissions as happens in Class A devices. Finally, except while an uplink transmission is being sent, Class C devices keep their receive windows open all the time. More details about the LoRa physical layer modeling are presented in the next Chapter, providing details about the system model. In Figure 1 a typical LoRa architecture is presented, giving details about each component of the architecture.

Lastly, in order to have a better view of the LoRa technology, the basic LoRa parameters are presented briefly, and a more thorough description will be followed in the next Chapter as some of these parameters will be part of the energy consumption optimization process. The main parameters that an IoT developer will encounter and needs to take care of are the following:

- Transmission Power (TP): in a typical LoRa device the TP ranges between -4dB to 20dB.
- Carrier Frequency (CF): is the central frequency with a range of 137 Hz-1020 Hz.
- Spreading Factor (SF): is the ratio between the rate of the symbols and the rate of the chirp. A higher spreading factor means an increase in the Signal-to-Noise ratio (SNR). As we increase the SF, the transmission time increases, therefore the energy consumption also increases. The values that can receive are graded from 7 to 12.
- Bandwidth (BW): higher bandwidth results in a higher data rate and conversely if it is lower, it results in a lower data rate.
- Coding rate (CR): used by the LoRa model and indicates protection against interference. Obviously, a higher encoding rate gives more protection against interference however it reduces the data rate. The values that can get are 4/5, 4/6, 4/7, 4/8.

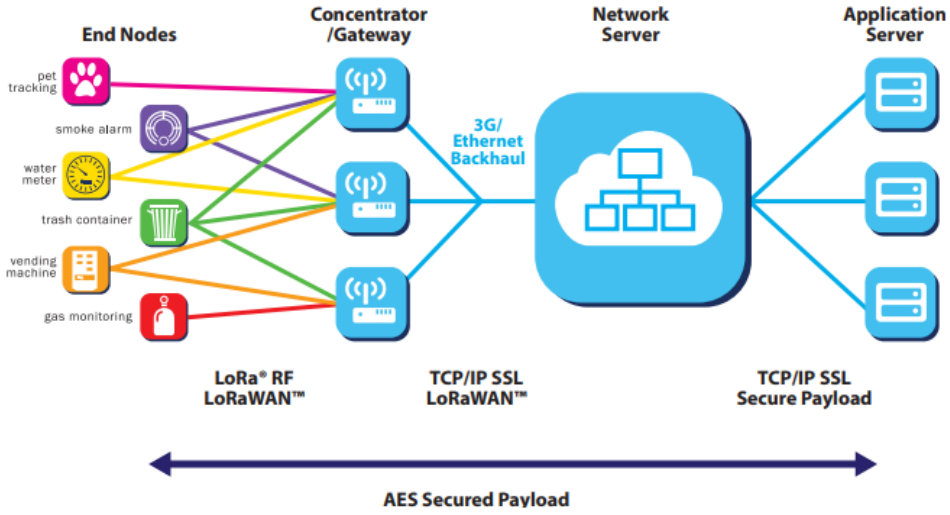


Figure 1. A typical LoRa architecture.

1.5 Search and Rescue: an IoT application

The radical improvement in terms of hardware, wireless technologies, and Network Protocols has led to the ability to implement IoT in many areas where the ability to automate and machine-to-machine communication is introduced. These areas can be industry management (Industry 4.0), smart city, home automation, search and rescue systems, etc. In this thesis the focus has been on the search and rescue IoT application, especially considering that the SAR operations can be vastly benefited by the IoT.

1.5.1 Definition

By Search and Rescue, in a very broad and general term we mean the process by which search and assistance are provided to people at risk. According to the official European Union website, we can find the following definition: *"The performance of distress monitoring, communication, coordination and search and rescue functions, including the provision of medical advice, initial medical assistance, or medical evacuation, through the use of public and private resources including cooperating aircraft, vessels, and other crafts and installations"* [19]. This concept includes a set of specialties and depends mainly on the type and place of rescue, as each case requires different equipment. For example, for rescue that occurs in the mountains, rescue dogs are usually used, while for rescue at sea, helicopters and various air and ground means are used. Also, of course, different means are used when it is a person who is lost and different when it is a whole group, or for example a ship or a plane that fell into the sea. Each state has search and rescue teams and historically there have been cases where there have been accidents in international waters, such teams have been mobilized in coordination from different countries.

1.5.2 Approaches

By the definition of SAR provided above, it is easily understood that the speed of the search process of the person that is lost is of paramount importance. Helicopters, planes, radars, etc. can be

used in this process, but with the rapid development of the IoT, IoT can be used for this purpose. IoT technology has mainly contributed to SAR operations using Unmanned Autonomous Vehicles (UAV)s, which are very powerful tools because they offer the ability to obtain and analyze data over the air. To save energy for these vehicles, but also to find the person faster, there must be a network infrastructure. First, the UAVs must communicate with each other in order to fly in flocks according to routing and flying algorithms. Their networking is a modern challenge, as in an urban environment where the network coverage is good can be easily controlled remotely, but outside the urban environment. The LoRa protocol can usually be used for communication between them, which in search mode is important, as the relevant parameters such as the height at which they will fly, the distance that the drones should hold each other, the speed, and the direction [20].

Another approach that is already being attempted is the use of wearables. Such a system can locate the user through wearable devices, which can be either a watch or a sensor that is integrated into the clothing (e.g. in shoes). The idea is that users, who may be older people with some form of dementia, young children, or people with autism spectrum disorders, i.e groups that are very easy to get lost and unable to return, are provided with wearables devices, and the people who supervise these people have the ability to spot them when they cross a boundary, which can be their place of residence or a wider area, such as their neighborhood. In addition to the above basic functions in the literature, some systems use biological data sensors and in combination with the above, the individual can be found when the biometric data exceed a certain limit.

Such systems with biometric sensors are proposed in the publications [21][22][23]. More specifically, such a system for collecting biometric data deals with the acquisition of data through sensor measurements, their transmission through a protocol, the analysis of this data, and always supported with encryption protocols for security. Usually, these systems should take into account the following:

- Data must be encrypted during transmission.
- It is important to do it with low financial and energy costs.
- Biometric data must be accurate.

A flowchart of the basic logic of a SAR system that is based on the biometric data of the person that got lost is presented in Figure 2.

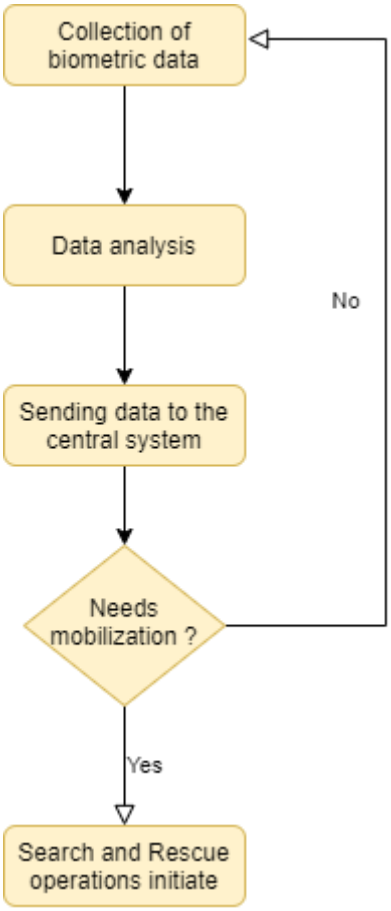


Figure 2 Flow chart for SAR system based on biometric data.

A wearable device-based monitoring system can be used for a large variety of cases. Indicatively, in these cases belong:

- People suffering from some form of dementia statistically have a 60% chance of being lost outdoors at least once.
- People with autism spectrum disorders who, in 49%, have been reported to have disappeared or been at risk once at the age of 4 due to a tendency to flee.
- Infants and children in large amusement parts with the risk of falling victim to malicious actions.
- Athletes (e.g. skiing) or missing persons outside local or broadband networks, such as in the case of maritime accidents. In these cases, the missing persons carrying the wearable device can be located from mobile stations, e.g. drones, which will execute positioning algorithms.

Alzheimer's disease (AD) and other causes of dementia are major public health concerns. There are reportedly about 5.4 million people in the United States who have dementia, with 70-80% of all people with dementia in the United States being cared for at home by a family member [24] with 15 million nurses providing an estimated 18.2 billion hours of treatment annually. It is projected that 60% of dementia patients will wander [24]. Wandering is a general concept that can be described as *"a syndrome of dementia-related locomotion activity expressed in lapping, random, and/or pacing habits, some of which are synonymous with eloping, eloping attempts, or getting lost unless accompanied* " [26]. Wandering can occur as a result of a person with dementia, such as Alzheimer's, being unable to recall his or her name or address, and becoming disoriented even in familiar surroundings. Wandering

and getting lost can happen during the mild, moderate, or serious stages of AD and can be risky (leading to falls and injuries, institutionalization, and death) as well as stressful for families and caregivers [25], [27]. Having dementia over a longer period of time, the severity of dementia (though wandering can occur at any stage), the prevalence of a sleep disorder, deterioration in day-to-day functioning, and behavioral disturbances such as anxiety and depression are all associated with wandering [28]. Having this said, we can conclude that is of paramount importance to monitor the people suffering from such diseases, in order to find them when they get lost, as it can be dangerous for them and very stressful for their caretakers.

Moreover, Autism spectrum disorder (ASD) affects about one of every 59 children in the United States, a neurodevelopmental condition marked by chronic deficiencies in social cognition and social contact, as well as limited and repeated patterns of conduct. Some people with ASD exhibit maladaptive behaviors, such as wandering/elopement, which is described as leaving a controlled, secure environment without the consent or permission of a caregiver. It is estimated that almost half of children with ASD aged 4 years and older have participated in elopement activity at least once, and of those who have eloped, about one-quarter went missing for a period of time that worried caregivers. Children with ASD are at a higher risk of serious injury or death as a result of this action. Drowning, in fact, has been found to be one of the leading causes of death among people with ASD, and wandering was cited as the most prevalent activity that resulted in drowning deaths. In a convenience survey of 1218 children with ASD aged 4 to 17 years, 24 percent had a history of elopement and were in danger of drowning [29].

According to the 2011 Pathways research survey [30], more than 25% of parents of children with ASD used fencing, gates, locks, alarms, or other barriers to avoid elopement in the previous year; 3.5% of parents reported using an electronic tracking system for their infant. The tracking systems are handheld systems that use a variety of technology, such as GPS technology, wireless networks, Bluetooth, or radiofrequency communications, to locate a child's location in real-time. Any monitoring system can also be configured to define safe zones, giving parents the option of being alerted if their child enters a potentially dangerous environment, such as a swimming pool. Although these features cannot physically prevent elopement, it is likely that tracking systems can increase parents' quality of life by giving them peace of mind in understanding that they may be able to react to elopement episodes more easily and locate their children. Andersen et al. [29] conducted a 2019 report to assess the efficacy, burden, and cost of multiple elopement avoidance measures in a cohort of children with ASD. They discovered that only 6% of households have ever used GPS trackers, and they confirmed that GPS trackers were considered by parents to be less reliable, more difficult to adopt, and more costly than certain physical approaches. They did, however, just look at GPS trackers, while this kind of system can use a range of technologies. Furthermore, their sample of GPS-enabled children was limited ($n = 534$), significantly restricting the accuracy (and presumably generalizability) of their results. In [31], the authors studied a vast nationwide population of children with ASD and history of elopement. The researchers discovered that using an electronic tracking system was correlated with reduced elopement incidence and duration, a lower risk of serious injury as a result of elopement, and increases in indicators of household quality of life. Many obstacles to such systems have been noticed, including bad fit or child distress, as well as the burden of use.

Furthermore, as far as the sports events are concerned, one example of a sports category is winter mountain sports and events are very common in the world. In the event of an accident, rapid localization of the person(s) involved in the accident is needed for a successful SAR operation. Mountain-based SAR operations, unfortunately, are common. For example, the French National Mountain Safety Observation System reported 5389 operations in France in 2012 [32]. 62% of mountain SAR operations are accounted for by two common scenarios: 1) the missing hiker and 2) the avalanche. Hikers are responsible for 59.41% of mountain SAR operations, with 37% of these operations are about trying to find the persons [33]. When it comes to winter sports (such as skiing and snowboarding), the majority of deaths are caused by human-caused avalanches, with over 150 people dying each year in North America and Europe alone [34], [35]. The rapid localization of people buried under snow is critical in these situations, as 60% of them die within the first 30 minutes [36]. The median burial depth of

avalanche victims is estimated to be 1 m [37]. Two radio-frequency devices are currently used to facilitate SAR operations for the person(s) involved in avalanche accidents: 1) avalanche beacons (ARVA, supervised in the EU by the ETSI EN 300-718-1 [38]) and 2) RECCO systems [39], which consist of an interrogator that searches for reflectors. ARVAs use double-sideband amplitude modulation to relay signals with no modulating auxiliary carrier. The mean pulse length is 1300 ms, with a service duration ranging from 5.4 to 69 percent. At a distance of 10 m and a frequency of 457 kHz, the transmitting power is controlled such that the output field strength is between 6 and 7 dBA/m. The use of UAVs to localize people is currently being investigated [40], [41], but ARVA-equipped drones must contend with the low performance of current antennas, which are intended to be as compact as possible while remaining convenient for the wearer [42]. The use of unmanned aerial vehicles (UAVs) can be allowed by using technologies with a longer radio range.

1.5.3 Requirements

In this section, the requirements in terms of the hardware, and other constraints are being discussed. First of all, a requirement is that the wearable device that the person should wear. This device should support a technology that can connect to the internet, and in many cases such as in suburban conditions where broadband or cellular wireless technologies are out of range, then different and emerging technologies should be used. Also, this device should support all the necessary sensors that help in the decision of the emergency state, such sensors could be heart rate sensors, etc. Furthermore, all the networking components and technologies such as cellular towers, femtocells, LoRa GW should be present, or the operator of such a SAR system should take special care in order for the wearable device to be able to have supplementary modules that support different technologies.

Another part that is of paramount importance in such systems is localization accuracy. Especially, in the wild and places with mountainous environments, a difference in the localization could be costly to the SAR operations. This can happen as an error of 500m radius could make the rescuers climb a hill, or descend a canyon, wasting both valuable resources but most importantly, wasting vital time as the person that has been lost can be in danger. Also, the data rate is important, too. In the scenarios where the person that is missing is for example suffering from ASD, the person can move freely, something that leads to a new problem: the need for almost real-time monitoring. One technology that can provide real-time localization with high accuracy is the well-known and widely used GPS. The GPS, formerly known as Navstar GPS, is a satellite-based radio navigation system owned by the United States government and run by the United States Space Force. It is one of the global navigation satellite systems (GNSS) that delivers geolocation and time information to a GPS receiver anywhere on or near the Earth where four or more GPS satellites provide an unobstructed line of sight. Obstacles such as mountains and buildings obstruct the GPS signals, which are comparatively small.

One of the drawbacks of GPS use for SAR scenarios is the fact that is highly energy-consuming. Despite its high accuracy, the battery life of the energy-constrained wearable devices is reduced dramatically, as the GPS module is enabled. In order to understand the importance of the large battery lifetime and consequently the energy consumption, it is good to examine the paper [43]. The paper [43] studies the existence of a rule for the selection of SAR operations based on the search time duration, in order to maximize the rescue of the living missing people. For a large number of survivors n = 1439, the average value of the search duration is 7.9 hours with a maximum duration of 323 hours or about 13 days. Specifically, by an estimated cut-off point of 51 hours, almost all the survivors have been located, whereas by 100 hours almost all the lost persons, dead or alive have been located (not rescued). Therefore, the battery life must be large enough to give the necessary time to the rescuers to locate and rescue the people. It is worth noting that it is important for the SAR operations to have “contact” with the wearable device, even though the wearable device’s battery is not fully charged.

2

Human-Computer Interaction

"Good design is actually a lot harder to notice than poor design, in part because good designs fit our needs so well that the design is invisible, serving us without drawing attention to itself. Bad design, on the other hand, screams out its inadequacies, making itself very noticeable."

— Don Norman

The world continues to revolutionize in different ways: knowledge, information, network computing, new inventions. All of those factors change the way that people lιωε and interact with each other. In the 21st century, there is a more obvious form of interaction, the interaction between humans and computers. Principles of Human and Computer Interaction (HCI) as well as User-Centered Design (UCD) is of great importance for the design of applications, sites, and networks.

2.1 Concept of HCI-an overview

The first appearance of the HCI term was in Shekel's paper: The ergonomics of a computer [44]. It was a try to address issues that concern users and the interface of the first computing machines. Although, the first conference and first journal appeared in the academic community years later in 1969 titled "The International Journal of Man-Machine Studies". In the 1980s three more journals were added and some conferences [45]. In the 1990s the technology goes digital. This period was focal for the term as the "I" shift meaning from Interface to Interaction. Users stop interacting only with the computer's interface, they dive more into the application itself [46].

Brad Mayers in 1998 review the history of the term from a technological aspect and showed that HCI began as a university research topic, expanded in commercial research in 1970, and focused on commercial products in 1980. Also, he predicted some future areas of HCI research such as gesture recognition, multimedia graphics, 3-Dimensional (3D) illustrations, virtual and augmented reality (VR) (AR), computer-supported cooperative works that mean remote participation of many people on various sites, and natural language and speech [47]. In Figure 3, there is an illustration of graphics that shown according to Mayers when work was performed on technologies from the past years like the computer mouse, the use of hypertext, text editing, etc. The blue bar indicates that is about corporate research, the green about the university, and the pink about the commercial.

Furthermore, in 1990 the usability term was linked and introduced in the HCI research area. Usability is a term that shows how well a user can interact with a specific context to achieve a particular goal effectively and simply. In the past, this and four other terms were developed under the HCI process: safety, utility, effectiveness, efficiency, and usability. All of them were used by Nielsen and Norman to define the main levels in user experience [49]. Nowadays the definition of HCI is that of a science field

that studies the design and use of computer technology. More specifically, it focuses on the interaction between the users and computers-applications interfaces and how under-right evaluation and implementation practices can be more useful and satisfy users [48].

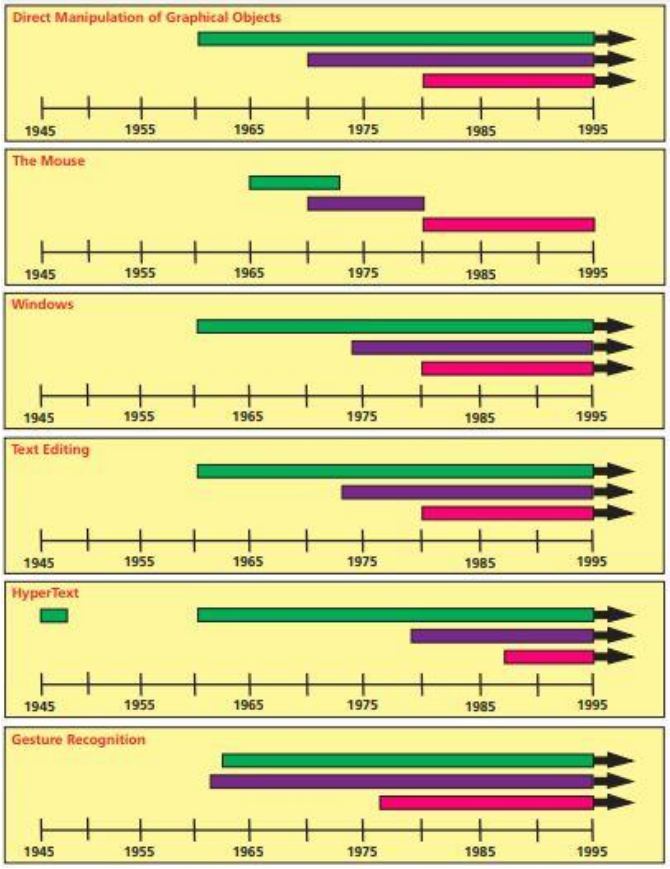


Figure 3 Timelines of major technologies from 1960-1995 [47].

2.2 Models of HCI

In order to give HCI a particular context, many researchers created a series of different models. The most known of them is Norman's model.

2.2.1 Norman's model of interaction

The model of Noman's is based on user's views about an interface that they focus on and how they can achieve their goal through it. Norman used for the first time the phrase *"user-centered design"* because his model tried to explain why an interface fails from the user's point of view [50]. For him, HCI is a cycle that has two main components, execution and evaluation, and two points of view one for the system and the other for the user. For his model he uses seven different points that he called seven stages of interaction that create a cycle, known as Norman's action cycle Figure 4 [51]:

1. Establishing the goal
2. Intention to act
3. Sequence of actions

4. Execution of the action sequence
5. Perceiving the state of the world
6. Interpreting the perception
7. Evaluation of the interpretation

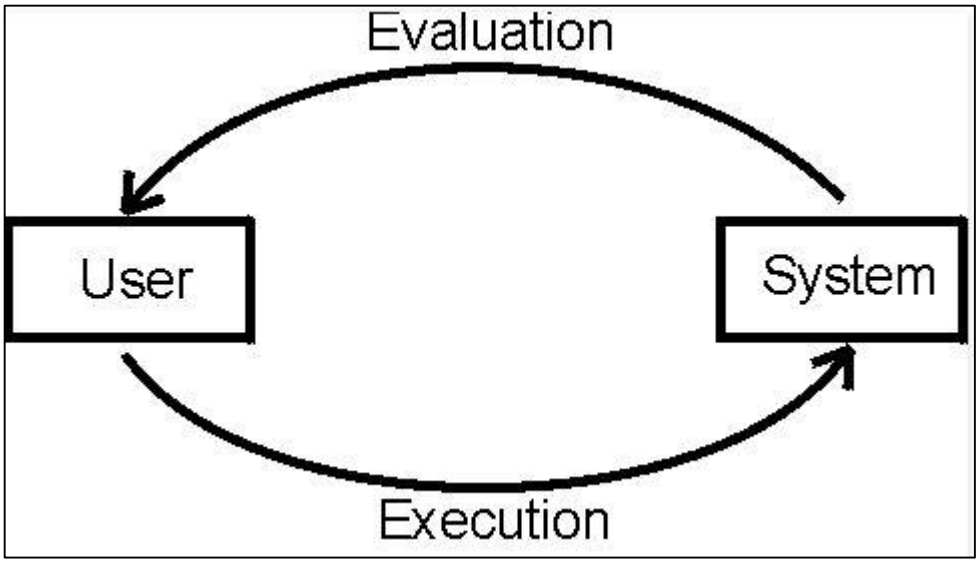


Figure 4 Norman's action cycle [51]

For Norman, the first four actions belong to execution, what the user wants the system to do with his order, and the next to evaluation, what the system gives to the user as feedback. Between those two there are two gulfs. The one is the gulf of execution. It is about the difference between the real intention of the user and the degree to which the system can support their actions or allow them to proceed with them. Many times this gulf appears when the physical language of the user is different from the machine language. For example, when a user needs to light a room he can guess the current state of the system for the state of the button. In this case, the gulf of execution is small and this is the goal for a good interface. On the other hand, the gulf of evaluation relies upon the difficulty of the user to perceive the state of a system and understand if his action is successful or not. In most cases, this gulf is small when the system provides information easily and understandably. For example, the spinning wheel appears every time a video is loading on a platform aiming to minimize the gulf of evaluation for the user [50].

2.3 Goals and purpose of HCI

HCI field has as its main purpose the creation of safe and useful systems. These systems are characterized by safety, utility, effectiveness, efficiency, and appeal. All those characteristics describe the system as a safe interface with quick processes and appealing design. As is mentioned before the aspect that gains the focus of the HCI research is the overall usability of the system that guarantees an easy-to-use system with the control of the user [53]. In order to establish a system like these there are some factors that designers must be aware of:

- Take into consideration all the factors (organizational, social, psychological) that guide people to operate in a certain way during the interaction with the computer system.

- Create and develop appropriate tools, techniques, and methods in order to help designers make systems that people can use without any problem.
- Achieve an interaction between humans and computers that is effective, useful, and safe for both sides [54].

The purpose of the HCI is to design a system that can meet the requirements of the users and their needs. So, designers in order to achieve these goals they need a guide to follow, an approach as they take the demands of the user and transform them into an effective and efficient system that users can interact with. Those approaches according to are:

- *Involvement of user:* It is crucial for a system that is designed for users that they have tested it or can be involved in some stages of the design process.
- *Integration of different fields:* HCI is a field that studies and combines many others in order to produce efficient results. So, it is important to use different fields and expertise in HCI design.
- Making an iterative design process by conducting tests that check if the system meets the user's requirements.

The design process in the field of HCI is not always easy. One of the challenges that this design deals with is to find a way to synchronize with the continuous technological developments and to ensure that these are used to maximize human benefit.

2.3.1 Search and Rescue goal

Search and Rescue in the context of this thesis is based on the IoT concept in which objects can communicate with one another simply and smartly [55]. The platform makes use of wearable devices that can be tracked and monitored remotely with the use of LoRa technology and the avoidance of adapting other geolocation technologies like GPS.

The platform aims to:

- *Locate and rescuing people in need by monitor their position with the use of technology and wearable devices.*
- *Propose a system that minimizes battery consumption.*
- *Provide a fully functional website that is user-centered design under the perspective of HCI heuristic evaluation methods.*

The system is based on Norman's action cycle and fills the gap between the theoretical aspect of the technology and the needs of users combining two fields: the engineering field that is deep in how the overall system works and the HCI field in which users can be rescued by using a friendly technology and platform most conveniently. The user has free will and many choices according to which he can easily intervene in the system and change the settings. The HCI purpose is that during the interaction between the user and the platform, the first must feel like he uses a normal website in his everyday life. The most important element is that this process can help people that are at risk such as elderly people that are diagnosed with dementia, children with an attention disorder, people who suffer from a psychological disorder, and other people having a high probability to wander and go missing or to elope [56].

2.4 User-center system design

The main goal of computer systems is to be designed under a user-centered approach to help people use them effectively and easily. Every computer system has a certain audience and for this reason, it has to follow the appropriate design that will satisfy the need and capabilities of that group. Designers of that system think that people have a certain task in their mind and they have to deliver them a system without complexity. Furthermore, it is very important to make people feel that are autonomous and have control of this system because in this way a computer does not limit the creativity of its users [57].

System designers must know how to translate user's needs into system capabilities and the first step in this process happens with a good design of a system interface. A well-designed interface allows people to interact with the system and deal with any difficulties without external help while at the same time they have full control of the machine. For this reason, the topic of user-centered design has become the most important concept in the design of interactive systems. The keyword, in this case, is the term usability [58].

2.4.1 Usability Heuristics by Nielsen

In the effort to describe usability, Jacob Nielsen gave ten general principles that can apply in the interaction design, 25 years ago. Those principles developed under steady study and experience in the field of usability engineering and now are rules in the field of HCI. Even they are concerned a past period, they are up to date to modern systems and applications.

The first principle is the *visibility of system status*. A user-centered system has as rule number one that people can feel that they have control of the system. In order to happen this, the system must provide its user with the appropriate information that which state system current status. Also, with this action user get feedback after every interaction that occurs between him and the system. Every system that gets interaction from the user must provide immediate feedback. For example, smartphones have many visual signs in their interfaces that informed users about battery energy, signal, Wi-Fi connection, and many more.

The second principle concerns the *match between the system and the physical world*. People have a certain metal model, in other words when they have to deal with a system they already have in mind a certain way or representation of how this can work. This happens because they have built an experience by dealing in their everyday life with similar systems. For this reason, designers use a language that is familiar to the user. An example is that in a computer interface when a user needs to save some documents it can create a digital file that have an icon that illustrates a file. This is a direct transformation of the physical world in which an employee uses a file to save a document on his desk.

The third principle referred to *user control and freedom*. It is a common phenomenon that users are not always concentrated and tend to make many mistakes or misunderstand things. Every system with a good design must provide the user with an emergency exit or a button that helps the user get back in a previous state before the wrong move. For this reason, many applications have a back button, an undo button, and an emergency exit to help users have full control of their moves.

Consistency and standards are the fourth principles. For designers to achieve a comprehensive system they use the same icons, buttons, visuals, and actions for the same concepts so as not to disturb users. An example of this principle is the commands of copy and paste that work the same in all mobile applications or all text edit programs on computers.

Error prevention. Don Norman identifies two kinds of error slips and mistakes [50]. Slips are mistakes that people tend to do because of low attention. The way to prevent users to do again the same mistake is by offering them a safe choice. This happens when the system use constraints in order to not

allow user enter inappropriate values, suggest common options in the search bar or use warning messages when they have to save a document. Mistakes are the result of people's wrong mental model. This happens when the user does not fully understand the communication process of a system and this kind of error is difficult to fix. The answer to this problem comes with a consistent design system.

Recognition rather than recall. *Recognition* happens when a person can easily recognize another person or situation because he is familiar with it and has seen it before. It is an easy retrieval from memory that does not require a complex cognitive process. *Recall* refers to a more difficult situation because the human brain has to find a specific name or a specific number by activating more memory links. A good interface must be based on recognition and does not urge the user to recall actions and commands. That is the reason why interfaces have icons, buttons with colors, and texts.

Flexibility and Efficiency of use. Every user has a certain type when he has to navigate an application or use a computer program. The main rule of this principle is to make an app useful and easy for a novice user as well as for a professional one. An application must provide users with alternative solutions like commands in the interface, shortcuts, and advanced options. Then, it comes to the user what type of action he wants to choose and proceed with.

Aesthetic and Minimalistic Design. *Minimalism* is a trend of the 21st century not only in fashion but in computer systems as well. The simpler a system is, the simplest its use. In this way, people find more easily important information and do not get tired by the use of the application. Also, these principles apply in the use of colors as some people may have color blindness and some others distract from a colorful interface.

Help users recognize, diagnose and recover from errors. People make errors when they interact with machines. In order to minimize both the errors and users' frustration the system must provide them with help and a message that give them full details about what went wrong so the user can solve the problem or avoid doing it again.

Help and documentation are the last principles. Designers must always remember that people have different needs, knowledge, and way of thinking. Based on that idea all the applications and programs come with a help and documentation section or FAQ's and tutorials to make the user get to know the system better [59][60].

2.4.2 New heuristics

Through studying evaluation methods, testing the website mockups, and searching for ideas in functional websites new heuristics were found based on the basic heuristics of Nielsen. The aim was to add some new relevant heuristics in the study in order to examine to which degree there were followed or not and to keep the thesis up to date with the changes in the website design world. Those heuristics were: resilience, reduction, and navigation, user privacy, aesthetic and responsive design.

Navigation is a major factor when it comes to website design. It is how designers use different tools such as buttons, links to help the user of the website navigate through the different pages. It is a form of a roadmap for website users in order to find information and material that the site provides them with. A general rule is that every visitor on a website must find everything within 3 clicks. In this way, people will remain on the website because they can navigate better. This is the reason why navigation comes first even to website aesthetic design. A navigation menu must be clear, simple, and have many alternative choices because not all people think the same [61].

Privacy concerns the piece of information that the site wants from the user. It is important that any form of information from the user is considered personal data and is protected by law. Also, when the user makes an account on a website his password and name must be unique and only he can enter with his credential. Also, every website has a privacy statement that describes the legal rights of the

owner to the data of the user. Of course, when the user visits and uses a site must be aware of privacy statements and accept them [62].

An attractive layout always enforces the usability of an interface. Last but not least responsive design is a Graphic User Interface (GUI) design approach which ensures that the content on a site can adjust in any form of screen sizes such as a mobile phone or a desktop screen. It is used on website design and maximizes the correct use of site functionalities. An element is the aspect ratio that consists of the height and width of the display device. General guides support that a website can fit its content on every smartphone, desktop, and PC in the market, buttons and text size must be of appropriate size and elements must remain interactive like links, photos that can be clicked and transfer the user to another page, forms must work efficiency, etc. [62].

An evaluation based on basic heuristics and the new can give valuable results about website usability and how can an existing one be more usable and user-friendly by combining ways and theories.

2.4.3 Norman's seven principles

In order to have better interaction between humans and computers, Donald Norman proposed back in 1988 seven principles that can help the designer of an interface to overcome difficult tasks and obstacles during his works [50]. In today's world are fundamental for every designer and describe the "have to" that an application, a website must contain to be more effective and delightful.

The first principle is discoverability or the use of both pieces of knowledge in the world and knowledge in the world. Every product today has many functions and operations. For Norman, good discoverability can help the user figure out all the possible functions and choose the one that helps him achieve his goal. For this reason, a system that follows these principles has to contain some clear focal points such as images, icons, headers that calls for action, the visual hierarchy for those elements so user not feel frustrated or confused and a good navigation system that will help the user understand the overall design. Many times spacing between elements on a screen helps the user understand better what actions he can proceed with.

The second principle is called feedback. The interaction between human and computer succeeds because, in every action of the user, the system gives him an answer positive or negative. If a system does not inform the user about the outcome of the action then it makes the user wonder or leaves the application/website. The description of Norman's feedback is: "*some way of letting you know that the system is working on your request*". It is important that the feedback must have four characteristics: immediate in its answers, informative that means that a simple message with the form "ok!" is not indicate, planned, and prioritized. The information must be clear especially when something goes wrong. For example, when a page is not loading on the internet appears an informative text that refers to the problem and gives a sort of possible solutions.

In the third principle, a designer meets with the conceptual model. The conceptual model is a simple explanation of how a product, application, website works. A good conceptual model helps the user feel that he has control over the system and knows how to use it. This is the reason why digital applications use some typical icons which work as metaphors and help the user understand what to do with actions such as using a trash icon to delete a file from their computer. In the case that a conceptual model is complex it leads the user to misunderstand actions and not be able to use a service appropriately.

Affordance is the fourth principle and one of the most important. For Norman, affordance is a type of relation between the user and a physical object. Affordances are used so people can perceive the action that they have to proceed with to complete a movement. For example, the knob of a door is an affordance. Affordances must be simple and indicate a type of action. There are also, two important elements that a designer must have under consideration: that affordances indicate the action that the user has in his head as the appropriate one and the relevance in the culture in which he designs.

Signifiers are the fifth principle and many times tend to use in combination with affordances. A signifier is a form of message that help user understands when and where one action takes place. There are many examples of affordances like labels on buttons, numbers besides a button, or a gear level that indicate the gear level. In the world of digital interfaces, a red button possibly means an important action that acts as an exit choice when a green button is a sign of consent. As happens in the case of affordances, signifiers rely upon the culture that is designed for.

The sixth principle is mapping. It is used to show the relationship between controls and how they affected the world. Norman stated that: “when mapping uses spatial correspondence between the layout of the controls and the devices being controlled, it is easy to determine how to use them”. Mapping helps users understand that movements they make on a digital interface are similar to those they have done in real life. For example, the brightness level on a mobile phone can change when users slide a bar right or left. A bad mapping can confused users as they cannot understand the action that they need to take to complete a task. A good method is that mapping and signifiers must work together.

The last principle is constraints that become an obstacle in information overload. A big description with many elements, an interface with many buttons and links, and general a complex layout make user frustrated and guide to a cognitive overload. For Norman there are four types of constraints: physical that restrict possible operations, for example in a text program the writer cannot write outside of the “paper”, semantic limitations that are signs of where action can take place like the sockets of a laptop for USB, social restrictions that depend on the culture and social conventions and logical restrictions that have to do with alternatives like the constant movement on a mouse for light up the screen of a pc that is in sleep mode [63].

It is upon the designer to apply all the above principles in order to have better communication with his user and produce an application that is user-friendly and effective.

2.4.4 Misconceptions on systems design

When a designer begins to create a system he has to follow the above principles and avoid some common mistakes that are presented below. In this way, the designer can deliver an efficient system like an application or a website that users feel free to explore and get familiar with it easily to make it use a trend.

The first misconception is that the design system is used as a side project. That means that basic and important principles like usability or efficiency are overlooked. When new features are added constantly without being estimated in advance the system that one was originally designed has not any relationship with the final product but is a total of symbols, icons, and features that do not support its initial goal. Another misconception is that once a system is designed then the evaluation will come. This perspective for a design view is false. The first step in a design process is to make some sketches and prototypes of the final product and show it to some experts on the domain to evaluate them by recognizing errors and propose solutions. Also, a survey with people from different fields: marketing, technology, design is needed so the designer can understand how his creation can help the community. A system that has been created without any evaluation will simply fail to meet users' needs.

The third misconception refers to the system as a simple total of layouts that can change again and again. When a designer wants to make a change or a modification to his application, it is necessary to know how this movement can affect the general layout of the application, as it can affect some of the available solutions. In another way, the application violated the heuristics about consistency and efficiency. There is also the problem that a design team will overemphasize the importance of consistency by making new components to solve existing problems that arose during the evaluation method. What a designer does, is to decide whereas the addition of a new component or the modification of an existing one can make the life of the user better and easier during the interaction with his product.

Another misconception is the belief that users of a system can memorize the guidelines of how to use it. For this reason, a guideline with a short extension is useful for the designing team when they have to deal with new changes or modifications to the system. This guideline can also distribute to end-users with the product to help them be familiar with it [64].

2.4.5 Requirements of the system

The way from the first idea about an application to the final development is long enough. During the whole design process, a requirement document must exist that can help the designer understand what he is called to create and how to create it. Some steps describe the requirements that give some clear insights about the final work.

The first step is a general description of the idea. In most cases, the description of the idea is a sentence long, and briefly, it describes the main goal of the work. In the case of this dissertation, the main idea is: "*a system that consisted of wearable devices and a website to help the population at high risk to go missing*". The next step is a description of the application's main features and navigation through different choices. In this step, there are ideas about the home screen, the registration process, the profile section, the sequence of actions that the user needs to follow in order to achieve his goal. In this step the creation of personas and scenarios is important as the designer will have different use cases to study in order to understand what a potential user will need for his creation.

The steps are continuous with the reviewing of existing applications in the market. A survey about applications that are made for the same or relative reason is very important as it can make the new application differ from the existing one or maybe support new features. Furthermore, some features like the login process or the profile section can easily adopt the template of existing applications. In that way, the designer saves time and proceeds with more complex tasks. The fourth step is the creation of sketches. Sketches are printed drawings without any colors that present the main idea. For example, how the main screen of the website would look like, what features will contain, which is the next screen on the website etc. As the fifth step comes the prioritization of features. Here designer decided which features are more important than others like the registration form rather than the color of the main menu and which features are not so important but they can be added. The sixth step is about wireframes that can accompany the text description of the website's screens. Wireframes work like a map that shows where each element will be put in the final version of the application, at which point of the screen, which elements it will contain [65].

2.5 Personas & Scenarios

One of the most often problems in the topic of user-centered design is realizing the real needs of users and transforming them into system operations [66]. There are many cases in which a system can be designed without considering people that will use it and the final results show a badly designed venture without any usability and a frustrated user [67]. Two tools are used in the pre-design phase and fill the gap between the needs of final users and the perspective of the designer: personas and scenarios.

A persona is the representation of a fictional character that has the characteristics and needs of a potential group of people that will use the final product. Personas contain the users' background (education, family, etc.), goal and values, preferences, and needs from a system. It is about a tool that can help the designer understand in more depth the final user and the functions that his creation is going to have. The creation of a persona requires user research from data that are collected from various users through interviews, surveys, or observations. In cases where real users are difficult to be found, personas

take their place and help the designer concentrate on his system requirements. Although, a persona is a description of an individual user it represents a group of people that have the same characteristics [68].

In most cases, personas are created as a representation of end-users that will interact with the product or the service. There is also the possibility that one persona will address a particular group of stakeholders. Stakeholders are people that are interested in the use of the final product or people that are affected directly or indirectly by the product or the service [69].

Scenarios are types of brief stories in which personas interact with the product. Scenarios show the reason why and under which circumstances and ways a persona use the product. They are based on personas' needs and behaviors. Designers consider scenarios as a form of guidance that helps them understand what is the main problem of the user that they have to solve with their designing idea. They create scenarios to understand the insights, what is the power that motivates users to make a choice, what are their needs in a certain situation, and which issue is reported as an obstacle. During the creation of a scenario, the following elements must be taken into account: the background of users, their motivations, the tasks that are going to do in order to achieve their purpose, and the overall environment of the product [70].

2.5.1 Personas & Scenarios: Search and Rescue

The creation of the Search and Rescue platform used personas and scenarios in order for the designer to not need to find real-time users in the phase of prototyping the platform. Below 3 different personas and scenarios are presented that used the platform one for his own goal.

1) Persona 1- Doctor that promotes the platform for his patients

Gannis Kottas is a 40 years old man that follows the profession of a doctor. Every day in his work he deals with a number of people that are diagnosed with an attention disorder. Giannis loves technology and seeks an idea that will help him be more efficient in his job and protect his patient. He fears that there is the possibility that some of his cases get lost due to their disorder.

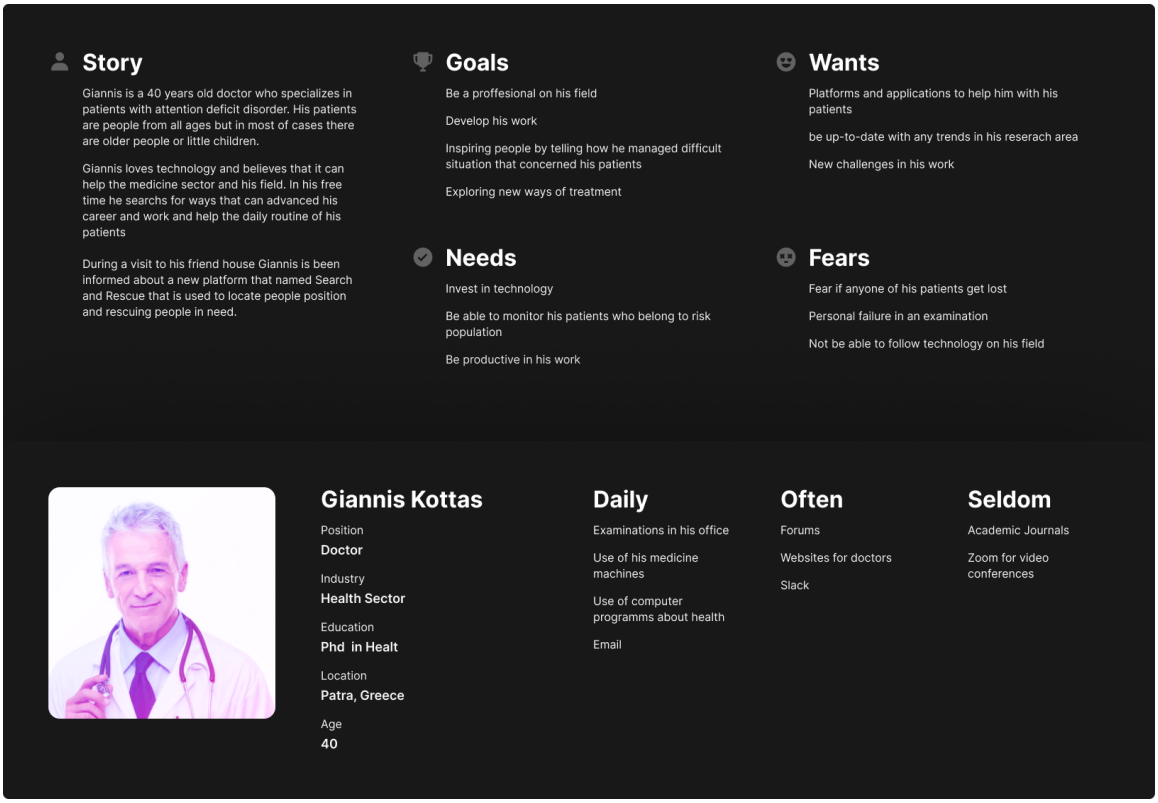


Figure 5 Person -Doctor.

2) Persona 2-Secretary, worried mother of a child with a neurodevelopmental disorder

Marina Kalergi is 40 years old and works as a secretary in a dentist's office. She is a woman that wants to have everything under control. Her educational background does not help her with technology. She has a child she loves but lives in a constant fear that she will lose it when she is not with him because of the neurodevelopment disorder he suffers from.

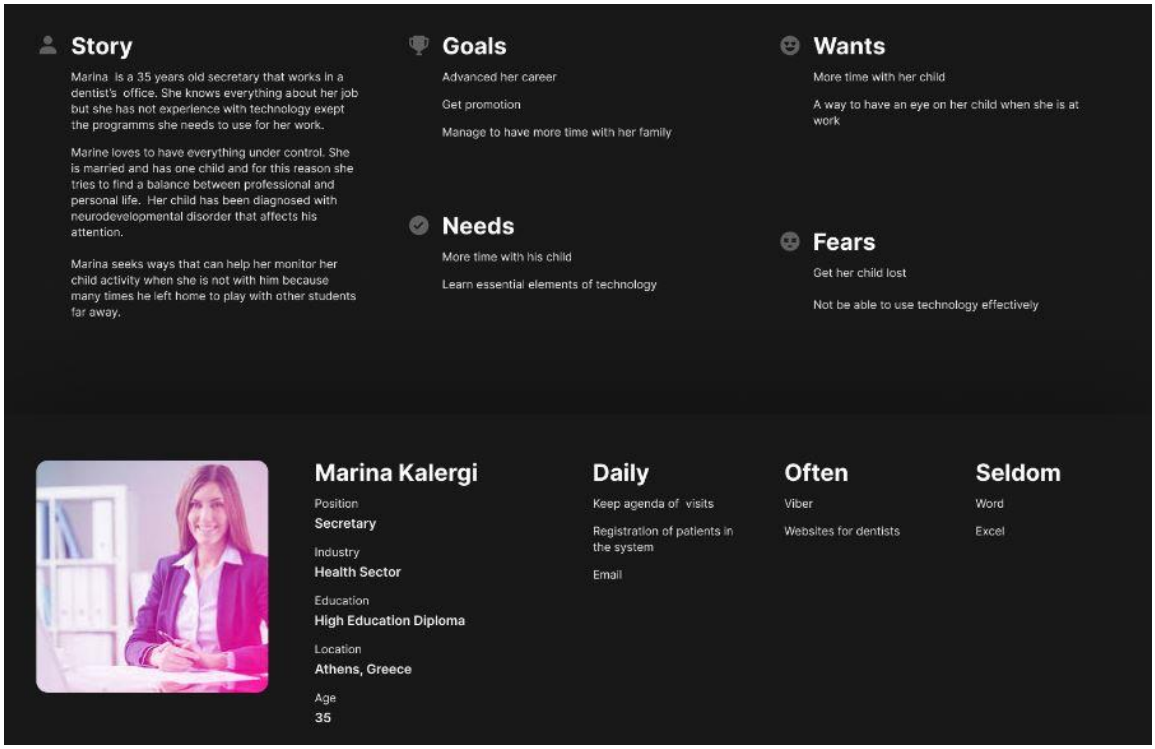


Figure 6 Persona - Secretary.

3) Persona 3- Retired man that belongs to risk population

Giorgos is a 70 years old man that enjoys long walks since he is retired. The biggest anxiety of his family is that there is the possibility that one day he will be lost. This anxiety is reasonable as Giorgos had been diagnosed with dementia some years ago and has started to forget important things about his life.

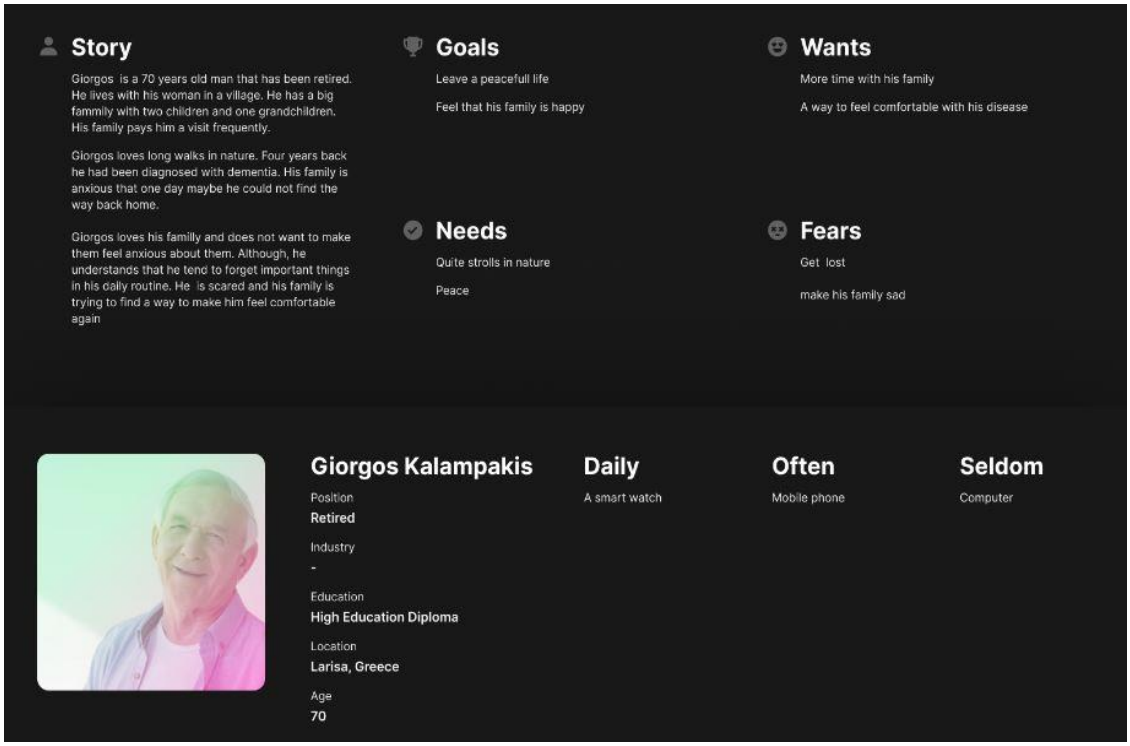


Figure 7 Persona - Elder person.

Giannis is a doctor that loves technology and how it can help his field in various ways. In his free time, he loves searching for applications that can apply in his field and help him with his works as well as his patients. The last few days he had started to read literature about IoT and various applications. During a visit to a friend's house, he learned about a system that is based on LoRa networks named Search and Rescue that had as a goal the location and rescue of people in high-risk groups by making the localization from wearable devices. Giannis realized immediately that this platform would make a difference in his work.

For many years Giannis specializes in patients with attention deficit disorder and try to find ways to help them and their worried families. Now, that he is familiar with the use of the Search and Rescue platform he proposes the system in his patient. Also, he ensures them that he will use the system as a way to monitor his behavior when they have to move in a certain area, the time that they are away from their home, the distance that they have walked, and other metrics that can help him in the treatments he suggests. Furthermore, the long battery duration of the wearable device is a bit of relief for Giannis as he is monitoring his patients at risk in real-time while he is examing other patients in his office.

Marina is constantly anxious for her child when she is at work. She wants to find a method that can help her have an eye on her child during her working hours. Although, any technological method seems to her like Chinese because she never had to deal with it. One day at the office she heard about a platform that was easy to use and can connect with wearable devices as a way of people tracking. She wrote down the name of the platform and when she arrived at home she searches for it on the internet.

On her first try, she makes an account, and as she did not know how to start searching the main screen. She found a menu choice that she felt familiar with “About”. There she found some frequently asked questions many of them she could have asked herself. She understands that all she has to do was to buy a wearable device and provide her child with it. The next few days she added the name and other

characteristics of the device in the platform, set the area according to interface instructions, and control the general process.

Marina now is at work and feels way more comfortable because she knows where her child is in real-time. The Search and Rescue platform act for her in a preventively way and help her be more concentrated in her work as she can monitor the child's position every time remotely and with full details.

One day Giorgos faced a very difficult situation. He was on his way home after a long walk when all out of a sudden he could not remember which way he had to follow in order to get back home. He sat on a bench for a long time. As the time passed some family members found him and returned to their house. His family decided to pay a visit to their doctor to help him with this situation.

The doctor recommended to the family a system named Search and Rescue that could track Giorgos' routine and provide them with information about his latest position based on a wearable device. Giorgos was hesitant at first but when he understands that was for his own and his family's good he accepted to wear the particular watch. Her grandchild makes an account on the platform and add his device and set permitted areas that frequented spots that her grandfather visited all the time.

From the history of the saved location, they know where and when the grandfather has visited a particular place. In this way, they can understand where he goes, and if he wanders for a long time. Giorgio will never forget the day when he has been lost in a neighborhood and has not a phone to inform his family.

From the above scenarios and personas, it becomes obvious that two personas are really users of the system (Bill and Marina) when the third one (Giorgos) identifies a group of people that do not use the platform but are affected by its use because it belongs to a high-risk population.

2.6 Design mockups and prototypes

When it comes to evaluation, in the field of HCI the creation of mock-ups/prototypes of a web page or an application is an important step in the whole process of creation. Mockups are visual drafts of what the final product would look like. The main idea behind mockups creation is that gives the designer space to consider problems that will arise during the normal interaction with his products and how the designer can fix it during the evaluation problem. They contain all the details such as typography, fonts, colors, background images and in their usual form are static. As far as it concerns the general appearance a mockup is usually close to the final version of the product. They are considered as a mid to high-fidelity representation of the final system in terms of interactivity, visual graphics, overall content, and commands [71].

The last step in the beginning stage of the design process is prototypes. Prototypes are based on the mock-ups screens and add motion and interaction with functional buttons, links, etc. They involve more the designer and the user that try the prototype in the designing process because they can have the experience of actual content, interact with the screens and commands like they use the real application and in this way they can find problems and errors that could set barriers in the user experience. Prototypes contain even the smallest detail so that designer will be sure about his final product.

Overall mock-ups can be matched with the visual design and prototypes with the function of the application/webpage. In the first steps of the design process belong sketches, simple drawings of what the designer has in his mind about the application. The designer can draw some simple or more complex screens and interfaces without any color to get an overall idea. Then the second step is the creation of

wireframes, a blueprint without any color that are used so the designer decide where he can put his content in his application or how to group information [72].

To achieve a fully functional website, this study used mockups and prototypes of the Search and Rescue site to evaluate. The particular design process starts with the general idea by creating mockups with different colors and a bit of information and then expands into prototypes with full interaction between commands and pages. Then experts tried the prototype under different scenarios to find what heuristics are been violated and which are the proposal for fixing errors and make the website even better in terms of usability and functionality.

2.7 Interview with an expert

In the HCI field user interview is a method in which the researcher asks participants some questions about the interface of a design, its usability, and the overall product environment. It is an easy way in which a designer can learn more about a topic that is interested in by facing one person at a time. There are three main types of interviews: unstructured, structured, and semi-structured that are related to the form that the researcher wants to collect information based on a certain protocol or not. Those interviews can occur in many cases such as: before the first steps of a design, to gain more information about the creation of personas, scenarios, and some first wireframes and at the end of a usability test to collect more information about the observation of evaluators [73].

In the case of the Search and Rescue platform, the first step of the designer was to conduct two interviews: the one was with in an expert in the domain of LoRa and Internet of Things networks in order to obtain some guidelines that would help him start his process from the first mock-ups to a fully functional website, the other was with a representative of the Child's Smile about how the proposed system would apply in case of students with attention disorders. Both of the two interviews were constructed with a guideline and prepared questions under careful study [74].

1. Interview with expert

Introduction:

Hi…

Thank you for accepting the invitation to this research interview on such short notice. In my thesis titled "*A LoRa based Search and Rescue system for people with special needs*" I am trying to build a fully functional rescuing platform via a website that will be based on LoRa network. I believe that your position as… gives you the ability to understand better the needs of people from a system like this and help me get an insight into the do's and don'ts of the website construction. I mainly focused on Low Power Wide Area Network known as LPWAN to build a system named Search and Rescue, that will provide its user the location of their devices and in this way, it will help save people in need. The competitive advantage of this system is the energy consumption of wearable device batteries. Before we get started, I would like to know more about your background in a form of an introduction.

Questions:

- Who do you believe are the main users of a LoRa system?
- What a platform like Search and Rescue is important to have?
- What is important for a user when navigating a website?
- What is the content that you would like to see on a site like this?
- In terms of usability, which one do you feel it is most important?

- Do you believe that a website like this needs a lot of graphic and visual content?

From this interview, the study got some important information. The main users of a LoRa system come from industries that provide IoT solutions in application such as Smart Cities and Smart Agriculture, the business development sector, and logistics. There are 151 LoRaWAN Network Operators in 167 Countries, a sign that LoRa technology continues to expand. For the expert, the main elements that the platform is good to have are a central map with indicators about the position of the wearable devices, a menu for the wearable devices, a history menu that will contain information about the devices that a user has activated and an application of an emergency state when a wearable device.

Also, he states that users need a simple interface and menu that would help them navigate better and easily between the different menus. Some restrictions in the form that they can use a button if there is no device or they can not put numbers in a field that needs only text is a requirement for the website. The content of a website like this could be a map with important information like the characteristics of a device, the energy consumption of battery, geographical coordinates, a page with all the active devices and permitted areas, a page in which the user could draw his permitted area or change areas and of course a page that would give the user the ability to edit his profile. The website that is going to be made must follow the main usability heuristics. From the point of view of the expert, the most important is the heuristic that connects the system with the real world. Since all people nowadays know how to use the internet many of them have experience with websites. For this reason, the Search and Rescue platform is important to have some standards that would make the user feel comfortable and familiar with the main functions.

As a final note, the expert believes that this type of website needs some balance. It is good to have some graphical content like an image or beautiful colors but not so much or so particularly that could disturb users for their goal. Considering that the website will contain a map and different elements the background of the website must be so simple that would help the user concentrate on the elements like the last location of the device, the duration of the battery, etc.

2. Interview with a representative of the Child's Smile

Hi…

Thank you for accepting the invitation to this research interview on such short notice. In the context of the thesis for the postgraduate program of the University of Patra's "Human-Computer Interaction", I would like to ask a few things about a monitoring system for people-children with autism spectrum disorders with mobile devices and more specifically for the way interact with both those responsible for supervising children with autism spectrum disorders and those with autism spectrum disorders. Initially, the postgraduate program "Human-Computer Interaction" provided by the University of Patra's deals with issues related to the study, design, and development of interactive technologies, ie technologies that interact with their users, as well as the study of phenomena related to interaction. of users with modern technologies such as the best navigation, a friendly user interface, the maximum functionality of an application, and in general its design based on the needs of the person who uses it.

Questions:

- Whether such a system would assist in the activities of the Child Smile organization.
- What are those activities and at what frequency they take place?
- What is the duration of those activities and how many people participate?
- Are kids familiar with the concept of wearable devices?
- Describe a typical day of a child in the Child's Smile.
- What people that are in charge of children's protection would like to know in terms of features (location, coordinates, date, exact time, battery percentage)

- Do you believe the technology that allows a long period to fully consume the device battery, would help find a child in case he has been lost from the care of the supervisor?
- Is there a question of violating the privacy of children?

From this interview, the designer gets valuable insights. The first thing is that the proposed system would help the activities of the organization like an excursion or an event in a place different from the facilities of the organization. For example, there are some camps for the summer or for the winter where children can play in nature and the parks. Furthermore, the organization from its beginning has set some parameters of actions to prevent cases of missing children while its equipment tries to save the lives of many children that are disappearing every year in Greece. As far as it concerns the organization structure some supervisors are responsible for the children but in some cases the number of children is big and the attention is distracted.

The wearable devices would help those in charge of children have an eye on them without additional worries especially children with attention disorders. Kids are to some extent familiar with the concept of wearable devices because they think that is a sort of game or a nice jewel. Furthermore, the information that a supervisor needs to know is the exact location of the children, the date and time, and the battery level in order when a child is out of the human eye range can be easily found in seconds. For this reason, battery energy consumption is very important in this profession. The main concern of a supervisor is to have his children under his vision and protection but he also fears the danger of losing one of them. With the implementation of a system like Search and Rescue even in the case that a child has been lost the energy consumption of the battery would assist the try of locating the children again. The only problem that will arise is the case in which a child diagnosed with attention disorder breaks his device in case of a seizure.

In the question about the daily life of the children in the organization, the answer was: “Children have more or less their own daily life. In the morning they go to the school of the area depending on their age, then they return for food. They read their lessons and do their extracurricular activities, depending on their interests. They always have the people from the Child's Smile close who take care of them. Older children go out on their own. We are having a birthday party. We go on vacation in the summer. In other words, they do what you do, with the difference that there are not two or three children in the house, but many more.”

In the final question about the privacy of children and modern technologies: “Any application that helps in the saving of children lives is a miracle. There is also relevant regulation about privacy and personal data. The equipment that is used by the unit does not violate the privacy of children in any way. The concept of the Search and Rescue system, I think is the same. Children would wear the wearable devices only in certain activities and part in their daily life and not when they are sleeping or doing their activities in the unit”

3

Algorithms and Mechanisms

"For me, great algorithms are the poetry of computation. Just like verse, they can be terse, allusive, dense, and even mysterious. But once unlocked, they cast a brilliant new light on some aspect of computing. Algorithms and Mechanisms"

— Francis Sullivan

3.1 LoRa simulation

3.1.1 Network simulation

The assignment of the different parameters in a network is a difficult task since the parameters chosen should be appropriate for the specific situation or application. As a consequence, it is important to use a simulator, in order to have an insight into the proposed mechanism before moving to a costly implementation. Moreover, it is necessary to understand the mechanism's behavior and results in different topologies and the various number of devices. This can be very helpful, because it may be difficult to have many devices due to high cost, so the cost barrier can be overcome.

A simulation program should, in general, allows the user to define the network topology, the characteristics, and features of each ED, the connection between them, as well as the traffic model and packet routing algorithms that can be used. Furthermore, the user can obtain the simulated network's performance metrics and, if available, use the simulation program to visualize these metrics. From a LoRa simulation perspective, these metrics could include Data Extraction Rate (DER), Network Energy Consumption (NEC) [6], and bit error rate, among others. Some simulators have a strong graphical interface and others that can only provide certain graphical representations through plots or even command line outputs. Simulators can be free, open-source, or commercial in general, but in the framework of the thesis, only free or open-source simulators for academic purposes were taken into consideration. First and foremost, as shown in Figure 8, users must identify the problem to be solved in order to correctly define the system's specifications and settings. Then they will move on to modeling the network in order to fine-tune the parameters. The next move is to run the simulation and see what happens. Finally, after analyzing this data, you can either repeat all of these steps with the feedback given to the simulation program, or you can pause the process and analyze the results [7].

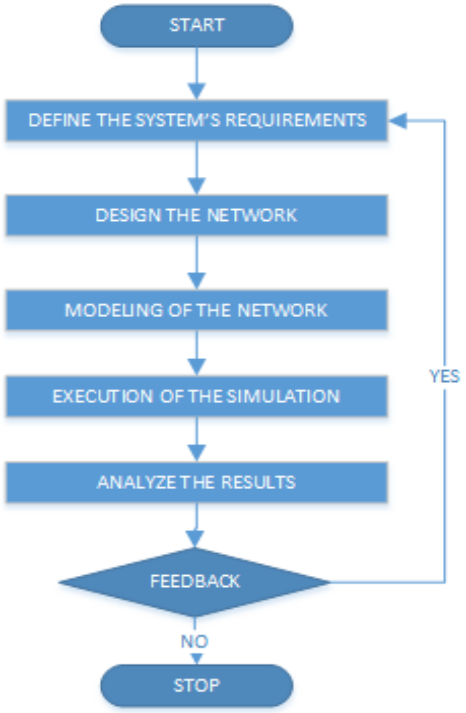


Figure 8 Flowchart describing the process of the network simulation process.

3.1.2 LoRa simulators

There are several simulation environments open to the scientific community such as the PhySimulator, FloRa, Ns-3 module for LoRa, and LoRaSim. In this thesis, the FLoRa and LoRaSim were used.

- The FLoRa simulator is based on OMNeT++ and INET framework. OMNeT++ is a discrete event simulator that is distributed under the Academic Public License. The INET Platform is an open-source library for OMNeT++ that allows researchers to model and validate their mechanisms using a range of network protocols. FLoRa uses the C++ and NED programming languages [8]. In OMNeT++, NED is a programming language that helps programmers to define the network's topology and messages. Furthermore, one of FLoRa's benefits is that the reports can be exported in Comma-separated values (*.csv*) format, making it easier to interpret the data using other software like Python's Matplotlib [7].
- LoRaSim is a discrete event simulator designed to investigate the feasibility of scaling LoRa networks and the collisions that can occur. It's a popular simulator that comes in a variety of forms. It enables the LoRa EDs to be placed in a two-dimensional grid. Python 2.7 is used to build the LoRaSim. Since only version 3 of Python is revised, this can be considered a drawback, but many tools can convert effectively to Python 3 version. The NumPy, Matplotlib, and SimPy Python libraries are also used in the simulator. This tool simulates four separate simulation scenarios, each with specific network and node properties [7].

In Table 1. a comparison of the most used LoRa simulators is presented.

Table 1 Comparison of the LoRa simulators

Features	PhySimulator	FLoRa	Ns-3 module	LoRaSim
Event	Discrete	Discrete	Discrete	Discrete
License Type	Free	Open source (study and research)	Open source	Creative Common Attributes 4.0
Language	Matlab	C++	C++, python	python
GUI	Only plots	Yes	Yes	Only plots
Energy Consumption statistics	No	Yes	Yes	No
Documentation	Ok	Ok	Average	Ok
Number of published papers	2	1	1	2
Website	Yes	Yes	No	Yes
Community Support	Good	Limited	Very Good	Limited

3.2 System model

In this section, the basic equations and assumptions concerning the LoRa modeling are presented. Starting with the path loss models employed in the context of this thesis, the Log-Normal path loss model was, used as there is a consensus in the research community that the LPWAN' path model can be described with small errors by the Log-Normal distribution and is presented in Eq. 1 [12].

$$PL(d) = PL(d_0) + n\ log\left(\frac{d}{d_0}\right) + X_\sigma \quad Eq.1$$

The $PL(d)$ stands for the path loss in distance d m from the GW, the $PL(d_0)$ represents the path loss value in a reference distance called d_0. The reference distance usually is 1 meter and in order to experimentally obtain $PL(d_0)$ in LoS conditions are necessary. Also, the n value represents the path-loss exponent and the X_σ stands for the noise due to shadowing. The shadowing noise is simulated using a normal distribution with zero mean and variance σ^2.

After describing the path-loss, the received signal power has been modeled in Eq.2. The P_{rx} represents the received power of the signal, the P_{tx} stands for the transmitted power of the signal, the PL stands for the path-loss and is described in Eq.1, while the G represents the gains of the antennae in dBi. Transmission is considered successful if the received power is higher than the sensitivity of the receiver, something that is modeled in Eq.3.

$$P_{rx} = P_{tx} + G - PL \quad Eq.2$$

Continuing with the LoRa modeling, the sensitivity is introduced in Eq. 3. S defines the thermal noise in a 1 Hz bandwidth that is only affected by the changes of the receiver's temperature. The receiver bandwidth is referred to as BW. The receiver Noise Figure (NF) is a constant for each hardware implementation. The spreading factor SF specifies the Signal-to-Noise Ratio (SNR) required by the underlying modulation scheme. The SNR increases as the SF increases.

$$S = -174 + 10\log_{10} BW + NF + SNR \quad Eq.3$$

Furthermore, the collision behavior modeling of LoRa is presented. It is common knowledge in the scientific community that some conditions can lead to packet drop in a receiver when a simultaneous reception is happening. In general, when two signals are being transmitted with the same SF simultaneously, usually they collide, and both signals are destroyed. But there are some cases where one of these two signals manages to be received by the GW. This happens when one of the two signals is transmitted with more transmission power than the other, at least more than 6 dB. Then the signal with the higher transmission power manages to be received by the GW, while the other fades.

3.3 Energy-saving consumption Mechanisms

When designing solutions some factors directly affect battery life. Some of these factors are:

- **Voltage accuracy**: for the battery to operate smoothly and not to damage the battery, the voltage must be within the operating limits. These limits are defined by the specifications of the microcomputer, memory, and peripherals, and the temperature as well.
- **Operating modes**: to reduce energy consumption in applications with battery-constrained devices, the concept of operating modes has been introduced. Depending on the technology, some modes are defined where the device has the lowest consumption while in other situations depending on the function to be performed, the consumption is higher [9].
- **Heat management in the devices**: the design of the device itself must be such that the temperature of the device does not increase too much, as this will have a negative impact on the battery life. Higher temperature leads to increased battery consumption and an increased chance of battery failure.

3.3.1 User-based Mechanism

3.3.1.1 User-Wearable state definition and mapping

The use of sensors is one of the issues that affect the energy consumption of modern IoT devices' batteries. As defined in [9], one aspect influencing power management is the introduction of the concept of operating states into such solutions. It becomes clear that dynamically adjusting the operating state of the sensors in response to the user's situation and needs is crucial.

To study the following SAR system, it is necessary to consider some situations and use cases in which the user may be. This makes it easier to understand the situations that can be set for the device, something that will help save energy:

- **Low risk**, e.g. the user is not engaged in any activity or the wearable is charging
- **Normal**, there is no danger
- **High risk - Emergency**, e.g. child has eloped by the parent’s supervision or has moved outside of a specific area.

We define the following three states to achieve energy efficiency on the EDs:

- **Off-state**: the system is turned off in this state.
- **Hibernate state**: In this state, the wearable device is operating, but the majority of the sensors (apart from the accelerometer) are switched off.

- **Normal state**: the sensors are taking measurements and transmitting them via LoRa to the application server.
- **Emergency state**: All sensors are switched off in this state, with the exception of those that aid in the localization of a missing person. Particularly, to this extent the LoRa module is important for user localization as some values of the transmitted packets, e.g. the RSSI of the signals are used. In Table 2 the effect on power consumption relative to the sensor management and the frequency of state transitions is presented.

Table 2 Parameter optimization of the energy consumption

Factor	**State**		
Sensor Management	Sensors off	Some sensors on	Sensors on
Frequency of state transitions	Small	Medium	Large
Data transmission	Sleep	Radio on	Transmission
Power Consumption / System Performance	**Low** >>>>>>>>>>>>>>>**Medium**>>>>>>>>>>>**High**>>>>>>>>>>		

Moreover, one important factor that affects energy consumption for IoT devices is the rate at which the sensors collect and send data. Consequently, there must be a difference in the rate at which data will be sent based on the user's state and the wearable device itself, as well. All these changes are happening in the application server. The application server sends to the node the state in which it will be set, disabling, or enabling components of the wearable device to save battery life. In the application server, a lot of parameters can be processed and one of them can is the battery level. For example, when the battery is low, the transmission frequency should be lower, so as to extend the battery life.

How the device changes its state from one to another is defined in Figure 9. Off-state is ignored in transitions from one state to another because it is supposed to express the state where the device is turned completely off. If we take hibernate state as the start, it goes to the normal state in this way: the device in every X seconds switches from hibernate mode to normal and then goes back to hibernate mode. Each Y seconds from hibernate mode changes to the normal state and the values are sent to the LoRa gateway. The X and Y values are calculated experimentally in each network because it is important to take into consideration the specific use case of the device, the device hardware, etc.

After sending the data, the wearable device's LoRa receiver opens two downlink windows to receive the packets from the LoRa GW. In the emergency state, the wearable device sends the values measured by the sensors to the LoRa GW, and then the packets are sent to the Application Server. After sending the data, the wearable device waits again for any packets then switches to hibernate mode. The state transitions are presented visually in Figure 9.

From the normal state the following transitions are made either in hibernate or emergency mode:

- After X seconds, the devices go from normal to hibernate.
- After pressing an emergency button, or a user fall was detected, or high heart rate was detected by the device, or the user was found out of a predefined area, the device sends a message to the Application Server to be assessed and it can go from normal to emergency state. We monitor the heart rate to monitor the health of the person wearing the wearable (as far as possible) to give an alarm if necessary. There is an option to disable the heart-rate sensor.

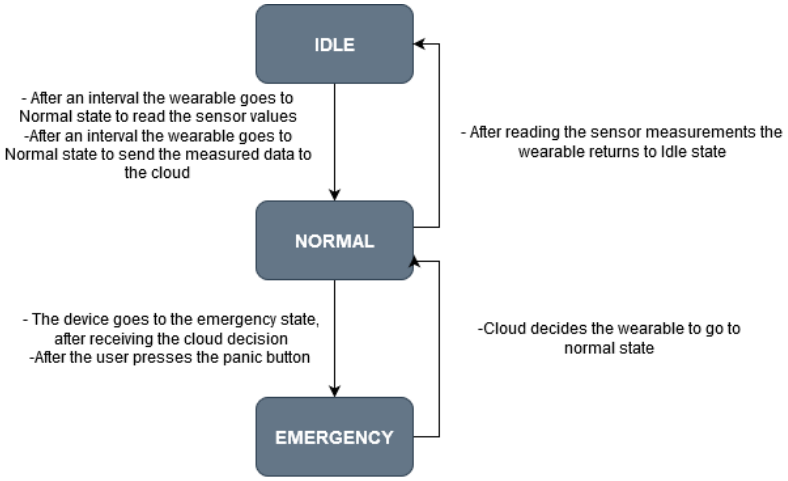


Figure 9 State transition

3.3.1.2 Energy consumption modeling

Having the above said, some basic requirements have been set, in order to decrease the energy consumption using the user's state. As said the frequency of the sensor measurements (X) and the frequency of the sensor measurements and transmission (Y) are vital and equilibrium between user experience and energy consumption should be met. The path to finding the best values of X and Y is to take a reference wearable device model and simulate in using simulation environments, namely the LoRaSim and FLoRa simulators. In this thesis, the Dialog's wearable device has been taken as a reference, as far as the LoRa module is concerned the SX1272/73 [10] has been taken as a reference and the energy models have been updated and changed accordingly. The energy consumption is calculated in the following equations:

$$E_{idle} = \sum T_{sleep} * P_{sleep} \qquad Eq.4$$

$$E_{air} = \sum T_{airtime} * (P_{normal} + P_{LoRa}) \quad Eq.5$$

$$E_{normal} = \sum T_{normal} * P_{normal} \qquad Eq.6$$

$$E_{Emergency} = \sum T_{Emergency} * P_{Emergency} \qquad Eq.7$$

Where E_{idle} stands for the energy consumption in idle state, E_{air} represents the energy consumption in transmission, E_{normal} is the energy consumption in the normal state and $E_{Emergency}$: Energy consumption in an emergency state. As far as the battery model is concerned, a simplified linear model is considered, as proposed in the paper [11]. Moreover, the Current and Power consumption values for each state have been extracted and presented in Table 3.

Table 3 Current and Power Consumption

Mode	Current(μA)	Power Consumption (μW)
Sleep	90	342
Normal	21106	80202.8
Emergency	2300	8740

3.3.1.1 Mechanism pseudocode

Having this information, the simulations could take place. Firstly, the simulations included only one ED and assumed that ED operated only in the normal state. The experiment lasted for 86400 seconds (1 day) and the X parameter had values 10 - 50 with 10 seconds step whereas the Y parameter had values 60 - 300 with 60-second step. As shown in Figure 10, for a particular Y, as X increases, there is a decrease in energy consumption, but this decrease is not linear with the increase of X. This happens because, in order to send the data, the sensor measurements are taken. Therefore, the values $X\epsilon\ (\frac{Y}{2}, Y)$, are not considered, because, in the time Y, the sensors will be measured, as well. Finally, looking at Figure 10 we notice that we have a decrease again when X = Y.

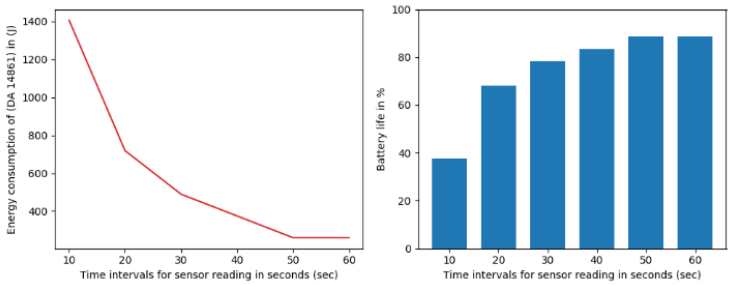


Figure 10 Power consumption for X 10-60 seconds and Y 60 seconds

Based on the above observations, a mechanism for reducing energy consumption was developed based on the battery level of the device and is presented below.

Pseudo code of the Mechanism

```
1:  Cloud sends downlink to the ED
2:  If (BatteryLevel >= BATTERY_HIGH)
3:     If (state is EMERGENCY)
4:           Y = Y_emergency_high_battery;
5:           X =Y /     value_emergency;
6:      Else
7:           Y =  Y_normal; X=Y / value_normal
8:  else if (BatteryLevel >= BATTERY_LOW)
9:       If (state == EMERGENCY)
10:           Y = Y_emergency_mid_battery; X=Y
11:      else
12:           X = Y / value_emergency;
13:  else
14:     if (state is EMERGENCY)
15:        Y = Y_emergency; X=Y
16:      else
17:        X = Y;
```

3.3.1.2 Simulations parameters and Results

To evaluate the above mechanism, many scenarios have been taken into consideration and many simulation runs have been conducted. Particularly, the mechanism was tested using one ED, in Normal and Emergency state, in order to find out the duration of the battery in each case. Then, in the next simulation scenarios, the number of the EDs was increased to understand the mechanism's behavior when the number of the EDs is larger in a specific region in terms of two important metrics, the **Data**

Extraction Rate (DER) and the **average energy consumption of EDs**. DER is defined as "*the ratio of received messages to transmitted messages over a period of time*" [12]. These two metrics were used because both metrics are very crucial in SAR scenarios. As explained, the extension of the battery life can be lifesaving for the user, but delivery DER is important as well because the localization algorithms are based on the packets that the EDs send, through the RSSI and SNR values. Finally, the mechanism was tested with a large number of EDs having different mobility models namely stationary mobility model, linear mobility model, and mass mobility model.

First and foremost, an experiment was performed for 777600 seconds, i.e. for a period of 9 days with one ED. As Figure 11 shows, the wearable device can operate until 2 days before running out of energy, when X has a fixed value. If the energy-saving mechanism is enabled, a reduction in consumption is achieved, resulting in the battery can last for up to 8 days, as presented in Figure 12.

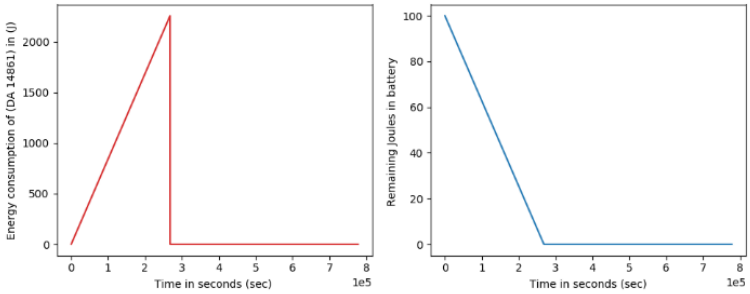


Figure 11 Power consumption and battery percentage for two days of use, without the power saving mechanism, while the user is in Normal mode

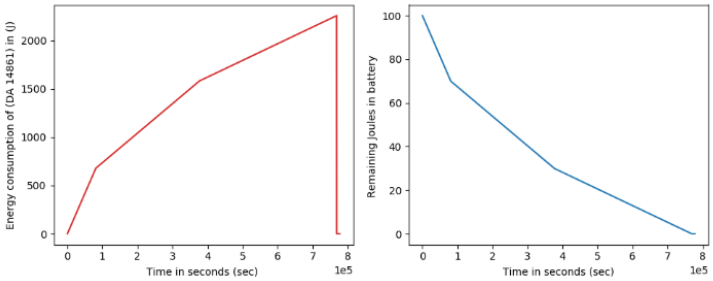


Figure 12 Power consumption and battery percentage for 9 days of use, with the energy-saving mechanism, while the user is in Normal mode

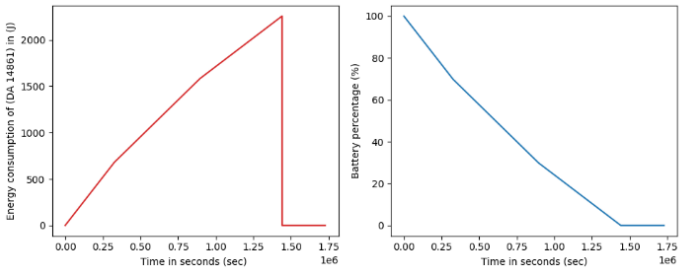


Figure 13 Power consumption and battery percentage for 20 days, with the energy-saving mechanism, while the user is in the Emergency state

Furthermore, the simulations included the emergency state. The characteristic of the emergency is the increase of the transmission rate, thus leading to an increase in energy consumption. So, to deal with the increase of the energy consumption due to the higher transmission rate, the unnecessary sensors are suspended. Figure 13 shows the power consumption and the percentage of the battery when the user is in the emergency state, and the power saving mechanism is activated. As it turns out, the battery can last about 15 days.

In order to examine the effect of the aforementioned mechanism in other aspects, we tested the mechanism in a simulation setup with multiple EDs and 4 GWs. Firstly, the simulation process assumed the EDs having stationary mobility model. According to the stationary mobility model, the EDs are put randomly following the Normal distribution in a predefined area. The area in which the EDs and the GWs are placed is Patras and Rion, in Greece. In this simulation scenario, as few as 200 EDs and as many as 1000 EDs are presented. The number of GWs is four since the localization process of the EDs needs the packet values to be listened to by at least four GWs. Each ED selects a Y value from the range of 60, 120, 180, 240, and 300 seconds at random, but abiding by the ISM restrictions. ISM restrictions imply that in this spectrum the EDs can transmit (thus using the spectrum) no more than 1% of a time frame. This means if the airtime of the packet is let say 1second, the ED can transmit again after 1*99%= 99 seconds.

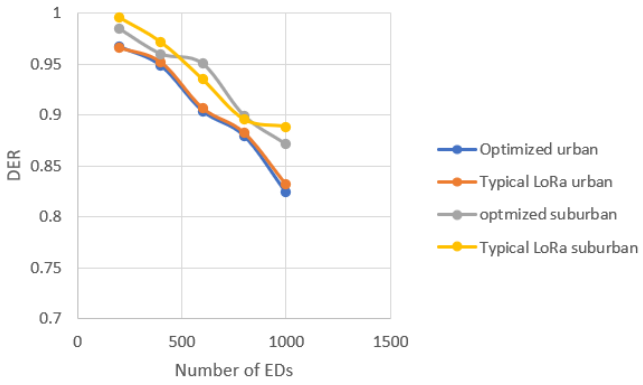


Figure 14 DER for the typical LoRa deployment and the optimized version

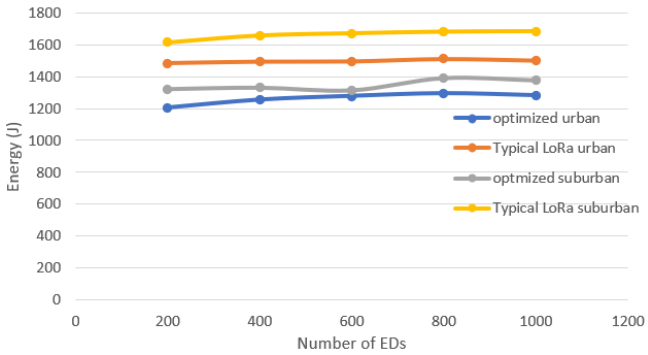


Figure 15 Average consumption of the EDs.

Apart from the above simulations, it was necessary to conduct further experiments assuming different ED mobility models, such as the Linear Mobility model and the Mass Mobility model [75], because in SAR operations it is common for the users to move. According to the Linear Mobility model, as described in the INET documentation [75] simulates the case where the ED is moving at a predetermined speed. Constant acceleration may also be used in this model. In the simulation case, the EDs are traveling at a constant speed of 10 mps. As far as the number of EDs simulated in this scenario, a smaller number of nodes was used, specifically 100 nodes to 500, as the mobility models increase the computational cost, leading to higher simulation duration. The results in the Linear mobility case are presented Figure 16.

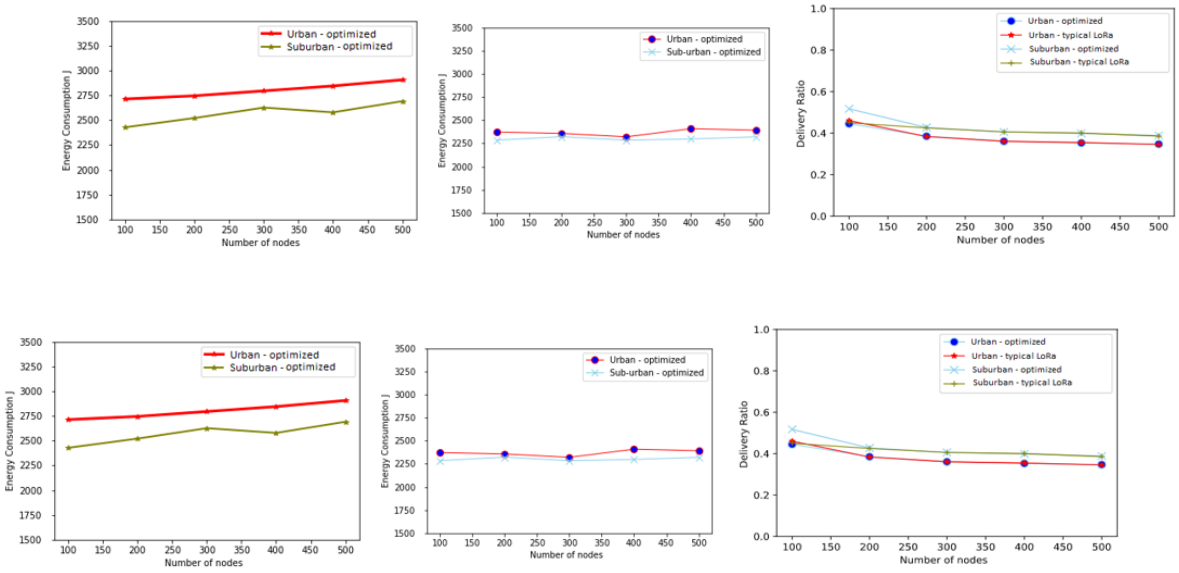


Figure 16 Energy consumption in urban and suburban conditions and the delivery ratio, where the EDs have the linear mobility model

Lastly, the mechanism was tested with EDs having the MassMobility model. As it is described in the documentation of INET[26], the MassMobility model emulates the case of a node with mass with inertia and momentum. In contrast to the LinearMobility, MassMobility model does not have a specific speed, the speed is set randomly according to the normal distribution, too. Also, the moving period before making a turn is normally distributed with an average period of 2 seconds and a standard deviation of 0.5 seconds. In the simulation the parameters are:

- changeInterval = truncnormal(2s, 0.5s)
- angleDelta = normal(0deg, 30deg),
- changeAngleBy = normal(0deg, 30deg)
- speed = truncnormal(15mps, 5mps)

The results of the experiment with Mass mobility model are presented in Figure 17.

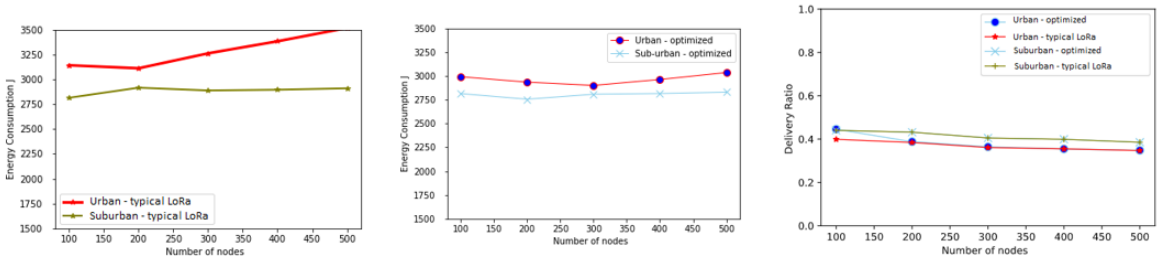


Figure 17 Energy consumption in urban and suburban conditions and the delivery ratio, where the EDs have the linear mass mobility model

As can be seen from the above graphs, our system has reduced the energy consumption of LoRa EDs in both urban and suburban settings, as well as in all three mobility models. In addition, the delivery ratio for the Stationary, Linear, and Mass mobility models is shown in Figure 14, Figure 16, Figure 17. In both urban and suburban scenarios, the delivery ratio does not decrease and is unaffected by the process. The statistics show that the delivery ratios in the optimized and typical LoRa deployment cases are nearly similar. As a result, in a SAR situation, the proposed mechanism can save a person's life by

reducing energy consumption while retaining the same delivery ratio. A drop in the delivery ratio may be fatal because it affects the localization's algorithms' accuracy.

It is important to understand the individuals involved, the tasks they are meant to perform, the environments in which they work, and the available technologies that are critical when developing real-life systems. You can map the user's use cases to the hardware's capabilities by first knowing the user's needs and use cases. As a result, once you have a better understanding of the target group's actions, you will reduce energy consumption even further. This brings up another point: energy conservation can be accomplished without using always sophisticated algorithms by observing people's use cases and the problem itself.

3.3.2 Machine Learning based mechanisms

In section 4.3.1, an energy-efficient mechanism has been proposed, using the user's states as the main drive to reduce energy consumption. Apart from this, another way to reduce energy consumption is through better resource allocation in the LoRa network. In this context, and having explained that in LoRa networks, one pivotal parameter that affects the energy consumption is the SF, a mechanism about SF assignment was examined. Increasing the SF value can lead to an increase in the airtime of the transmitted packet, thus it is more possible for the receiver to receive the packet, but with higher energy cost. In other words, the SF value should be carefully be chosen as it can affect both the delivery ratio and the energy consumption of the EDs. Many research works focus on the SF assignment. Paper [76] examines the various SF assignments in order to confirm the theoretical limits and obtain the LoRa radio's realistic output profile. Paper [77], on the other hand, investigates the impact of SF assignment in rural areas on mobile network coverage. Also, by using multiple-access dimensions based on a multi-hop LoRa network, off-load data traffic into many subnets can be attempted, too [78]. In paper [79] a system that is opposite of the de facto LoRa deployments is presented. The authors propose a tree-based LoRa topology, demonstrating that the energy consumption of the nodes can be reduced in such a topology. Apart from these methods, Machine Learning techniques can be used, as well.

Machine Learning is made up of a variety of approaches aimed at assisting people in making decisions, and the approaches can be divided into three groups. supervised learning, unsupervised learning, and reinforcement learning. Supervised learning is the method of learning by the use of data that we know exactly what class they belong to, also known as labeled data. The learning process is known as training, and the dataset used is known as the training dataset. After the preparation, we must test an unknown portion of the dataset known as the testing dataset to see how well the algorithm performs. For classification and regression problems, supervised learning may be used. Classification problems include making predictions about discrete finite labels, while regression problems are concerned with making predictions about continuous target labels. When there are no target labels in the learning process, it is referred to as unsupervised learning. Clustering is the most popular application of unsupervised learning, in which the clustering algorithm tries to find certain groupings in the data. Finally, reinforcement learning is the process of learning and anticipating the next step to maximize the gain - to maximize a numerical reward signal- while lowering the cost in the future.

As far as the use of ML-based resource allocation in LoRa networks is concerned, many research works have been published in the scientific community. The update process of LoRa parameters, such as the SF, was defined as a reinforcement learning problem by Sandoval et al. in their paper [80]. Neural networks are used to configure the parameters and their proposed policies are claimed to have resulted in a 147 percent rise in throughput. Furthermore, a multi-agent Q-Learning algorithm is proposed in the paper [81] in order to achieve better resource allocation in LoRa networks. The SF, in particular, is dynamically updated to reduce the possibility of collisions caused by SF transmission. The results were consistent, but their mechanism's input is the position of the EDs, which is unrealistic for many applications. For example, if the network operator is unaware of the ED's position, a GPS module is required, which increases energy consumption and negates the mechanism's benefits. The authors of the

paper [82] look into the possibility of using machine learning to optimize LoRa networks. Their research concluded with the creation of a framework that employs machine learning techniques such as clustering, Long Short-Term Memory Neural Networks, and decision trees to predict the packets' inter-arrival time, with promising results. In the next subsections, the machine learning-based approach of this thesis is presented, and the experimental results using the FLoRa simulator are presented.

3.3.2.1 Problem Formulation

In this thesis, supervised learning in a classification sense is used to categorize the SF value. The aim is to give the SF a numerical value in the range from 7 to 12. As a result, the SF assignment problem can be characterized as a classification problem. The classes are numbered from 7 to 12 since the target values range from 7 to 12. In this thesis, the algorithms used include the k-NN, Nave Bayes, and Support Vector Machines, and the Logistic regressor, after defining the learning task.

3.3.2.2 Machine Learning algorithms used

k-NN

Firstly, the k-NN algorithm is a classification algorithm whose basic assumption is the fact that the data points in the dataset that have similar behavior exist in a small proximity. This assumption leads to the formulation of the learning task as the classification of the new unseen data points by calculating the distance of the K data points in the training set that has the smaller distance in the feature space. The distance is a function that is used to express how similar or not is the new unseen data point with the data points in the training dataset. The distance can be the Euclidean, Hamming, or Mahalanobis distance. The distance is expressed in Eq. 8.

$$l = \sum_{1}^{n} (|x_i - y_i|^p)^{\frac{1}{p}} \quad Eq. 8$$

Naïve Bayes

Naïve Bayes is a group of probabilistic classifiers rather than a single classifier. The basic idea is that a Naïve Bayes classifier applies the Naïve Bayes theorem to an input vector that represents an unseen data point, assuming independence between the features of the input vector. It's reasonable to conclude that the probabilities in Eq. 9 $\Pr\{t = c\}$ and $\Pr\{x_i | t = c\}$ follow a distribution. The Gaussian or Bernoulli distribution, for example, can be used by the Naïve Bayes classifier. The Gaussian version of the Naive Bayes classifier is used in this study. In comparison to more complex models such as neural networks, the key benefit of the Naive Bayes classifier is that it can achieve high accuracy with limited data. The Bayes' theorem is used (t is the class variable and $X = [x_1, x_2, \ldots., x_k]$ is the input unseen data point) the classification problem is expressed in Eq. 9

$$y = \arg_c \max Pr\{t = c\} \prod_{i=1}^{n} Pr\{x_i | t = c\} \quad Eq. 9$$

Support Vector Machines

The Support Vector Machines (SVMs) are the polar opposite of the Naïve Bayes: a non-probabilistic classifier family. The core theory behind SVMs is that the aim is to find a hyperplane that divides the training set's classes with the greatest margin. When new, previously unknown data is provided into the SVM, the label is predicted depending on where it lands on the hyperplane. SVMs are one of the best classification algorithms because they can solve both binary and multiclass problems. In

the binary case, the problem is formulated as a linear classification task, and it is solved as a constrained optimization problem.

Decision Trees

The algorithms listed above are not the same as the decision trees. The Decision tree aims to construct a paradigm that uses basic if-else sentences. It can be used in both classification and regression activities. The decision trees are straightforward to comprehend and imagine. The difficulty with the Decision tree is that it is impossible to generalize it and as the problem grows more complicated, the tree becomes more complex and difficult to do as well as other classification algorithms like SVMs.

Logistic Regressor

Despite its name, logistic regression is a classification model rather than a regression model. In the literature, logistic regression is often referred to as logit regression, maximum-entropy classification (MaxEnt), or the log-linear classifier. In this model, a logistic function is used to model the probabilities that describe the possible outcomes of a single trial. Among the several penalized logistic functions are the l_2 and l_1. As an optimization problem, the binary class l 2 penalized logistic regression minimizes the following cost function:

$$\min_{w,c} \frac{1}{2} w^T w + C \sum_{i=1}^{n} \log\left(e^{-y_i(X_i^T w + c)} + 1\right)$$

l_1 regularized logistic regression, on the other hand, solves the following optimization problem:

$$\min_{w,c} ||w||_1 + C \sum_{i=1}^{n} \log(e^{-y_i(X_i^T w + c)} + 1)$$

Logistic Regression is a simple and commonly used Machine Learning algorithm. It's easy to set up and can be used to get started with any binary classification query. Deep learning can benefit from the fundamental concepts of deep learning. Using logistic regression, the relationship between one dependent binary variable and two independent variables is established and estimated.

3.3.2.3 LoRa Simulation Parameters

In order to meet the requirements of the presentation of the results, the following experiment was executed in the FLoRa simulation environment. Table 4 lists the simulation parameters needed for the execution of experiments. For two separate cases, the LoRa topology consists of multiple EDs ranging from 100 to 700 with a 100 ED step.

Table 4 Testbed of the LoRa topology for the Evaluation of the classifiers

Parameter	**Urban**	**Suburban**
Network Size	480m*480m	9800m*9800m
Number of Nodes	100 - 700	100 - 700
σ	0	0
Spreading Factors	7-12	7-12
Code Rate	4	4
Number of GWs	4	4
Bandwidth	125KHz	125KHz

3.3.2.4 Feature Selection and Data preprocessing

To begin, the simulation was run without the ADR mechanism turned on for both urban and suburban. The dataset created was used in the training process. It is necessary to extract the necessary information about the generated dataset as part of our analysis before moving on to the training process. As a result, the number of instances of each class is shown on the left in Figure 18. The ADR mechanism allocates the SF values of the EDs, resulting in an unbalanced dataset, with the SF with value 12 having the majority of instances and the SF with value 7 having the minority. As a result, synthetic data was required, which was done using the SMOTE-NC technique [83]. This aids in reducing the bias towards those SF values.

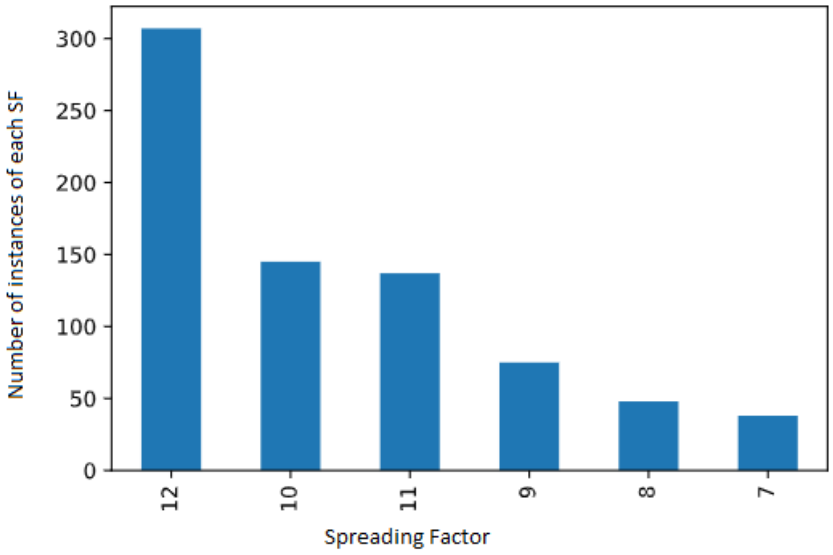


Figure 18 Bar chart of the number of the instances of each SF in the dataset

In order to train the machine learning models, it is important to extract the main features from the data during the training process. The total energy divided by the total packets sent and the TP were chosen as features in the feature selection process using chi-squared analysis. It is worth mentioning that the ED's location was left out and was not considered as a possible feature since LoRa networks' localization is not always accurate. The generated dataset is shown in Figure 19 and Figure 20 for the urban and suburban cases respectively. The x-axis represents Energy/Packet, while the y axis represents the TP value. Each color represents a different SF value. The SF classes in Figure 19 and Figure 20 can be easily distinguished as are seperable, thus these two characteristics can be used to characterize the SF.

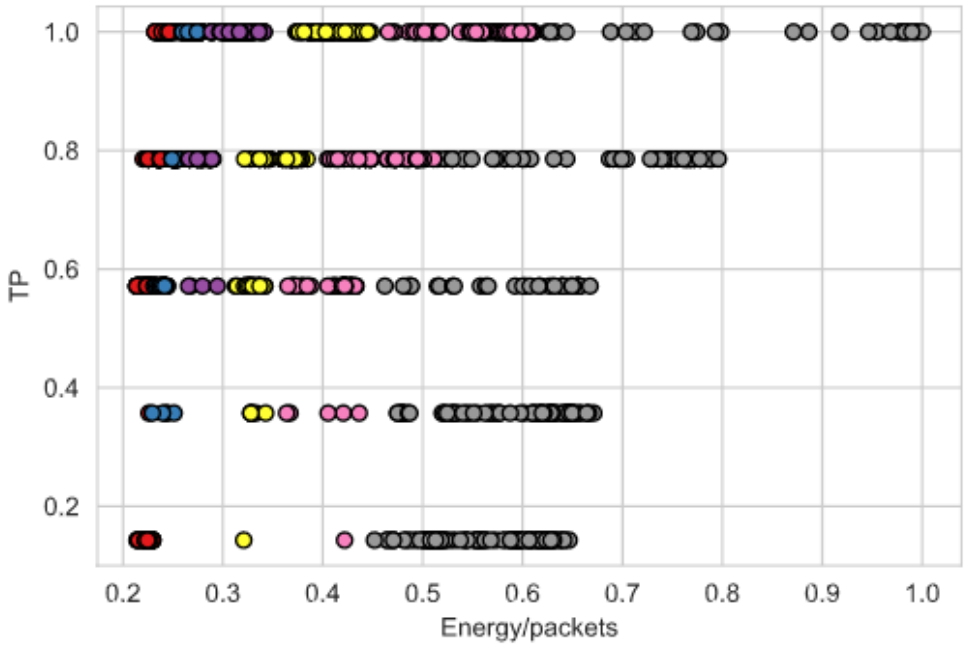


Figure 19 Visualization of the dataset in the urban case

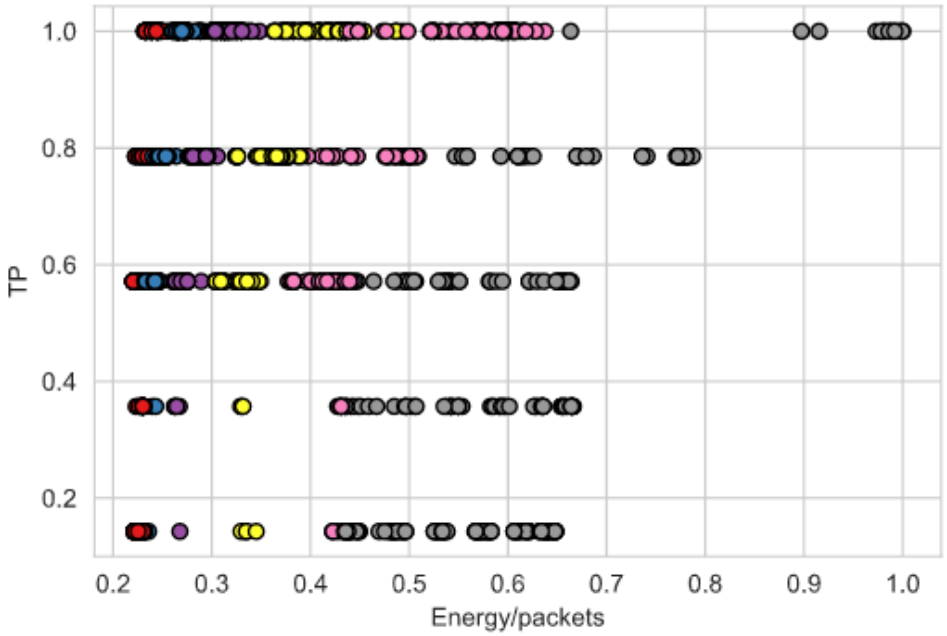


Figure 20 Visualization of the dataset in the suburban case

After the preprocessing and feature selection processes, the classification algorithms were trained. The dataset was split into two sections, with the training dataset accounting for 75% of the total and the testing dataset accounting for 25%. Using 10-fold cross-validation for the k-NN with k varying from 2 to 50, it was determined that k=4 appears to be the most appropriate value, with an average accuracy of 96 percent in the 10-fold cross-validation. In addition, the Naive Bayes classification algorithm was used to compare the results of the ML mechanism with the results of three different classifiers. The Gaussian Naïve Bayes algorithm was preferred over the other variants of the Naïve Bayes algorithm because it produced much better results in terms of accuracy. The disparity between the Gaussian and the other Naïve Bayes variants was enormous; for example, the Multinomial variant had an accuracy of

only 30%. In the case of the SVM, 10-fold cross-validation was used once more. The parameters were first reduced using the Random Search process, and then the final parameters were chosen using Grid Search. The linear function as the kernel function and c = 10 are the parameters that achieve high scores. In the 10-fold cross-validation, the mean validation score is 0.946. Finally, in order to find the most appropriate parameters for the decision tree classifier, we used random and grid search once more. The model with the following parameters was chosen from the 10-fold validation that was performed in each set of parameters: the Gini function was chosen as the criterion of the quality of the split, the maximum depth of the tree is 23, the maximum number of features that are considered is 1, and the minimum number of samples to split an internal node is 2. This model has a mean validity score of 0.99 and a standard deviation of 0.08.

3.3.2.5 Evaluation of classification algorithms

The models were evaluated after the training process was completed. The accuracy, precision, recall, and F1 score were used as metrics for the ML algorithm evaluation in the testing dataset after the models were fitted with the training dataset. The ratio of accurate predictions to total predictions is referred to as accuracy. The precision metric is the ratio of the correctly predicted answers of a class to the total number of the answers that predicted this class. The recall metric is the ratio of the number of correctly predicted answers to the number of the actual instances of the class. F1 refers to the relative contribution of precision and recall.

Figure 21 and Figure 22 show the five classification algorithms in terms of accuracy, precision, recall, and F1. In all four metrics, the SVM algorithm scored the highest, following by the k-NN, Decision Tree, the Logistic Regressor, and the Naïve Bayes. As all the algorithms are robust as in all metrics the scores ranged from 0.8 to 0.94 in the urban scenario, while for the suburban scenario the values ranged from 0.64 to 0.94. The reason that all algorithms scored very highly is that only two features were used for the classification problem and the phenomenon of the "curse" of the dimensionality was not present, and the data were separable in most cases, thus the performance was great. With such high scores of the classification algorithms, it can be assumed that it is possible to use classical ML algorithms instead of neural networks to optimize the LoRa network operations. This fact is an advantage, as usually, neural networks need to have a vast amount of data, something difficult in LoRa networks as the rate at which the data is sent in this technology is very slow In all four metrics, the k-NN algorithm scored the highest, following by the Decision Tree, the SVM, and the Naïve Bayes.

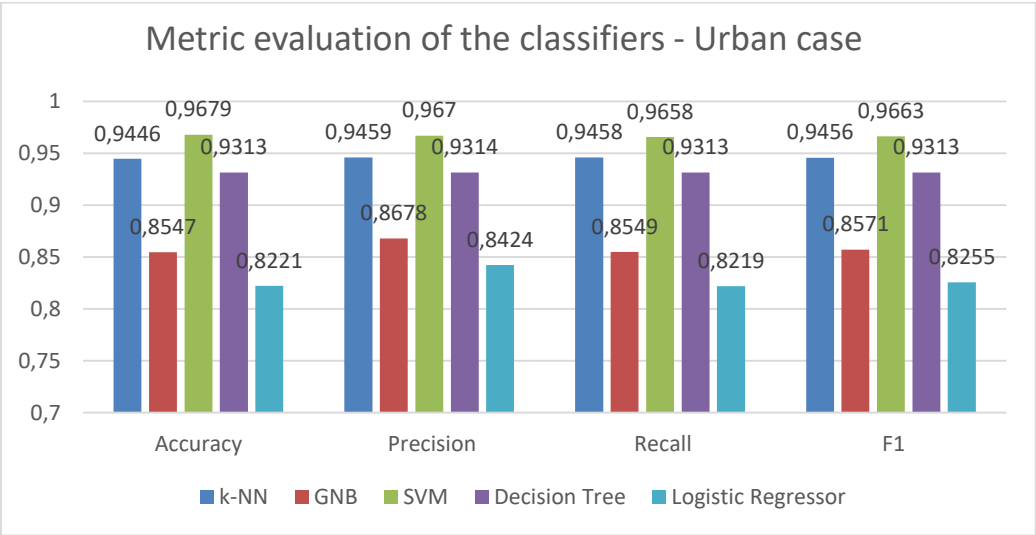


Figure 21 Evaluation of the classifiers in the urban scenario

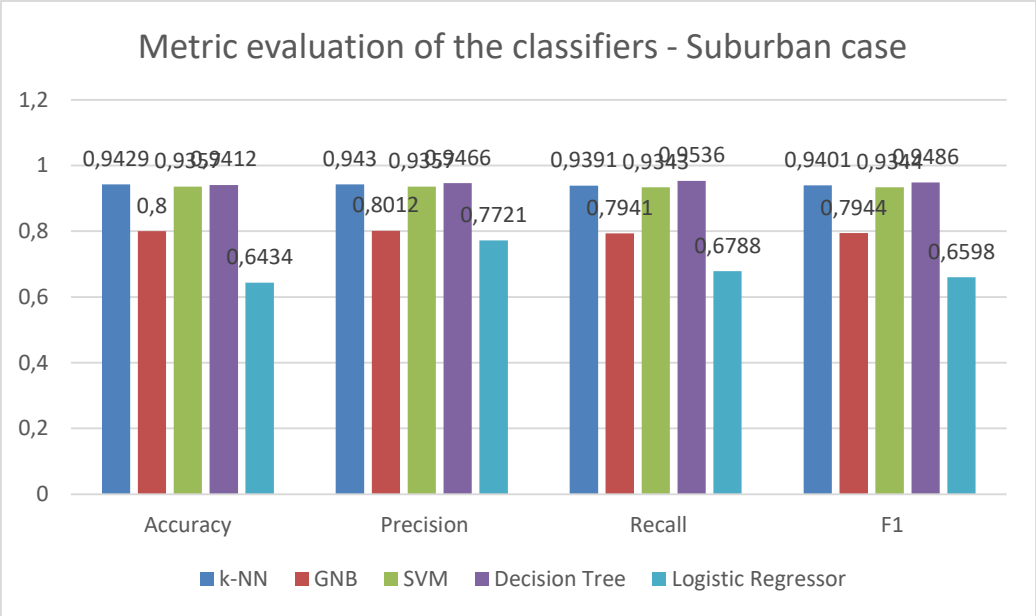


Figure 22 Evaluation of the classifiers in the suburban scenario

Table 5 Numerical data of the classification algorithm evaluation

Metric	**k-NN**		**Naïve Bayes**		**SVM**		**Decision Tree**		**Logistic Regressor**	
	Urban	**Suburban**	**Urban**	**Suburban**	**Urban**	**Suburban**	**Urban**	**Suburban**	**Urban**	**Suburban**
Accuracy	0.9446	0.9429	0.8547	0.8000	0.9679	0.9357	0.9313	0.9412	0.8221	0.6434
Precision	0.9459	0.9430	0.8678	0.8012	0.9670	0.9357	0.9314	0.9466	0.8424	0.7721
Recall	0.9458	0.9391	0.8549	0.7941	0.9658	0.9343	0.9313	0.9536	0.8219	0.6788
F1	0.9456	0.9401	0.8571	0.7944	0.9663	0.9344	0.9313	0.9486	0.8255	0.6598

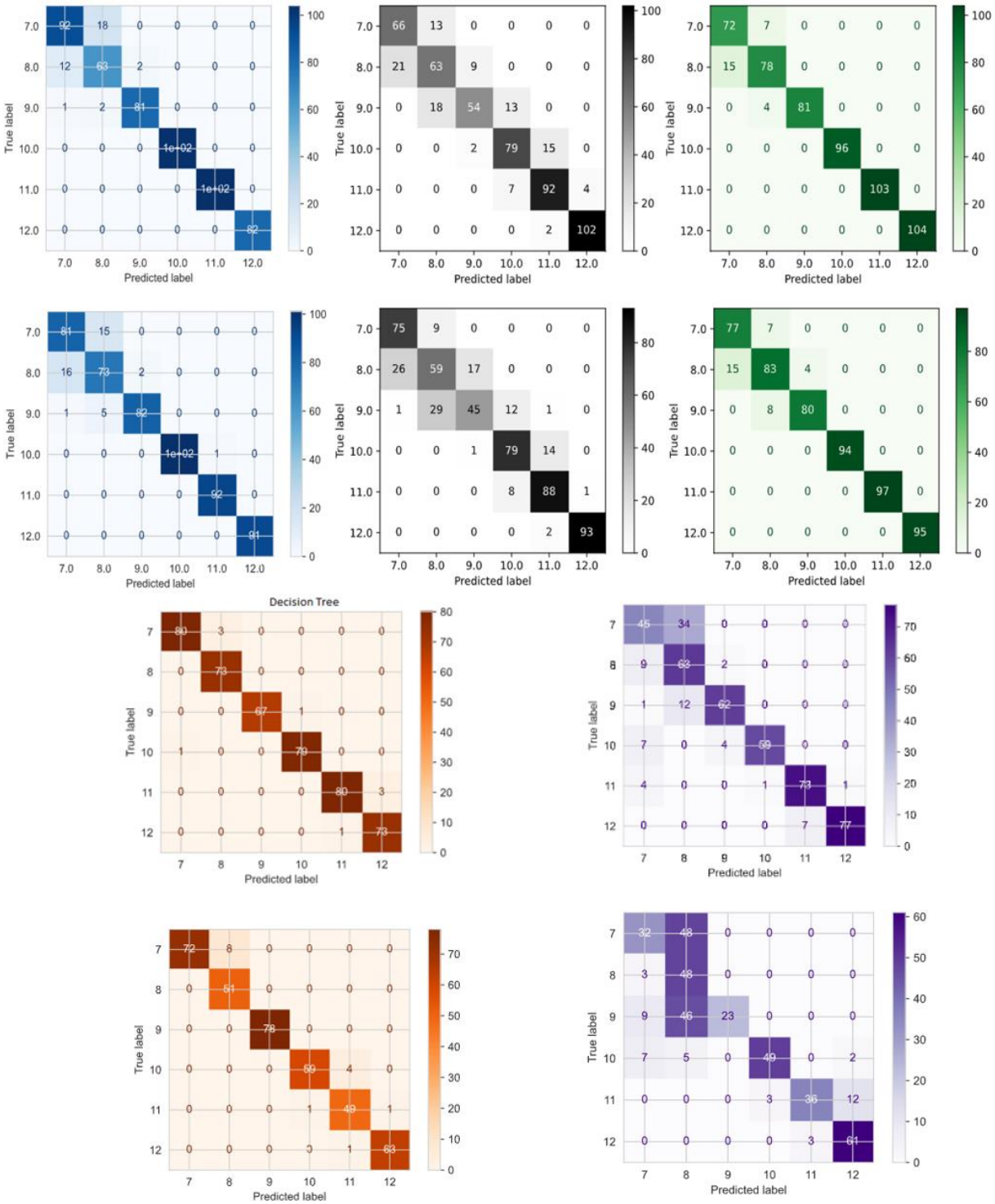


Figure 23 Confusion matrices of the classifiers blue: k-MM, grey: Gaussian Naïve Bayes, green: SVM, orange: Decision Tree, and purple: Logistic Regressor

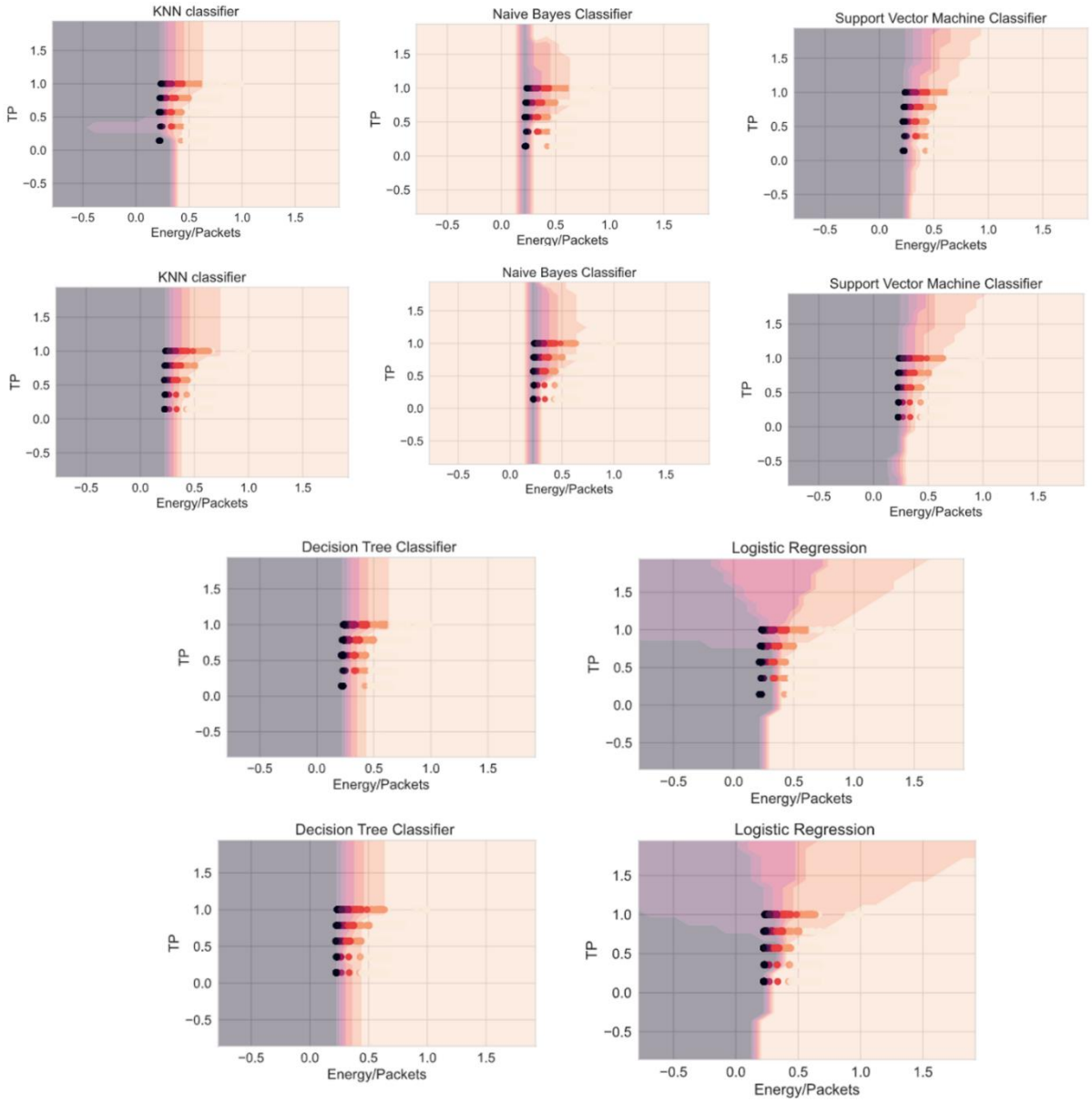


Figure 24 The decision boundaries of the classifiers.

3.3.2.6 ML mechanism integration in LoRa network

The overall ML-based process for SF selection in LoRa is discussed in this subsection. In the system model, the mechanism makes decisions about the SF in the NS, which is in charge of the transmission parameter selection of each ED. Figure 25 depicts the communication between the FLoRa simulator and the sci-kit learn library in the framework of the simulation process. Three steps make up the mechanism: a) Export NS values to the ML server; b) Select SF using ML algorithms; and, eventually, c) Setup SF configuration to the LoRa network. First, the stored data must be retrieved and evaluated in order to choose the best SF for data transmission to a single ED. As a result, ML is used to extract the ideal SF that could be used from NS for data transmission using the k-NN and Naïve Bayes algorithms (based on the training dataset). In this phase, the k-NN and Naïve Bayes classifiers were chosen to be tested, due to computational costs and due to the fact that both these classifiers have yielded good results as

presented in 3.3.2.5. The chosen SF is exported and written to a file ending in.csv. Following that, the csv file is used as an input into the NS to continue the transmission.

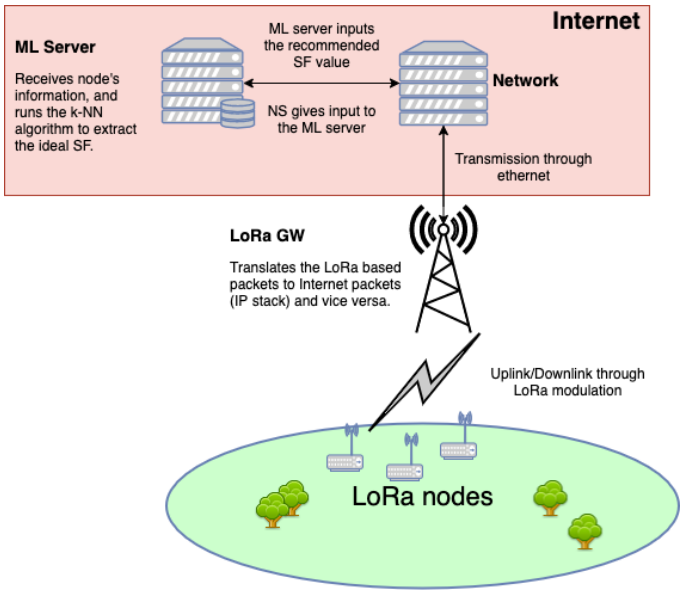


Figure 25 SF selection architecture through ML

3.3.2.7 Comparison mechanisms

This section examines three different approaches regarding the selection of the SF during transmissions in a LoRaWan environment.

1st Approach – RSF(Random SF) selection

For data transmission, the first method that the machine learning-based algorithm will be compared relies on random SF selection. In order to be used during transmission, the algorithm selects a random value between 7 and 12. SF values remain constant in the simulation. This is plausible because, in many situations, it is unclear what SF the user should allocate, so the ED's SF can be considered as random.

2nd Approach – ADRSF (ADR SF) selection

The ADR mechanism is the second method discussed in this thesis [84]). EDs closer to the GW do not need the high link budget associated with SF12, nor do they need to have large airtime. According to the link budget of each ED, the ADR will optimize the ED's SF and minimize the corresponding Time on Air. ADR is a very simple heuristic mechanism that is divided into two components, one of which runs in the NS and the other in the ED itself. The ADR adjusts the data rate according to a set of basic rules: The data rate can be reduced if the connection budget is high (i.e. the SF is increased) The data rate can be reduced if the connection budget is poor (i.e. the SF is reduced) [84]. The pseudo-code for the second method is shown below.

The ADR mechanism is heuristic and simple to understand and execute. In general, dynamic parameter selection is advantageous to both the EDs and the network, as it can result in lower energy consumption and a higher delivery ratio. In comparison to other proposed mechanisms in the literature, the ADR's key flaw is that it is heuristic and does not always contribute to optimal resource allocation. Furthermore, the ADR converges slowly, and many unsuccessful uplink transmissions must occur before the SF or TP transition in many situations. These major flaws have piqued the attention of researchers all over the world who are looking for better alternatives.

Two variants of the ADR mechanism are investigated in this thesis. The first version of the ADR is the classic version, while the second one is proposed in [12] uses the average of the latest obtained frames to estimate link quality in the NS section, while the second version of the ADR proposed uses the maximum SNR value from the last 20 frames to estimate link quality in the NS part. The pseudo-code that follows refers to all versions, with the exception that the average operator is used instead of the max operator. We call the ADR variant that uses the max operator MaxADR, and the ADR variant that uses the average operator AvgADR.

Pseudo code – ADR part running in the ED

```
int SF=0; % initialize the SF
int ADR_uplink = 0
int threshold = 96
while (uplink transmissions):
   ADR_uplink ++;
   if ADR_uplink > threshold;
        SF = increaseSF(SF);
   else:
       Request Downlink frame
       transmit(); % NS transmits the data

   function increaseSF(SF):
       if (SF > 7 and SF <12):
              SF = SF + 1;
              return SF;
```

Pseudo code – ADR part running in the NS

```
SNRm = max of the last 20 frames
SNRmargin;
steps = floor(SNRmargin/3)
int threshold = 96
while (steps>0 & SF>7):
   SF--; steps--;
while steps >0 and TP>2
   TP =TP-3; steps--;
while steps<0 and TP<2
   TP =TP+3;  transmit();
    steps++;
```

3.3.2.8 Simulation Results and Evaluation

The experimental findings are discussed in this paragraph. From the above classification algorithms, the k-NN and the Naïve Bayes classification algorithms were chosen to be tested in a LoRa simulation process. Table 6 lists the parameters of the simulation configuration, which is classified as urban [12]. The EDs were placed in the region at random, according to a uniform distribution. Every 1000ms, each ED sends uplink packets in a time that follows the exponential distribution. The simulations adhere to the ISM bands' service cycle restriction of one percent. The simulations were repeated several times to minimize bias, and each simulation took 10 simulation days. As far as the evaluation is concerned, we present the following: ADR mechanism using the max operator, ADR mechanism using the average operator, the case where the SF is set randomly is called RSF, the k-NN based ML mechanism, and the Naïve Bayes ML mechanism. We compared the ML-based mechanism with the ADR, as the ADR is the de-facto mechanism used in LoRa. As far as the ML is concerned, we used two algorithms, in which both achieve high scores in 4 classification metrics as Table 5 presents. Again, the mechanism is evaluated using two metrics the ADR and the average consumption of the EDs.

Table 6 LoRa testbed for the testing of the ML mechanisms

Parameter	Value
Number of Nodes	50 – 250, 50 step
σ	0
Spreading Factors (SF)	7-12
Transmission Power (TP)	2 to 14 dBm
Code Rate	4
Carrier Frequency	868 MHz
Bandwidth	125KHz
Number of GWs	1
d0	40 m
PL(d0)	127.41 dBm
Packet size	20 bytes
λ	1000 ms

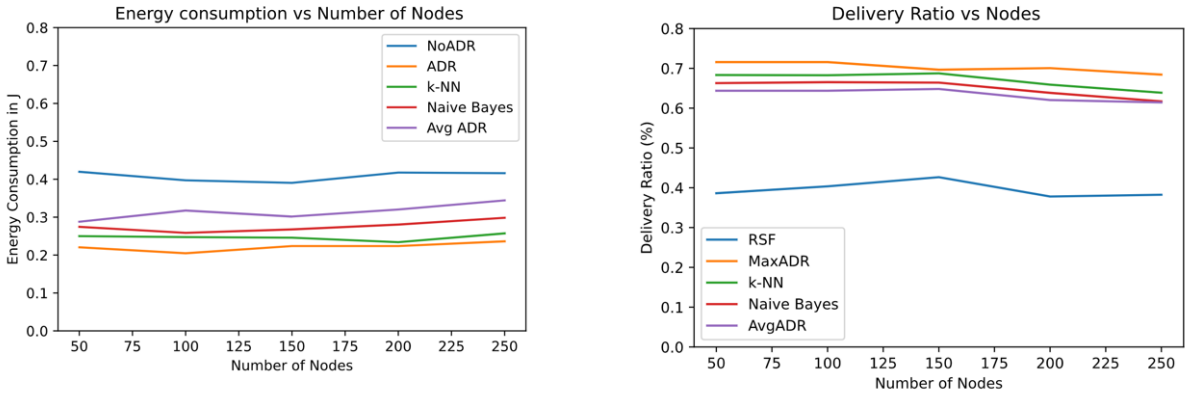


Figure 26 Energy Consumption and Delivery Ratio in the urban case.

The energy consumption in the RSF case, with ADR and ML mechanisms, is depicted in Figure 26. The random assignment of the SF, according to Fig. 3, is the worst method. When comparing the four remaining methods, the ADR uses the least amount of energy, while the AvgADR uses more than the ML-based mechanisms. The ML mechanism based on Naive Bayes consumes slightly more energy than the k-NN, but the energy consumption is nearly identical when 100 EDs are used. The reason the ML mechanisms appear to perform a little worse is that, unlike the ADR, only the SF is optimized, whereas, in the ADR, the TP changes as well. ML-based algorithms can, however, come close to the ADR algorithm even if there is no policy to change the TP. As can be seen in Fig. 4, the RSF case, the case with ADR enabled, and the case with ML mechanisms enabled all have different delivery ratios. Furthermore, there is no significant difference between the optimized cases, especially as the number of EDs increases, whereas the SF method with random assignment produces the worst results. The ML-based mechanisms outperform the AvgADR-based mechanism.

In order to evaluate the delivery ratio results, a thorough insight of the created data was investigated. After the research, the authors concluded that the main reason for the slightly worse performance compared to the ADR algorithm can be understood from Figure 27, in which the Random SF selection case, yields the worst results, due to the largest number of packets that could not be received by the GW. This derives from the signal power that falls below the GW's sensitivity threshold. Among the 4 mechanisms, namely the two variants of the ADR and the two ML mechanisms, the MaxADR has the least number of packets that fall below the GW's sensitivity threshold. The ML mechanisms fall between the AvgADR and the MaxADR, as the number of packets that could not be received by the GW is

between the MaxADR and AvgADR. This is the reason that the ML-based mechanisms perform slightly worse than the MaxADR, but better than the AvgADR.

It's crucial to understand the part of the ADR algorithm that runs in the EDs at this stage. The ED asks the NS to send a downlink packet within the next 32 uplink packets after 64 uplink transmissions. In the case where the ED's SF is less than the GW's minimum required value, 96 uplink transmissions are required to raise the SF value. In order to achieve the lowest SF value, more than 96 uplink transmissions must be sent when the ML models make one false prediction that causes the ED's SF value to fall below the sensitivity threshold. In comparison to work [13], no assumptions about the lowest SF were made in order to make the simulations more practical.

A simple application-layer mechanism to keep track of the lowest SF was created. Despite the fact that no prior information was presumed, unsuccessful uplink transmissions occurred in some cases to detect the lowest SF. Finally, in comparison to [13] the EDs in this paper were able to transmit within the possible TP value range. The authors presumed that all EDs transmitted at the highest possible TP value, which is not always the case in real-world scenarios and deployments. Furthermore, the EDs could transmit with a variety of TP values, but the ML mechanisms did not adjust the TP values dynamically, as happens in the ADR mechanism. Despite this, the ADR mechanisms produce marginally better performance, making the use of the ML mechanism a viable choice for SF selection.

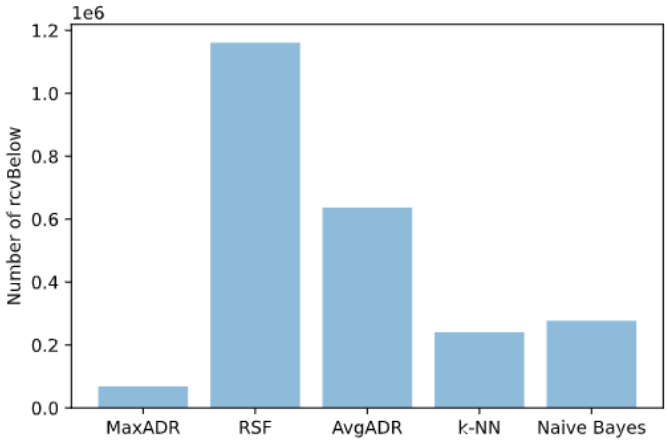


Figure 27 Number of packets fell under GW's sensitivity.

3.3.3 Localization Algorithms

In this subsection, the localization algorithms are reviewed, and the localization algorithm used in this thesis is presented. The location of sensors in IoT applications can be critical. Environmental control, surveillance, rescue operations, traffic monitoring, and other applications may all benefit from localizing sensors. In most cases, satellite-based location systems (such as GPS or Galileo) are the primary solution to these types of problems; however, due to high energy consumption or high hardware costs, this solution is not feasible, forcing the research community to look for other ways to complete the task of localization in LoRa networks. The localization algorithms for LoRa networks are dependent on the RSSI values, angle of the signal, the Time of Flight of the signal, or the time difference measurements from sensors. These raw data are given as input to the different algorithms and the output is the estimated position of the ED.

To determine the position of a moving target, several techniques based on distance measurements can be used. The most widely used localization techniques are Trilateration and Multilateration [85][86]. The basic concept is that an ED is sending a packet and this packet is received by a LoRa GW. This transmission has some properties that are calculated in the GW, such as the RSSI. Based on the RSSI values the distance between the ED and the GW is estimated. A circle centered at the ED's coordinates

with a radius equal to the approximate true distance (the estimated by the RSSI values) between the receiving LoRa GW and the ED is created for each receiving LoRa GW with which the object communicates. Based on the number of communicating receiving LoRa GW, the circle's centers and radius provide information to estimate the ED's position. The ED needs to be able to communicate with at least three non-collinear receiving LoRa GWs in order to determine its orientation, which is determined using the intersection of these such circles.

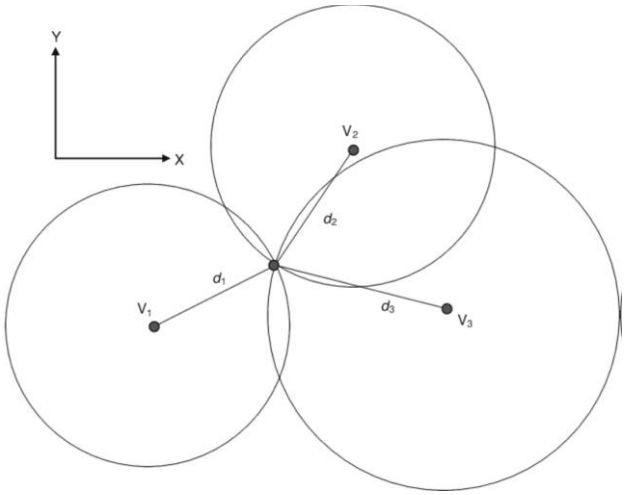


Figure 28 Trilateration Algorithm representation.

As far as the Multilateration is concerned, Mulitateration is defined as the "Multilateration is a navigation and surveillance technique based on time of arrival (TOA) measurements of energy waves which have a known propagation speed". The receiving LoRa GW must have synchronized 'clocks' to use this process. An individual ED can send and receive signals to and from the receiving LoRa GW. Multilateration systems are also known as hyperbolic systems because they use the intersection of the hyperbolas identified between each pair of base stations to find the coordinates of the ED. There are three main categories of Multilateration. The first is called ToA based Multilateration, the second is the Time Difference of Arrival (TDoA) based Multirateration algorithm, and the third is the Time of Flight (ToF) based Multilateration algorithm. In the first case, the ToA of the signal is used to determine the distance between transmitter and receiver by measuring the signal's transmission time from transmitter to receiver. Much of the time, the transmission speed is the speed of light, which necessitates the use of very sensitive clocks in order to obtain precise measurements. The ED's and receiving stations' 'clocks' must be coordinated at all times. The following Eq. can be used to calculate the distance between the receiver and the transmitter (the ED and the LoRa GW):

$$Distance = c(t_{arrived} - t_{sent}) \quad Eq.10$$

The c denotes the propagation speed, $t_{arrived} - t_{sent}$ signifies the duration of the signal travel. In this method, it is necessary to know the position of each receiving LoRa GW, and the number of the receiving GWs should be at least 3.

As far as the TDoA method is concerned, in contrast to the ToA method, which uses distances between the receiving GW and the ED, this method uses time variations of the signal the object sends to the receiving GW. Only the receiving GWs' clocks must be synchronized for this method to work. The location of the ED can be obtained by solving the following equations.

$$\Delta t_i = \frac{1}{c}\Delta d_i \quad Eq.\ 11,$$

$$\Delta d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2},\ Eq.\ 12$$

Where Δd_i is the distance between the receiving station selected as the base and the respective receiving GW. Also, because the ED does not have a clock synchronized with the receiving GWs, the signal

transmission time is unknown and the differences in signal reception times from the receiving stations are used to locate the location. This difference is denoted as Δt_i.

Finally, the ToF based Multilateration method is presented. ToF is a distance measuring technique that does not involve coordination between the ED and the receiving LoRa GW. Instead, the average time of 2-way contact between the receiving stations and the object is used to calculate the distance. In order to obtain precise measurements, this approach necessitates that the ED's response time be constant. The following equation can be used to measure the distance:

$$distance = c * = \frac{t_{arrived} - t_{sent} - t_{received}}{2} \quad Eq.13$$

Where $t_{arrived}$ is the time it takes for the signal to reach the receiving GW, t_{sent} is the time it takes for the receiving station to transmit the signal to the ED, and $t_{received}$ is the time it takes for the ED to send a message to the receiving station.

3.3.3.1 Thesis' approach for the localization process

In this subsection, the approach followed in the context of this thesis is presented. Due to the simplicity and the wide use of trilateration, in the scope of this thesis, the trilateration localization method was used. The implementation and mathematical analysis of this method developed in this thesis will be presented in this subsection. First and foremost, it is important to explain how the distance between the ED is the receiving LoRa GW is estimated, then the geodetic-cartesian coordinates transformation used will be presented, and finally, the mathematical method used to extract the position information of the EDs using the RSSI values will be presented.

Firstly, knowing the locations of the receiving LoRa GWs and having at least three receiving LoRa GWs to communicate with the ED at the same time is a requirement for measuring the position of the ED. To provide distance information, receiving station data is properly processed using mathematical formulas known as path loss and was presented in Section 3.2. An association between the RSSI value and the distance between the LoRa GW and the ED is used to characterize radio channels in a particular context. It is possible to establish a relationship between the obtained power (RSSI) and the distance. In the path loss Eq. 1, we substitute the PL with the RSSI values. Then, assuming $\mathrm{d}_0 = 1\ meter$ we solve the equations with the unknown being the distance (d). So, the estimated distance is calculated as follows:

$$d_i = 10^{\frac{RSSI_i - RSSI_0 - X_\sigma}{10n}}$$

Then as mentioned before we need at least 3 receiving LoRa GWs, we can proceed to the coordinates estimation of the ED. Substituting the d with the Euclidean distance $d = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2}$, where x, y, z are the ED's coordinates, and x_i, y_i, z_i are the coordinates of the receiving LoRa GWs, respectively.

$$\sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} = d_i =>$$
$$x^2 - 2x_i x + x_i^2 + y^2 - 2y_i y + y_i^2 + z^2 - 2z_i z + z_i^2 = d_i^2$$

Now having n equations where n is larger than 3, we choose a LoRa GW let be m to be a reference GW. The equation of the distance estimation of the m LoRa GW is subtracted by all the other Equations. Then the form of the equations is like:

$$-2x(x_i - x_m) + x_i^2 - x_m^2 - 2\mathrm{y}(\mathrm{y_i} - \mathrm{y_m}) + y_i^2 - y_m^2 - 2\mathrm{z}(\mathrm{z_i} - \mathrm{z_m}) + z_i^2 - z_m^2 = d_i^2 - d_m^2$$

At this point, using the least-squares method we will structure the matrices appropriately and estimate the position. Least squares are one of the most common approximation methods, a very good method to choose when we have many measurements and we want to model them with a function that depends on a few parameters. The aim is to find a straight line that approaches our measurements as best as possible, minimizing the error (residual) for each point. Choose one of the equations and subtract it from the rest. Thus, the matrices are the following:

$$A = \begin{bmatrix} 2(x_1 - x_m) & 2(y_1 - y_m) \\ \vdots & \vdots \\ 2(x_{m-1} - x_m) & 2(y_{m-1} - y_m) \end{bmatrix}$$

$$b = \begin{bmatrix} {x_1}^2 - {x_m}^2 + {y_1}^2 - {y_m}^2 + {d_m}^2 - {d_1}^2 \\ \vdots \\ {x_{m-1}}^2 - {x_m}^2 + {y_{m-1}}^2 - {y_m}^2 + {d_m}^2 - {d_{m-1}}^2 \end{bmatrix}$$

The solution of the above system comes from the next equation.

$$X = (A^T A)^{-1} A^T b$$

3.3.3.1 Datum transformation

Finally, one last aspect that must be addressed in a real system is the datum system. In the above system, the equations assume that the coordinates are cartesian, hence it was necessary to take care of the datum transformation. In this subsection, the approach followed in the scope of this thesis is presented. One of the most fundamental tasks in computational geodesy is the transformation from Cartesian (x, y, z) to geodetic (ellipsoidal) coordinates (φ, λ, h), where φ is the latitude, and λ is the longitude and h the height. This kind of transformation is used to monitor moving and stationary objects in space. Many scholars have addressed the issue of converting from Cartesian to geodetic coordinates; their list can be found in Featherstone and Claessens [88] and it continues to pique interest.

The basic equations that were used in this thesis are the following:

$$x = (N + h)cos\varphi\, cos\lambda$$

$$y = (N + h)cos\varphi\, sin\lambda$$

$$z = [N(1 - e^2) + h]sin\varphi$$

Where N is the normal radius of curvature: $N = a/\sqrt{1 - e^2 \sin^2 \varphi}$, the e^2 is the first eccentricity squared, a is the semi-major ax of the ellipsoid. From the above equations, it is possible knowing the latitude, longitude, and height to convert to cartesian coordinates.

In order to return to the geodetic coordinates, the inverses of the above equations should be found. The value of the longitude is immediately extracted, knowing the x, and y from the next equation the longitude is:

$$\lambda = \arctan(\frac{y}{x})$$

As far as the latitude is concerned, the value of latitude cannot be calculated immediately, and an iterative method should be applied. The reason is that the inverse is

$$\varphi = \arctan(\frac{z + Ne^2 sin\varphi}{p})$$

Where $= \sqrt{x^2 + y^2}$. As the next equation presents, the latitude is on both sides of the equation, thus an iterative algorithm should be used. Many algorithms have been proposed, such as Paul's method [89]. In the framework of this thesis, the latitude calculation is happening using the simple iteration method. In the beginning, an estimate of the right φ is calculated

$$\varphi_0 \rightarrow arctan\frac{z(1+e^2)}{p}$$

The φ_0 is put in the next equation. The new φ_1 is then again feed in the right part of the equation. This procedure is repeated until the difference between successive φ reaches an acceptable limit. In the development phase, it was found for coordinates in the area of Greece, the latitude is calculated in 10 repetitions.

Finally, the height is calculated as:

$$h = \frac{p}{cos\varphi} - N$$

4

Implementation and Evaluation of the Web-based application

"Programmers are constantly in maintenance mode."

— Andrew Hunt, The Pragmatic Programmer: From Journeyman to Master

4.1 Introduction

This thesis approaches the interface of the website using as a method the heuristic evaluation of Jacob Nielsen [59] as well as the new set of heuristics. Usually, an expert in engineering design called a user interface expert is called to examine and then evaluate an interface using his experience and guidelines report problems, seek alternatives solutions, etc. Among all other methods, heuristic evaluation is believed to get faster results without much effort [90]. In this section, mockups in a form of prototypes were evaluated by experts and then a final evaluation occurred in the live version of the website.

4.2 Heuristic evaluation process

Heuristic evaluation is a usability engineering method that helps designers find out weak spots and usability problems in their designs. For the evaluation problem generally, a small group of evaluators for the different background are needed because one individual is impossible to identify all the problems. Some problems are common and can be founded out by many evaluators as well as problems that are difficult to be found by the majority of evaluators and then there were identified from an individual. Each evaluator is given sufficient time to test the design in form of mockups or prototypes, find usability problems, write them down on a catalog and also propose a change. When the evaluation process is done for all the evaluators then they are allowed to communicate with each other and discuss their findings. This procedure is important because in this way the evaluation process is independent and unbiased.

The most common method is that the evaluator fills in a report about the problem and potential solutions for the interface whereas there are cases that the evaluator speaks during the process and the researcher writes down notes. Written reports are of course a more formal way of evaluation and can be used in the next design phase when the interface takes its final form. Furthermore, the results of the

evaluation are available very soon. The observer is not allowed to intervene in the whole process of the evaluation. The only thing that the observer can do is to help the evaluators with the operation of the interface when a problem arises [38].

General for a typical evaluation, the session for an individual evaluator lasts one to two hours. There are longer evaluation sessions that occurred when evaluators have to deal with larger or very complicated interfaces with many elements and sub-categories. During the evaluation session what the evaluator does is to go repeatedly through the interface and inspect the various elements comparing them with a list of recognized usability principles (the heuristics). These heuristics are general rules that describe the most common properties of usable interfaces. In addition to the general checklist of heuristics, the evaluator can consider and add any usability principle that it comes to his mind as long as it relevant to the interface he tests [39].

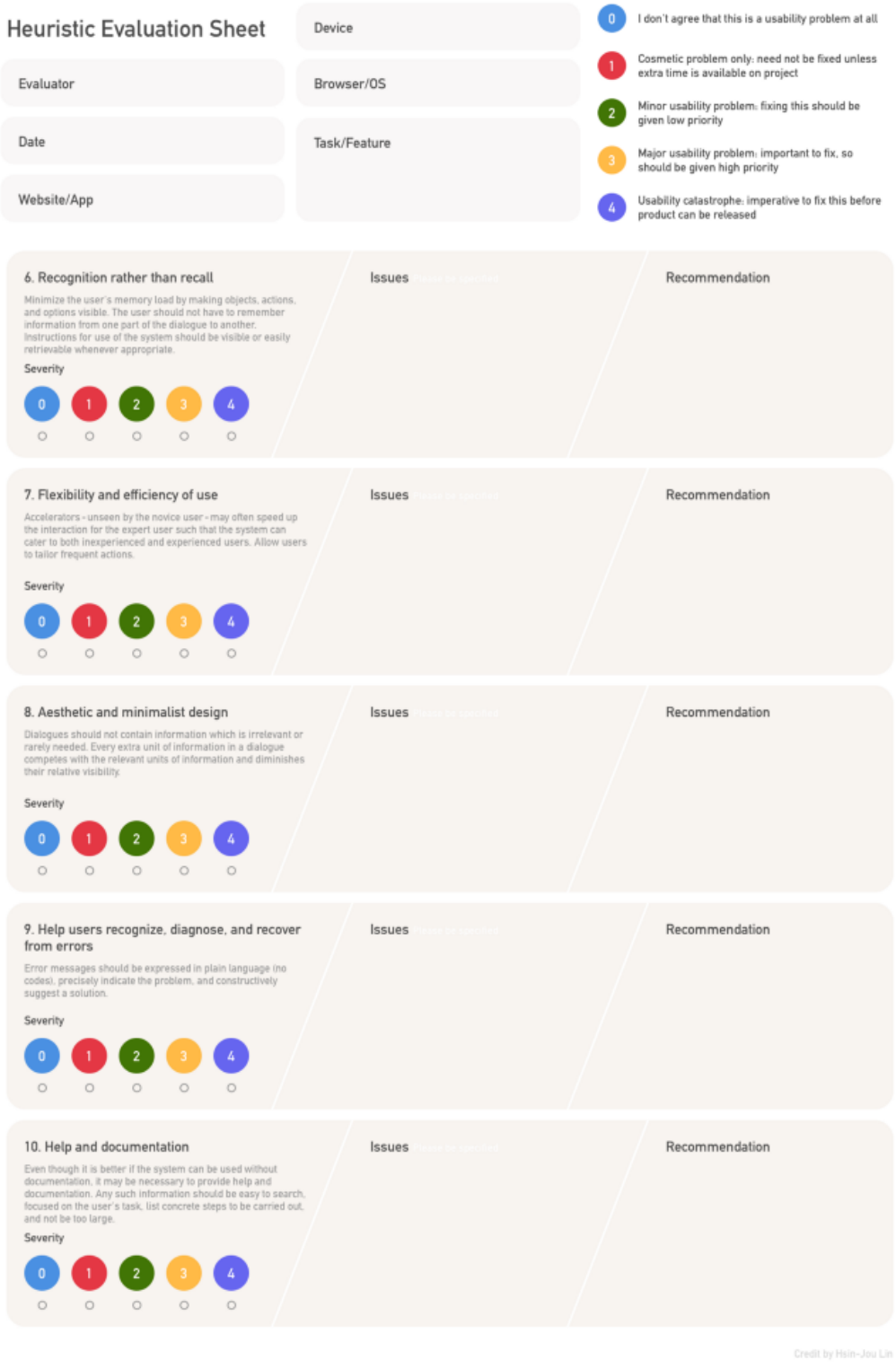
4.2.1 Heuristic evaluation process: Search and Rescue

In May 2021 the evaluation process of the Search and Rescue prototype took place in the office of Research Unit 6 at Rio, Patras. The evaluation team consisted of three people: two HCI students and one engineering with a background in Business and Management Administration. Each evaluator has a certain time of arrival and in 40 minutes it had to evaluate the prototype alone only with the company of the website's designer that had the role of observer. The reason that the evaluation occurred on prototypes instead of simply mock-ups was that prototypes allowed the changes between different pages of the website in order to achieve the feel of a real functional site.

Evaluators were given a heuristic evaluation sheet that was relevant to the 10 heuristics (Figure) [40]. There they could note issues and problems that would arise and in the next frame their recommendation about how the interface could be better. Also, on the left side of the sheet, they could note the severity score for each one of the heuristics. The severity follows a particular scale:

- 0-I don't agree this is a usability problem at all.
- 1-Cosmetic problem only needed not be fixed unless extra time is available on the project.
- 2-Minor usability problem: fixing this should be given low priority.
- 3-Major usability problem: important to fix, so should be given high priority.
- 4-Usability catastrophe: imperative to fix this before the product can be released.


Heuristic Evaluation Sheet
Device
Evaluator
Browser/OS
Date
Task/Feature
Website/App
0 I don't agree that this is a usability problem at all
1 Cosmetic problem only: need not be fixed unless extra time is available on project
2 Minor usability problem: fixing this should be given low priority
3 Major usability problem: important to fix, so should be given high priority
4 Usability catastrophe: imperative to fix this before product can be released
1. Visibility of system status
The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
Severity
0 1 2 3 4
Issues
Recommendation
2. Match between system and the real world
The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
Severity
0 1 2 3 4
Issues
Recommendation
3. User control and freedom
Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
Severity
0 1 2 3 4
Issues
Recommendation
4. Consistency and standards
Users should not have to wonder whether different words, situations, or actions mean the same thing.
Severity
0 1 2 3 4
Issues
Recommendation
5. Error prevention
Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
Severity
0 1 2 3 4
Issues
Recommendation



In the next paragraphs are presented problems that were founded by evaluators, what is the problem, the proposal for the evaluators, and the new interface with the changes. The addition heuristics (Navigation, minimal design, privacy, responsive design) were written behind the sheet.

1. First screen

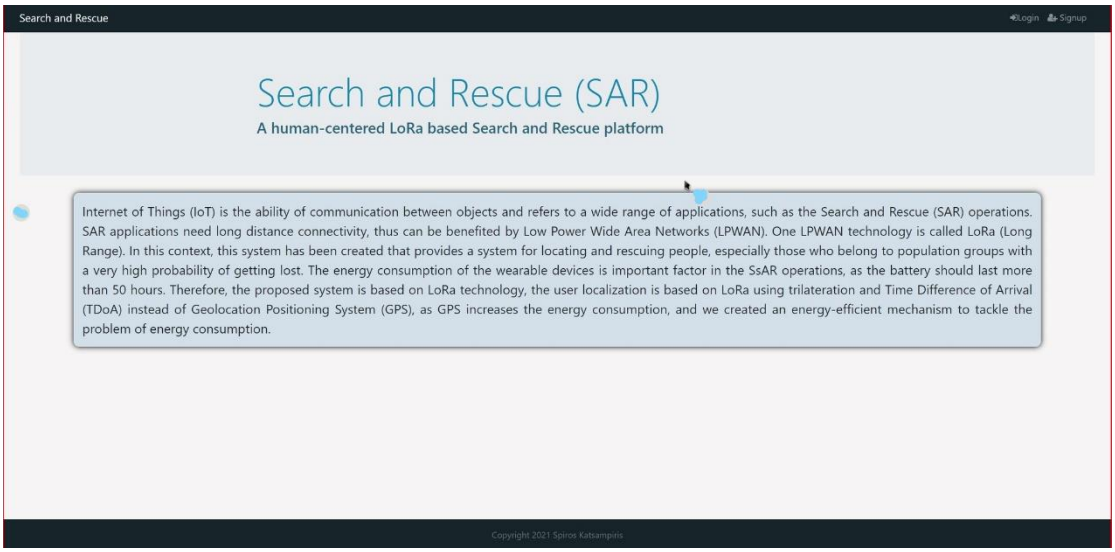


Figure 29 Initial screen

Issue	The first screen of the website provides users with two main options login for users that have already account and sign up for first-time users. The two options are on the upper right side of the website due to the fact that most sites have those options on this side so it is kind of familiar for the users. Also, there are the main title of the website and a subtitle to inform user that is in the first screen. The text in the frame includes technological information for the system and how it works. Experts in their evaluation believe that that this configuration is circumventive and required a change in terms of color and text management Figure 29Color and text management that violated visibility of system status and aesthetic and minimalistic design
Problem severity	3
Recommendation	Better management of text may be divided into two main columns with an introduction Figure 30.

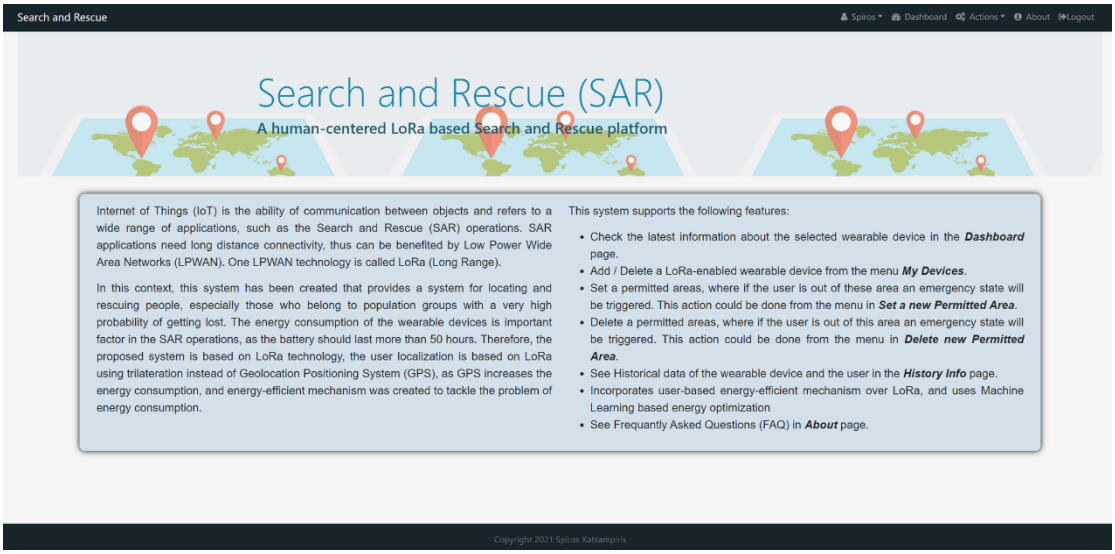


Figure 30 Initial first screen after the evaluation.

2. Menu actions

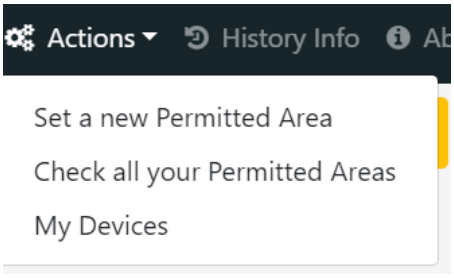


Figure 31 Menu "Actions" before evaluation

By clicking on actions choice in Figure 31, a submenu appears with three choices: Set a new Permitted Area, Check all your Permitted Areas, and My Devices. According to experts the order "My Devices" is irrelevant with the category "Actions" as it affects the connection of users between the physical and digital world. A proposal was that this order could be possibly put into the category "My profile" which has the name of its user like it was done in Figure 32	
Issue	A change in the sub-category choice "Actions", the choice "My devices" is irrelevant and frustrates the user that seeks his devices from the profile menu. Violation of match between system and the real world and consistency and standards.
Problem severity	11
Recommendation	Removal of "My Devices" choice from the Actions menu and addition to profile menu. After changes the two menus became:

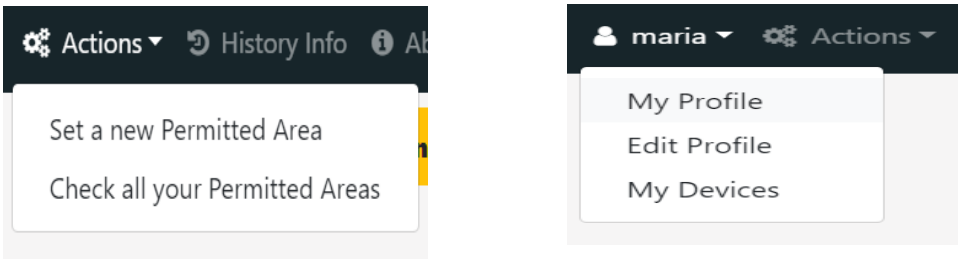


Figure 32 Transfer of choice "My Devices" into "My profile" menu

3. Set a permitted area

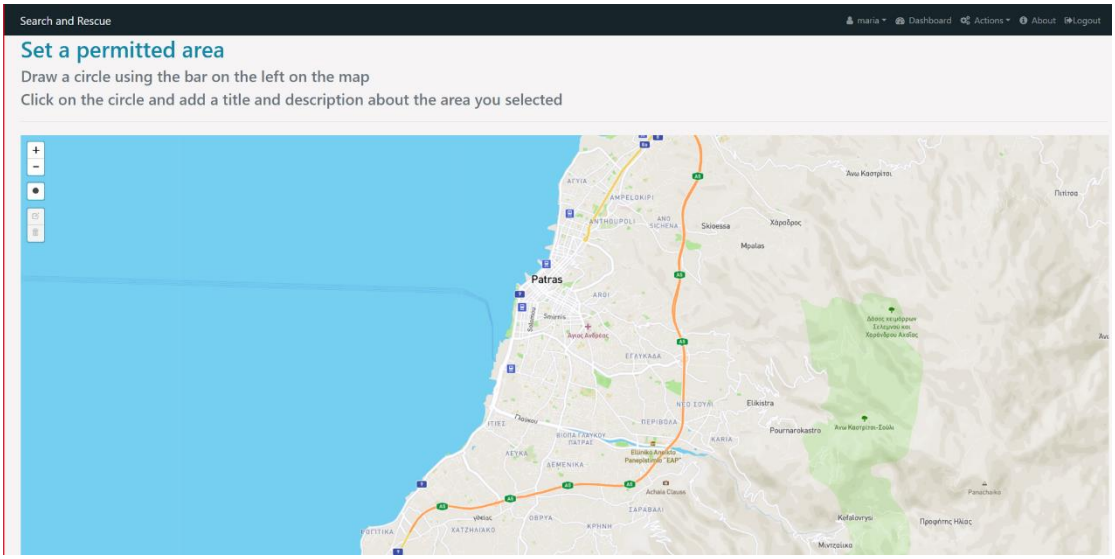


Figure 33 Set a permitted area screen.

Issue	The choice set a permitted area to bring the user in front of the map. There is also additional text that helps the user navigate better and understand what to do with the tools in the map Figure 33. For experts, this one was a good tactic that is followed on many websites about geolocation. Although, they believe that some indications like icons of locations that the user has put his location could be added.A good screen overall. Some users would like to see icons that would indicate places where they had put their devices when they are to set a new permitted area. Violation of aesthetic and minimalistic design.
Problem severity	1
Recommendation	An icon that indicates the position of devices.

4. Check the permitted area

Issue	On this screen, the main problem mentioned was that when a circle was created then the next step was the addition of information and then the circle become a marker like a case in Figure 34. For experts that violated the consistency of the system and they propose the existence of many red circles at the same time instead so they could have the ability to have an overall view of their permitted areas as is illustrated in Figure 35. A good screen overall. Some users would like to see icons that would indicate places where they had put their devices when they are to set a new permitted area. Violation of aesthetic and minimalistic design.
Problem severity	1
Recommendation	An icon that would indicate the position of devices.

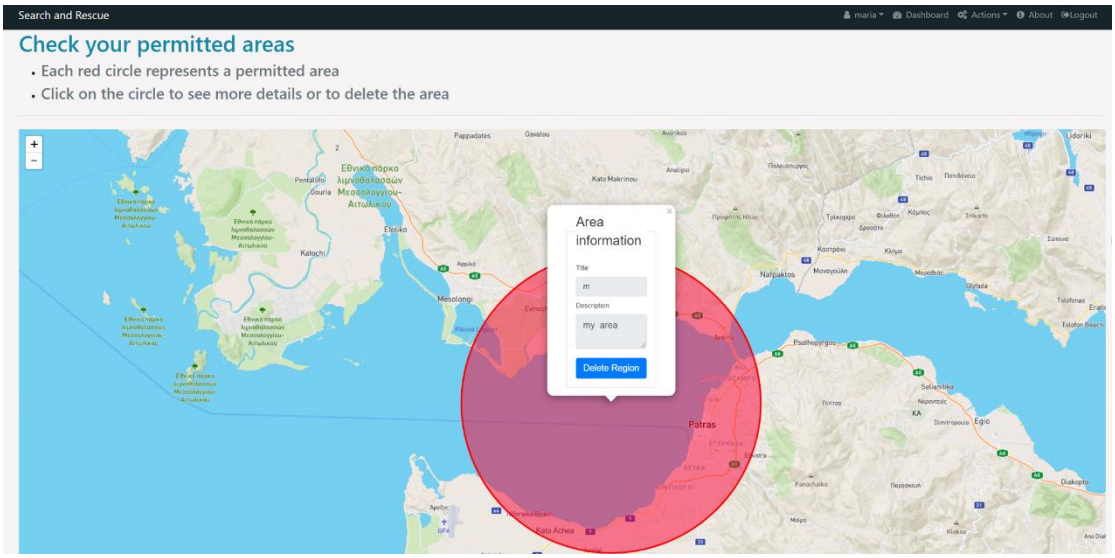


Figure 34 Creation of permitted area screen before evaluation.

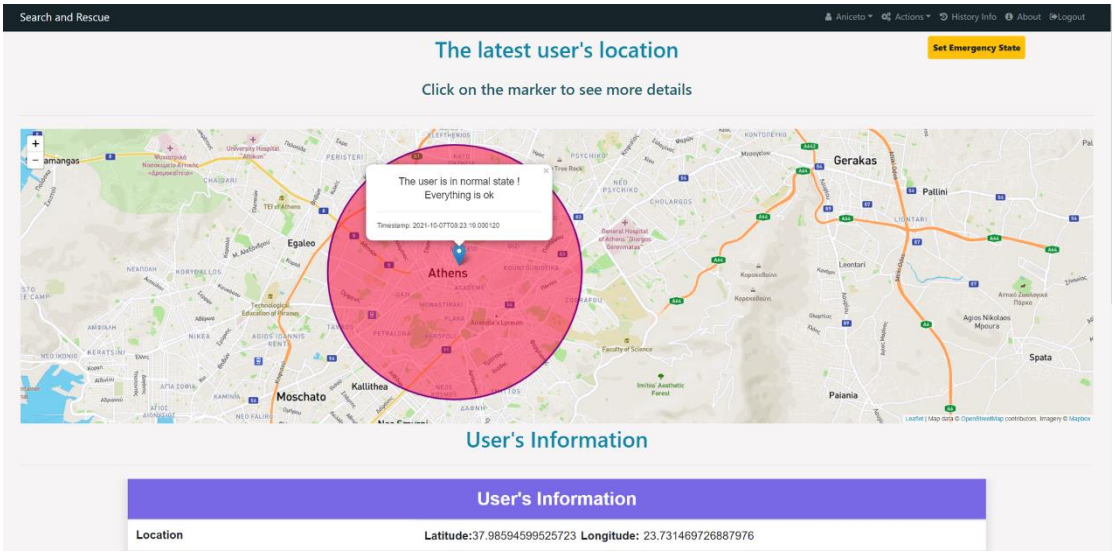


Figure 35 Creation of permitted area screen after the evaluation.

5. Add permitted area

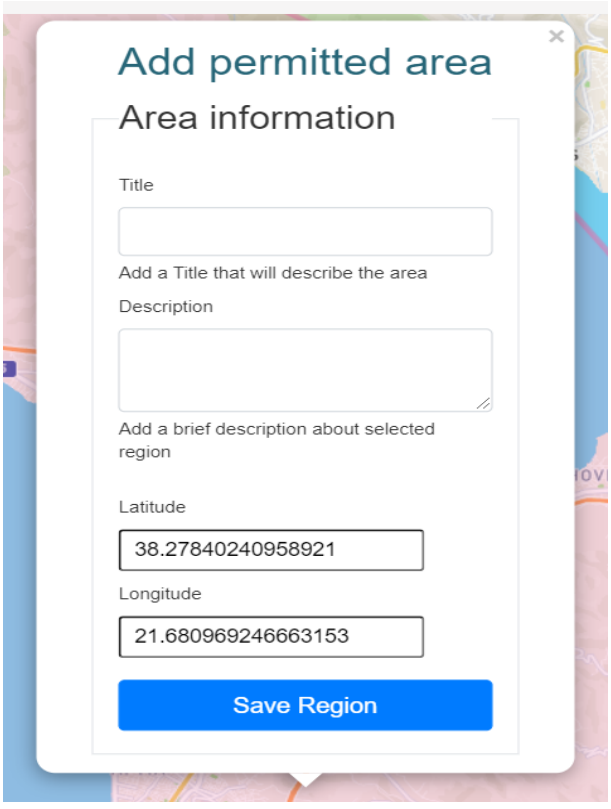


Figure 36 Add permitted area window with explanatory text.

Issue	When the user adds a new permitted area, the user must give system information such as title and description. After a suggestion from evaluators, an explanatory text was placed under the title and description to give to the users more guidelines about the use of these options as is

	illustrated in Figure 36. The window where the addition of a new area takes place needs an explanatory text under the fields of title and description for a better understanding of the concept from the user. Violation of help and documentation heuristics as well as navigation
Problem Severity	2
Recommendation	Addition of explanatory text under the text and description fields.

6. Registration of new area, wearables list and addition of wearable device

Issue	On those two screens Figure 37 user has the ability to add or select an already existing device. For experts, the two buttons have a sign of text redundancy that can disturb users from their goal. Instead, they propose simple orders such as "add" and "select" in terms of a minimalistic design. Furthermore, in the Macaddress because not all users are experts on operating such systems experts pointed out that there is a need for an error message or colored text when a user type an invalid value like words instead of numbers instead the error prevention heuristic is violated. The same reasoning comes to this screen. Although, it is a warning message according to Nielsen error prevention principle it violates the heuristic about consistency and minimalistic design Figure 38. The change that is needed is a red color for the title to refer to warning and a simple "Add" button. The buttons use more words than the necessary ones. Minimalistic design is violated. Also, users can enter wrong values in any field like symbols or numbers when the platform expects only letters. The error prevention is violated.
Problem severity	3
Recommendation:	Change commands on buttons to "Add", "Select" and make the right corrections in order when a user put a wrong value the system gives as feedback an alert.

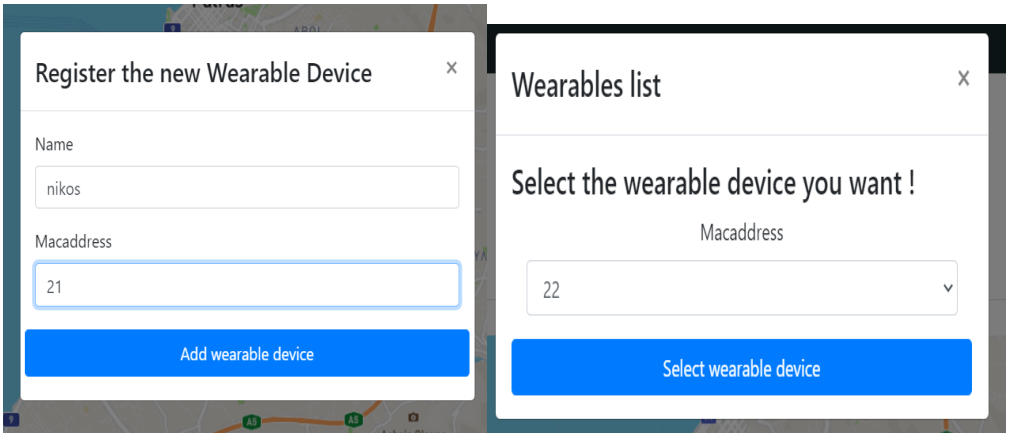


Figure 37 Initial buttons for addition and selection of devices

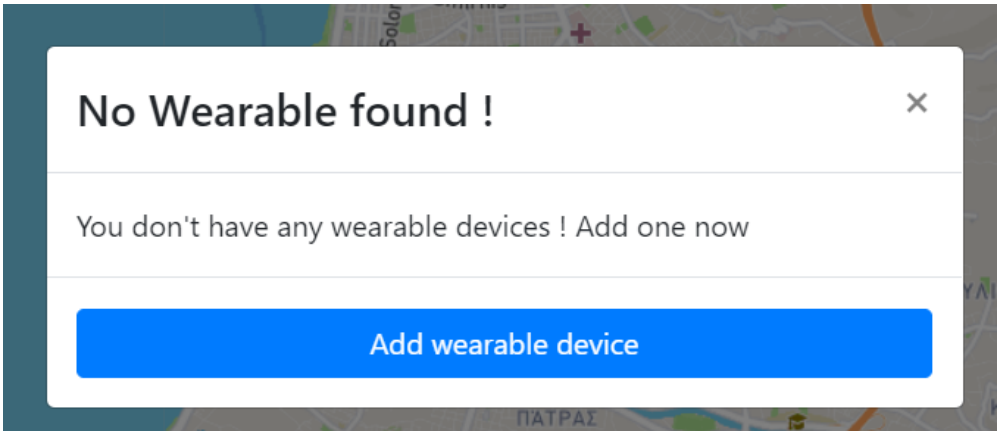


Figure 38 No wearable alert message before evaluation.

7. History

Issue:	In Figure 39 users observed that all the elements on the history section were only in words and not with indicative icons. From a designing point of view and because users of the internet have used websites with icons that explain more the content they propose the addition of some icons as it is illustrated in Figure 40. Text without decorative and explanatory icons. Heuristic of aesthetic design was violated
Problem severity	1
Recommendation:	Add some icons that are related to the text.

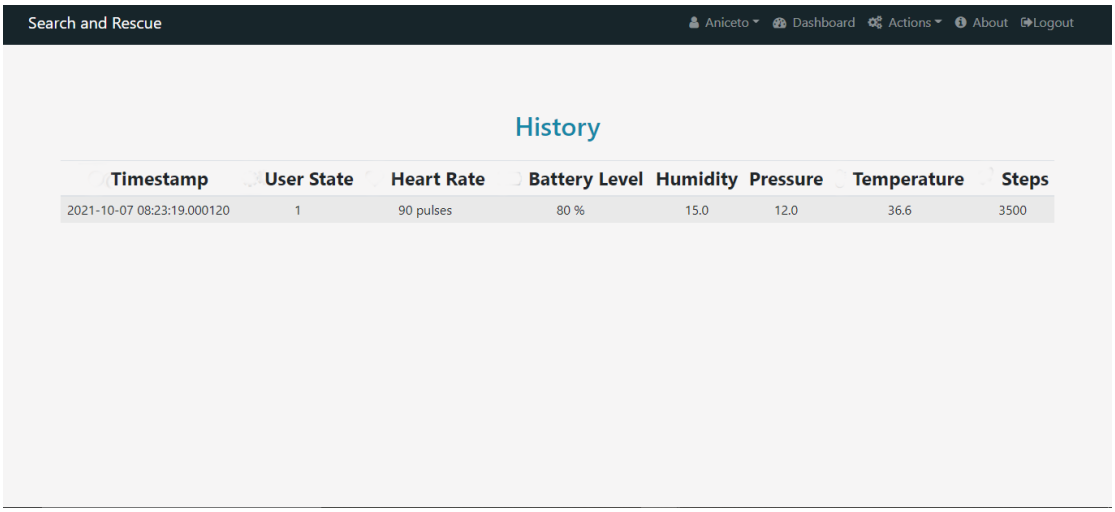


Figure 39 Initial history screen.

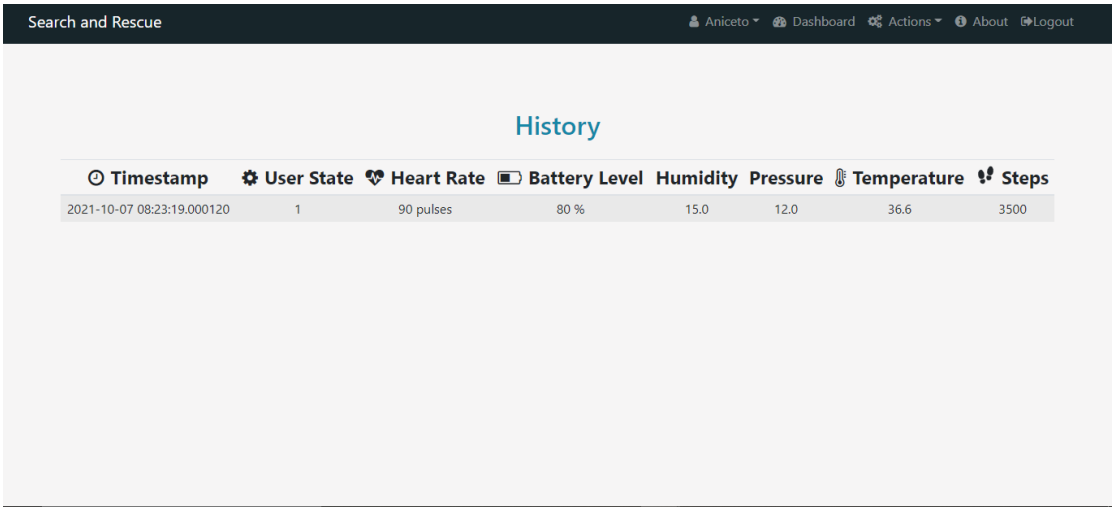


Figure 40 History screen with icons.

8. Emergency button

Issue	When the user does not have any connected device, the system needs a way to show that there is a case of inactivation. In many cases, evaluators click on the set emergency state button but when there was not a device in the system there was not any feedback at all. There is a violation of the match between the system and the physical world as a user believes that any button that he can click can trigger an action (Figure 41). In order to fix this, the button fades out when the user does not a device in the system as is shown in Figure 42. Set Emergency State button is not operational when there is not any device connected in the system
Problem Severity	3
Recommendation	Make the button inactive

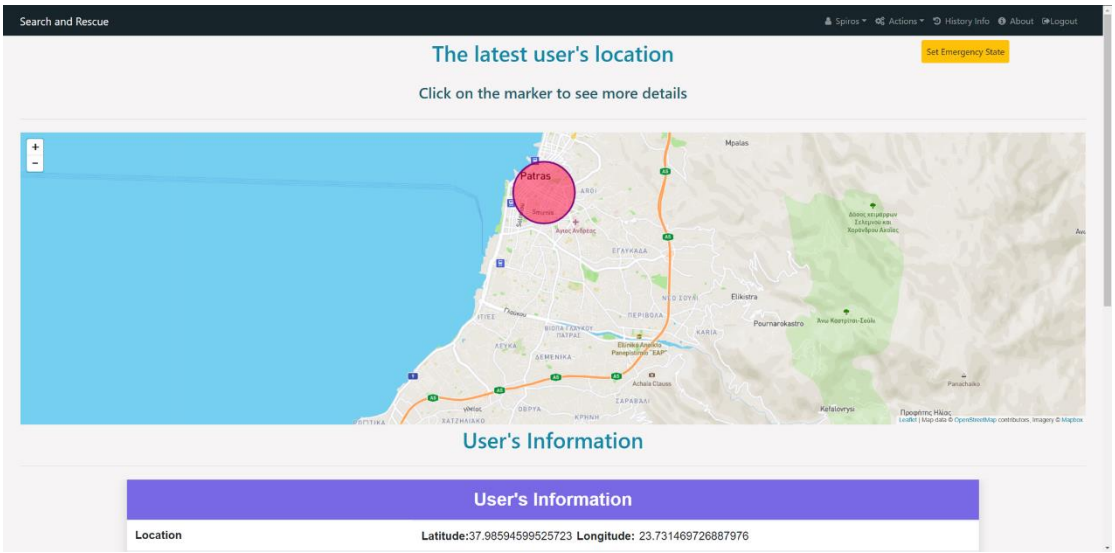


Figure 41 Emergency button that gives no feedback.

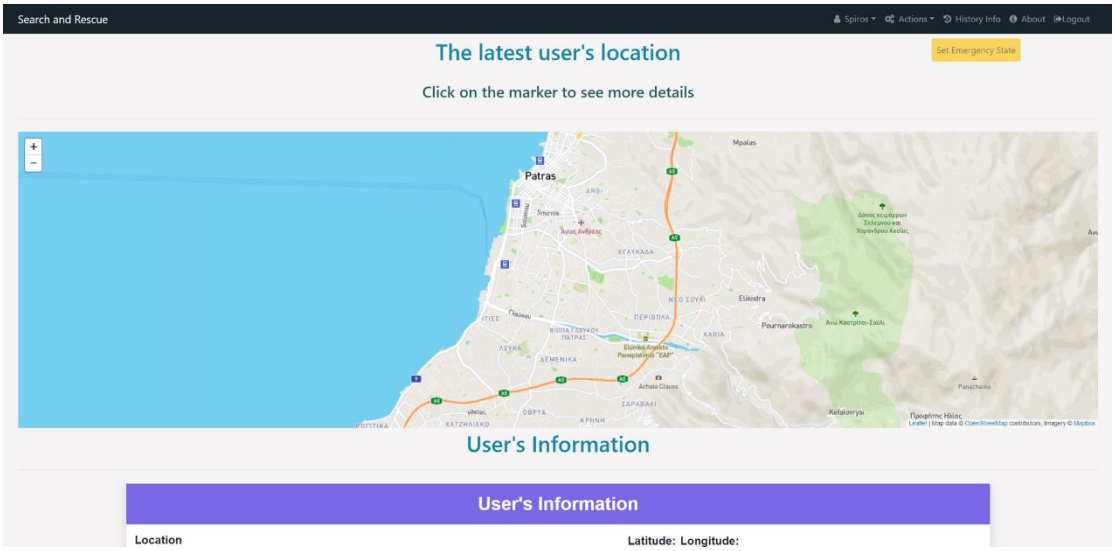


Figure 42 Emergency button faded as a mean of inactivation.

9. Emergency state

Issue	When the user clicks on the emergency button, the system triggers an alarm that means that one of the subjects with the wearable device on it has been lost. In the prototype form what the system did was to notifying users by making the whole screen red on every page (Figure 43). This change bothered all the participants that did not understand what was the meaning of the red color. This action violated the heuristic of visibility of system status as well as consistency and standards. The red screen when the set emergency state is active disturbs users
Problem Severity	5
Recommendation	Find an alternative way of showing danger and emergency (Figure 44).

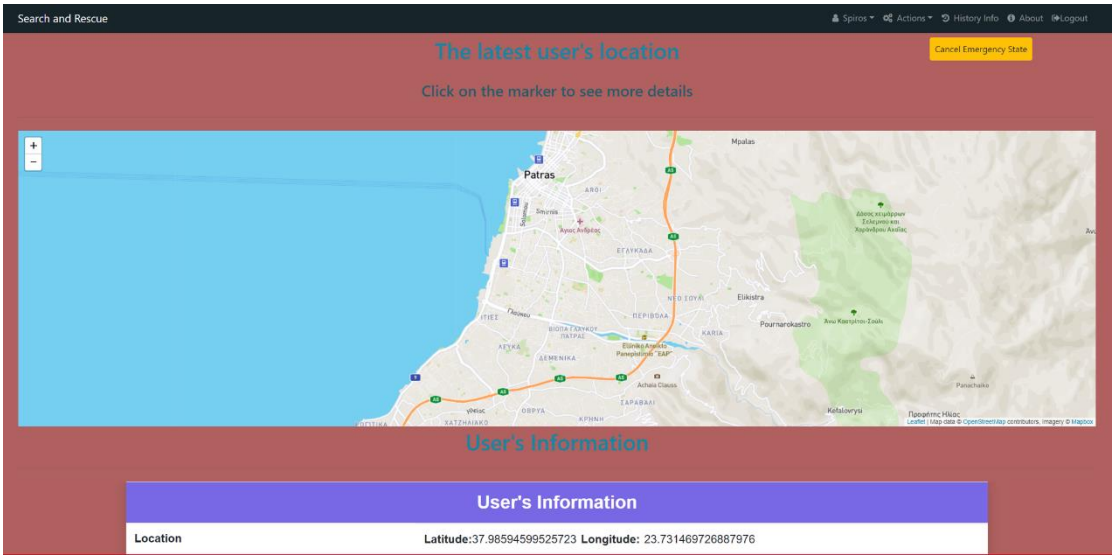


Figure 43 Initial emergency state case.

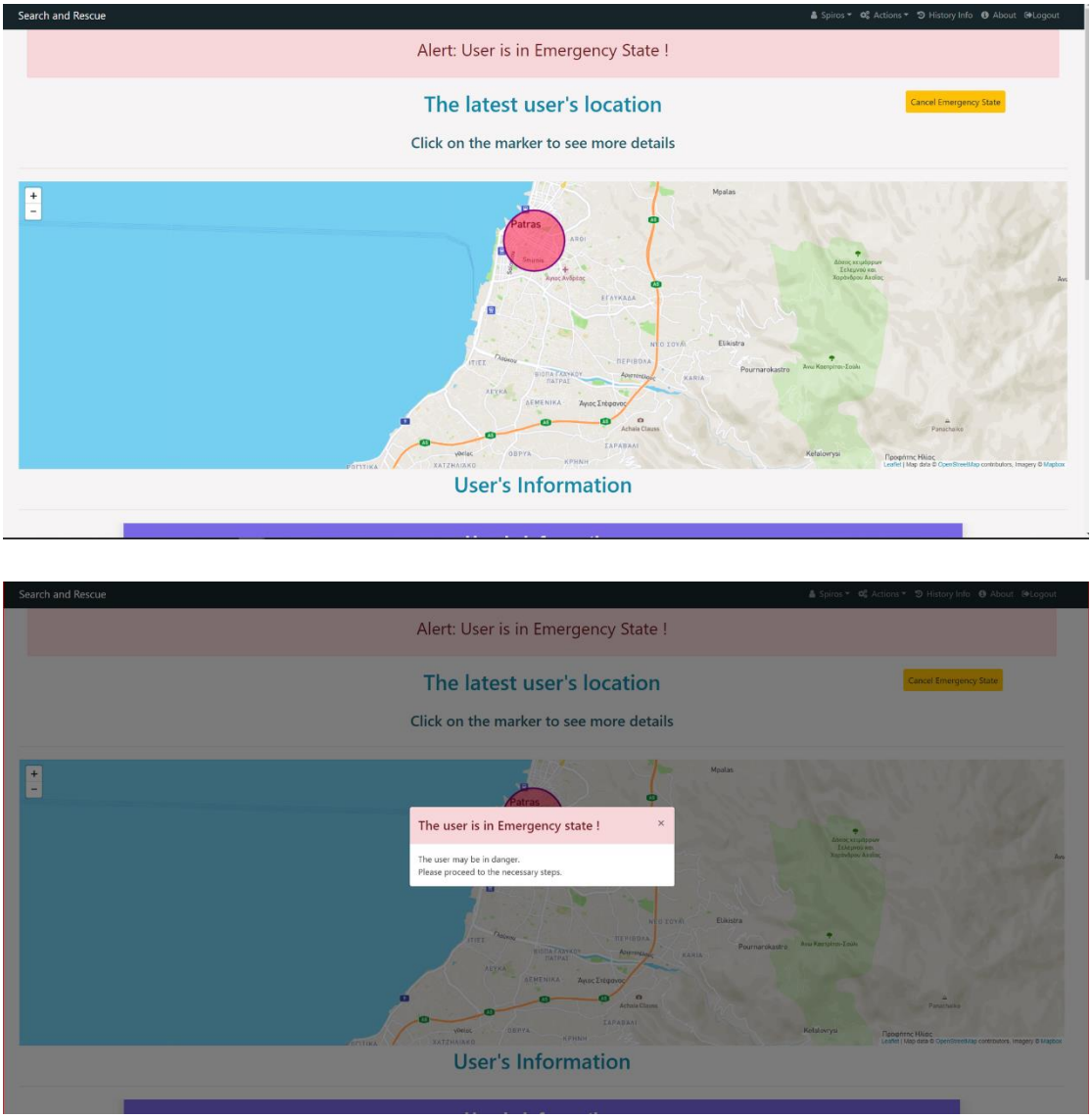


Figure 44 Emergency state alert after evaluation.

10. Window segmentation

Issue	One of the evaluators notices that when it comes to windows that they have to fill or select with devices, enter an address, etc. there is not segmentation between the title of the window and the main content (Figure 45) something that violates the minimalist design of the website. The designer proceeds with the change by putting a background neutral color in every header of the windows as illustrated in Figure 46. There is no clear header in window menus
Problem Severity	2
Recommendation	Find a way to state the difference between the header and the main body.

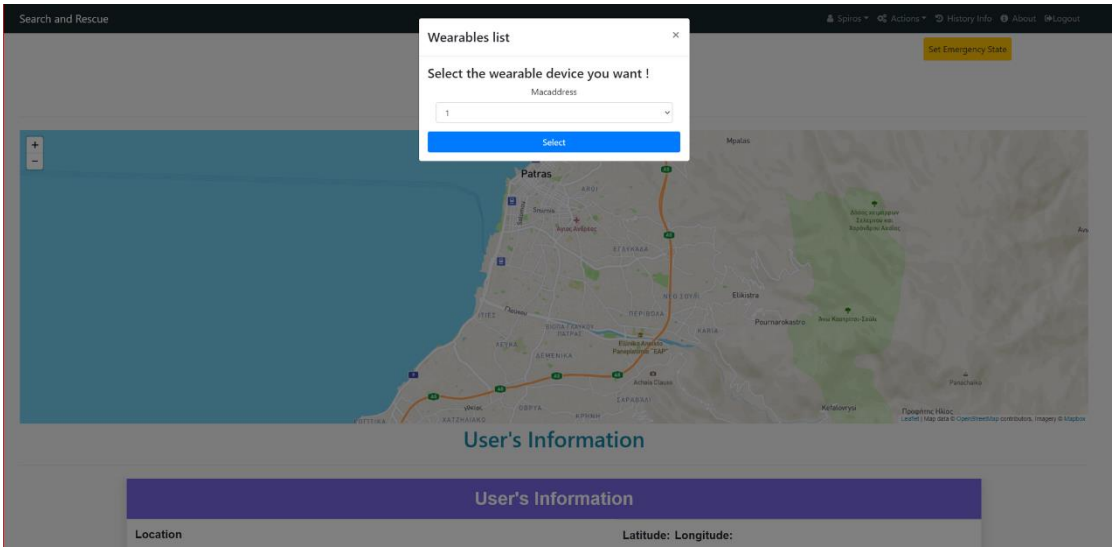


Figure 45 Case of no segmentation between commands and text.

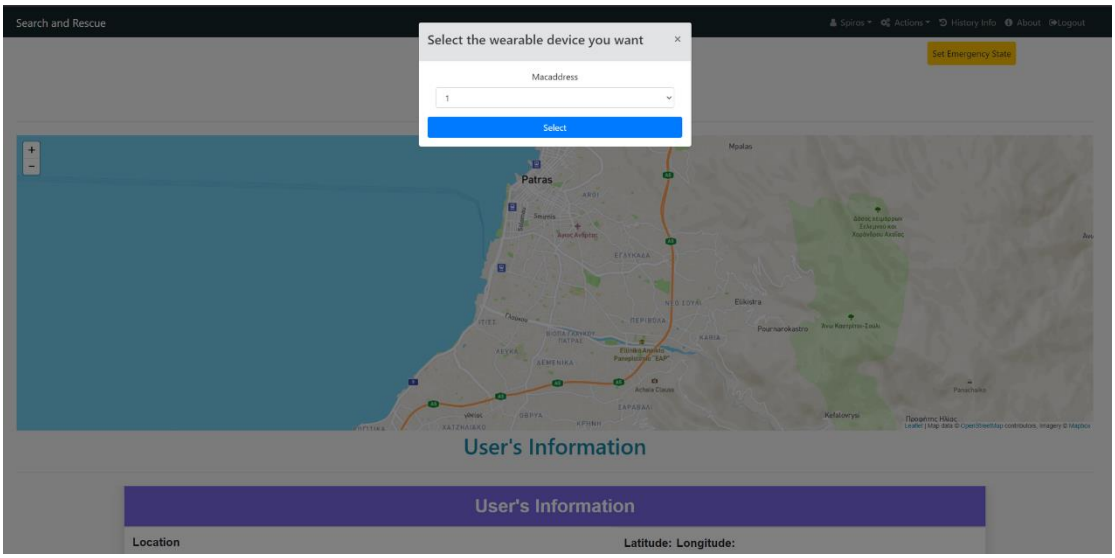


Figure 46 Fixed case.

11. Redirecting between pages

Issue	When a website contains menus and URLs every time the users click on the redirect to different pages. A problem that arises through the evaluation was that many times when a user edits his profile or confirms his answer in a dialog block the website transfers him to a different page. This move violates the good navigation of users on the system. With minor changes in the code, the problem was solved. Unnecessary redirection between pages.
Problem Severity	3
Recommendation	No, reroute between pages when there is no such need.

12. Responsive design

Issue	Evaluators asked if there was the ability for responsive design in the case that the application would be used by mobile users or from a desktop. From their point of view, it is important that every element of the website should respond to every device interface. That was the reason that the study has set the heuristic of responsive design. After some modifications, the menu of the website and the page can fit every possible screen as it is shown in Figure 47 Figure 48. No existing of responsive design
Problem Severity	3
Recommendation	Make the pages and the main menu respond to different screen sizes Table … shows a summary of the problems that arise through the evaluation process and the heuristics that were violated.

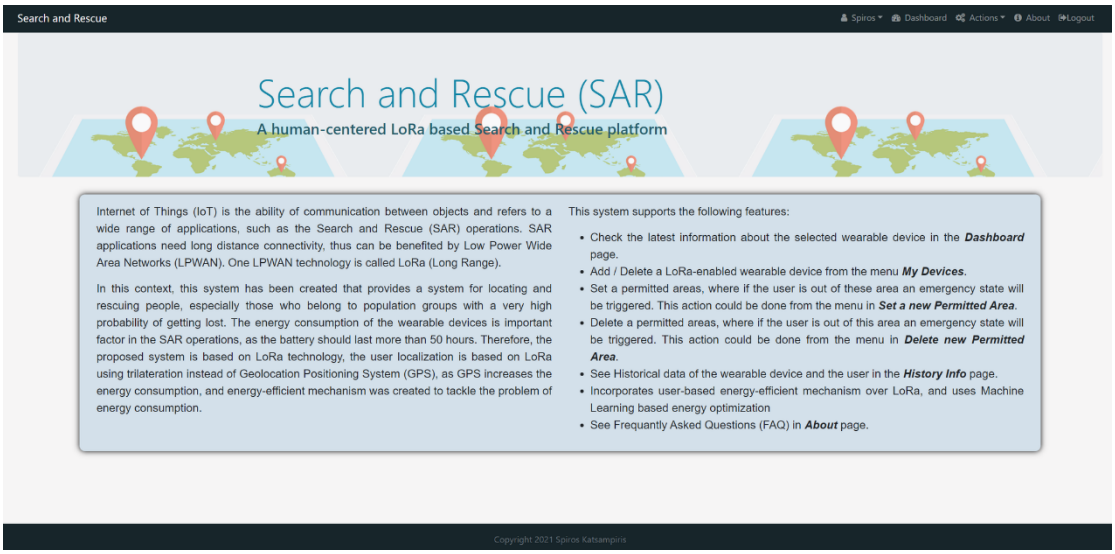


Figure 47 Responsive design for desktop.

Figure 48 Responsive design for more small screens.

The table that follows lists all the problems that arise through the evaluation process as well as it mentions the type of heuristic that was violated

Table 7 Heuristic violated in the evaluation process.

Problems	**Heuristic violated**
1. First screen	*Aesthetic and minimalistic design*
2. Menu actions	*Connection between physical and digital world*
3. Set a permitted area	*Aesthetic and minimalistic design*
4. Check the permitted area	*Consistency of the system*
5. Add permitted area	*Help and documentation + navigation*
6.Registration of new area, wearables list and addition of wearable device	*Error prevention*
7. History	*Aesthetic design*

8. Emergency button	*Connection between physical and digital world*
9. Emergency state	*Visibility of system status*
10. Window segmentation	*Minimalistic design*
11. Redirecting between pages	*Navigation*
12. Design of pages and menu	*Responsive design*

4.3 Usability questionnaire

After the evaluation process takes place a usability questionnaire was given to each one of the participants of the evaluation process and at seven other random participants frequently internet users that were called to test the prototype online and only answer the questionnaire. This happened in order to give the thesis a more professional and integrated value. The study uses a standard questionnaire that could help with the formulation and validation of the questions. More particular the questionnaire that was used was the SUS questionnaire (System Usability Scale). This certain type of questionnaire was created by John Broke that make it available in 1986 as a type of questionnaire that must distribute to evaluators and participants exactly after the testing session [91].

The questionnaire is based on a Likert scale from 0 (strongly disagree) to 5 (strongly agree) (Figure or Appendix). Broke also gave instructions on how to measure the results of the questionnaire: First sum the score contributions from each item. Each item's score contribution will range from 0 to 4 or 1 to 5. For items 1, 3, 5, 7, and 9, the score contribution is the scale position minus 1. For items 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SUS. Generally, a good score is considered a value close to 68. Any score above this value is above average and any score below this value is below average. Also, participants have the choice to add some comments on their own about the system. The word "system" of the questionnaire can be replaced with the words "applications", "website" etc. [92].

The purpose of the work was not to make a statistical analysis but to use the questionnaire as an additional mean of evaluation. After all, the number of participants as it was mentioned above it was small. Considering this situation the answers that are presented are the most characteristic ones. In the first question the 50% participants agree that they wanted to use more frequently a system like Search and Rescue because of the purpose it serves and the rest 50% were divided into neutral and disagree answers. This discrepancy occurred because expect the three participants from the evaluation process that had an academic background the other participants were high school graduates that use frequently websites and internet . In the second question "I found Search and Rescue website unnecessary complex" three of the participants were neutral with a scale of 3, five strongly agree with a 4 scale score and the other two participants answer strongly disagree with a scale of 2 as it is illustrated in Figure 49.

The fact that 70% of the participants score was 3 and above reveals in combination with the comments through evaluation process that i) users were not familiar with a technical website that are aiming in one certain purpose ii) the design of the website many times had some problems that did not help users feel comfortable with its use . Something that arise also from the answer in the questions 8 and 9. In eighth all of the ten responds were neutral while in the ninth (Figure 50) only the 30% of the participants strongly agree (5) about how confident they were with the use of the website when the 70% of the answers were divided into neutral with three responds and 4 disagree. The fact that they were

engaged with internet websites it was sufficient enough to make them feel confident about the use of this particular website.

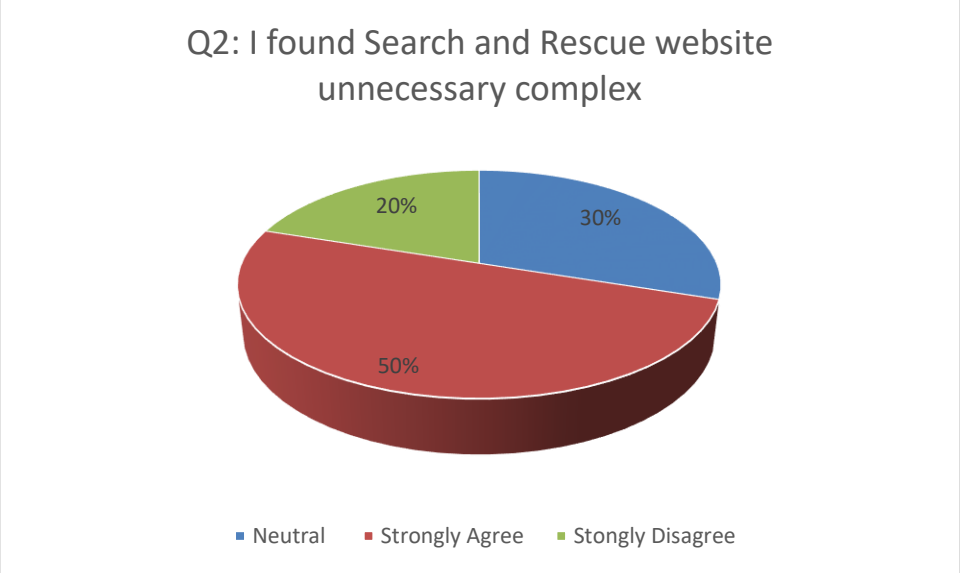


Figure 49 Distribution of answers to question 2.

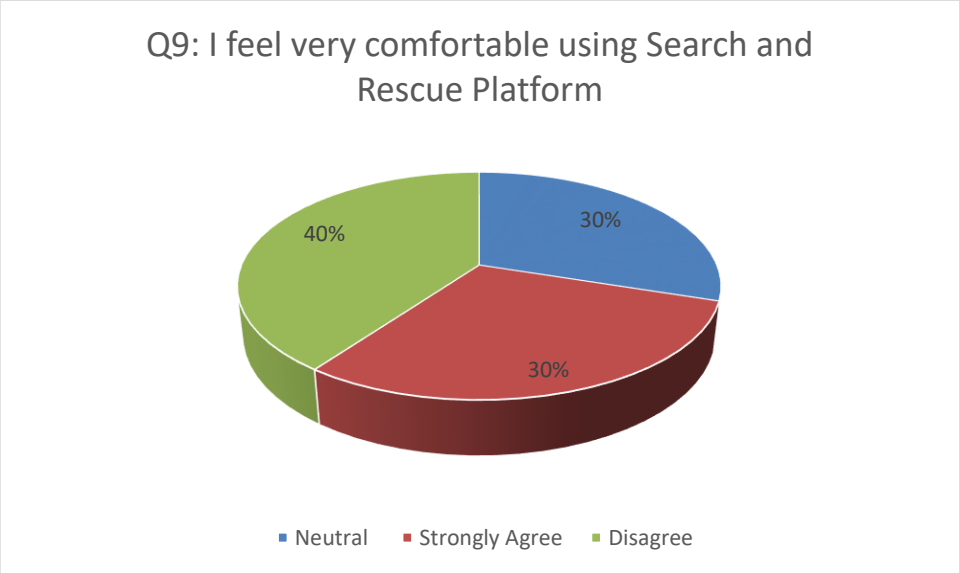


Figure 50 Distribution of answers to question 9

The overall answer in question 4: "I think that I would need the support of a technical person to be able to use Search and Rescue website" was in the section of strongly disagree with 2 (80%) and 1 scale (20%) get the preference of the participants. This type of respond was expected because all the participants were frequent internet users as is shown in the pie of Figure 51.

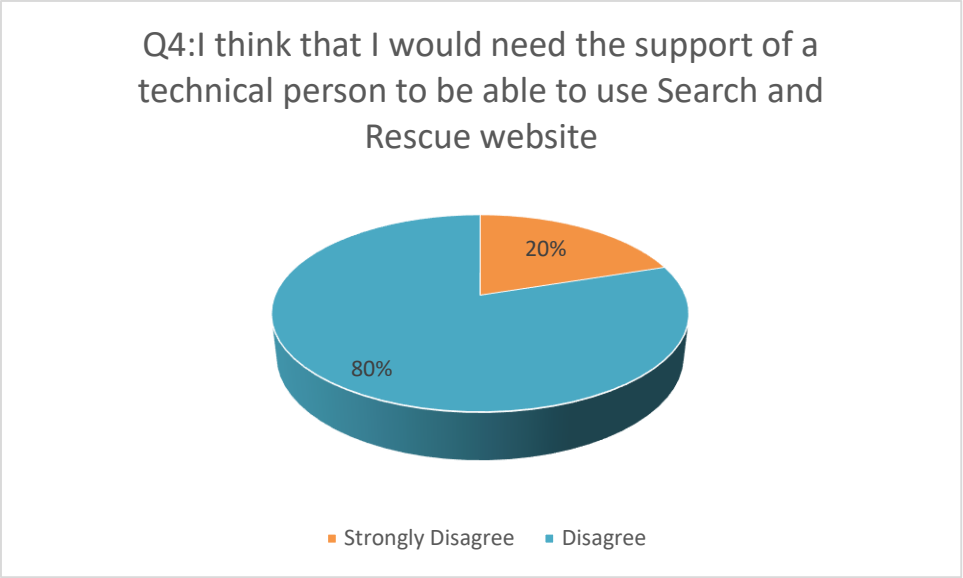


Figure 51 Distribution of answers to question 4

As far as it concerns the question number 6 about the inconsistency of the system the answers were polarized, five participants were neutral (3) two strongly agree (4) and three responds strongly disagree (2) (Figure 52). The design of the system as the evaluation process showed still needed some changes and for this reason this question got answers from all the scales. As far as it concerned questions that were referred to extra heuristics, they did not yield any controversial results. In the comments section users that had participated in the evaluation process point out issues from it while the rest of the participants left some comments about the general design interface and the hope that the platform will help the community if it gets fully functional.

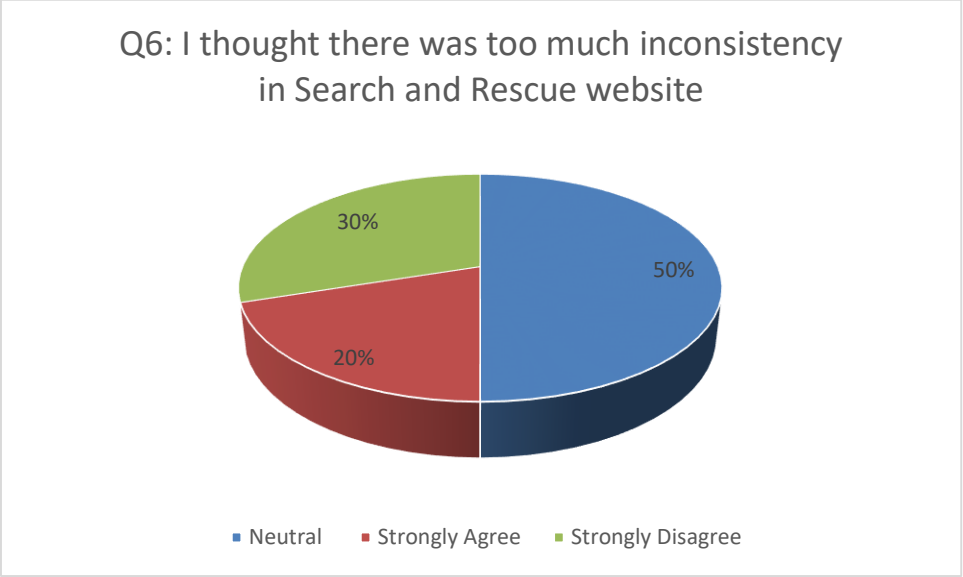


Figure 52 Distribution of answers to question 6.

The score of the questionnaire was 72.5. The general guideline for SUS questionnaires classifies it with grade B, that means that the designed system is good and it also greater than the average grade of 68.

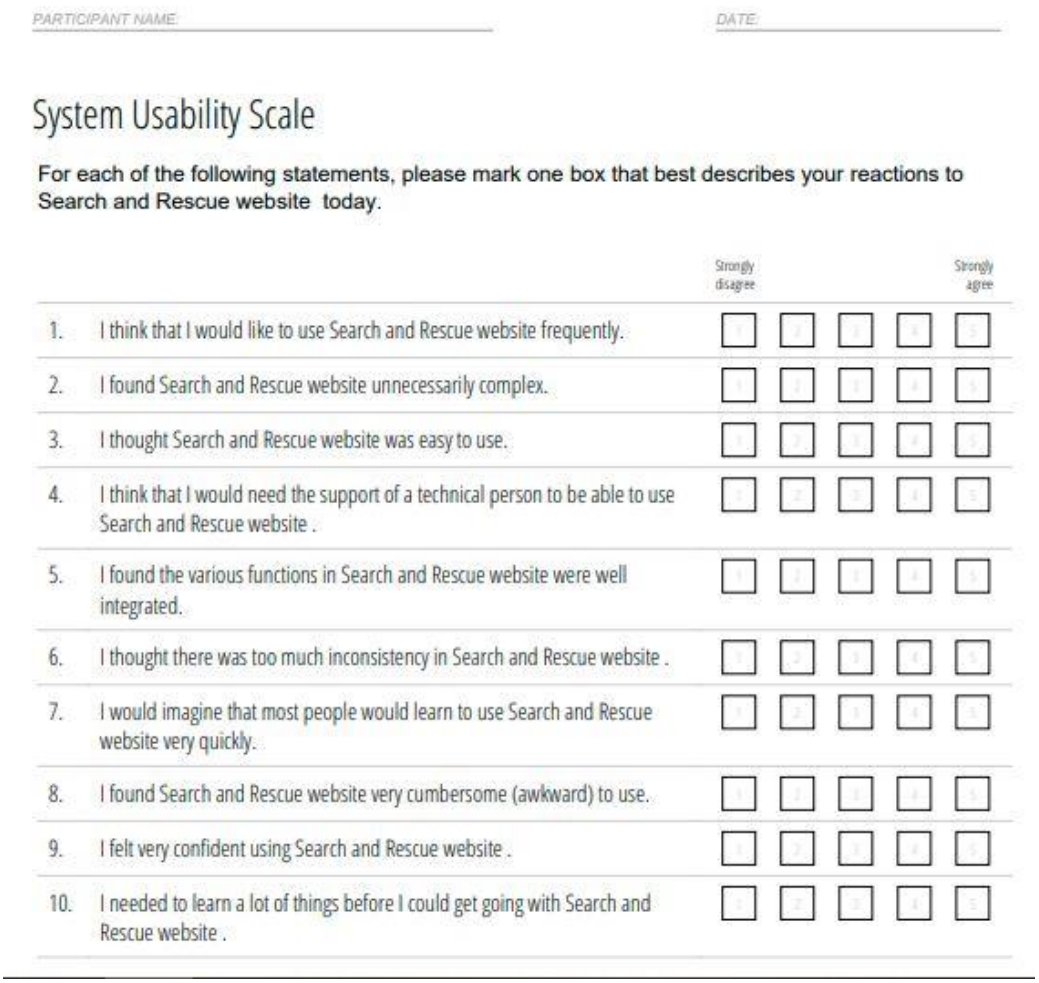
SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Figure 53 The SUS Score interpretation

The score was calculated as follows:

- Sum of odd numbered questions: 4+3+3+3+2=15
- Sum of even numbered questions: 0+4+4+3+3=14
- (15+14)*2,5=72,5

From the evaluation process and the answers from the questionnaire, the study gets valuable insights that helped it in the next design phase: the final construction of the website in a functional form.



PARTICIPANT NAME: DATE:

System Usability Scale

For each of the following statements, please mark one box that best describes your reactions to Search and Rescue website today.

		Strongly disagree				Strongly agree
1.	I think that I would like to use Search and Rescue website frequently.	☐	☐	☐	☐	☐
2.	I found Search and Rescue website unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought Search and Rescue website was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need the support of a technical person to be able to use Search and Rescue website .	☐	☐	☐	☐	☐
5.	I found the various functions in Search and Rescue website were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in Search and Rescue website .	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use Search and Rescue website very quickly.	☐	☐	☐	☐	☐
8.	I found Search and Rescue website very cumbersome (awkward) to use.	☐	☐	☐	☐	☐
9.	I felt very confident using Search and Rescue website .	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with Search and Rescue website .	☐	☐	☐	☐	☐

Figure 54 The questionnaire that was disseminated.

4.4 Web-based application

4.4.1 Technical information

After having introduced the background information, in this paragraph, the technical specifications and process of the web application are explained. First and foremost, the main technical aspect of the application is the web framework called Flask. Flask is a Web Server Gateway Interface (WSGI) web application platform that is lightweight. It is intended to be simple and fast to get started, with the ability to scale up to complex applications. It started as a simple wrapper around Werkzeug and Jinja and has since grown to become one of the most common Python web application frameworks. Flask makes recommendations but does not impose any dependencies or project structure. It is up to the developer to choose which tools and libraries to use. The community has created a plethora of plugins that make it simple to add new features.

As far as the front-end development is concerned HyperText Markup Language 5 (HTML), Cascading Style Sheets 3 (CSS), Bootstrap 4, JavaScript ES6, and jQuery 3.5.1 were used. Bootstrap is a free and open-source CSS platform aimed at responsive, mobile-first front-end web creation. It

includes CSS- and (optionally) JavaScript-based design templates for typography, forms, buttons, navigation, and other interface components. For the Relational Database Management System (RDMS) the SQLite 3 technology has been used. SQLite is a library that runs in the background and implements a self-contained, serverless, zero-configuration transactional SQL database engine. SQLite's code is in the public domain, which means it can be used for any reason, commercial or personal. SQLite is the world's most commonly used database, with more applications than we can count, including many high-profile projects. SQLite is an embedded SQL database engine. SQLite, unlike most other SQL databases, does not have a separate server operation. SQLite reads and writes to standard disk files. A full SQL database, including tables, indices, triggers, and views, is stored in a single disk drive. The database file format is cross-platform, which means that you can freely copy a database between 32-bit and 64-bit systems, or between big-endian and little-endian architectures.

As far as the maps in the web application are concerned the Leaflet has been used. The leaflet is the most widely used open-source JavaScript library for creating mobile-friendly interactive maps. With just about 39 KB of JS, it contains all of the mapping functionality that most developers would ever need. The leaflet was created with the goals of accessibility, efficiency, and usability in mind. It runs smoothly on all major desktop and mobile devices, can be extended with a plethora of plugins, has a lovely, simple, and well-documented API, and simple, readable source code that is a joy to contribute to. Finally, as far as the ML framework used in order to classify the SF value in a LoRa network, the Scikit-Learn framework was used. Scikit-Learn is a framework that emphasizes classical supervised and unsupervised learning algorithms such as the k-NN, SVMs, k-NN, etc. Scikit-Learn is based on the Python numerical and scientific libraries NumPy and SciPy. Table 8 presents an overview of the used technologies.

Table 8 Specifications of the web-based application

Web technologies used	
Web Application Framework	• Flask 1.1.2
Front-End components	• HyperText Markup Language 5 (HTML) • Cascading Style Sheets 3 (CSS) • Bootstrap 4 • JavaScript ES6 • jQuery 3.5.1 • Jinja 3.0
Back-End components	• Python 3.8.5
Maps	• Leaflet 1.7.1
Machine Learning package	• Scikit-Learn 0.24
Database technology	• SQLite 3
Operating System (OS) in the Development	• Windows 10

4.4.2 Database Schema

The database consists of the tables “user”, “allowedregion”, “wearable”, “wearable_info”, “lorapacket”, “send”, and “loragw”. The table “user” contains the information necessary for the users of the system, such as the e-mail address, etc. The table “allowedregion” contains the information of the regions that the user sets, in which if the person having the wearable device exits these regions, then the

emergency state is triggered. The table “wearable” contains the data concerning the wearable device such as the MAC address, etc. The “wearable_info” contains the information about the wearable device’s sensor, and other processed information such as if it is out of the region, etc. The table “lorapacket” contains the information from the uplink packets sent by the wearable device through LoRa. The “sent” encompasses the information of the LoRa transmission, such as the RSSI values and the SNR, and the LoRa GW that listened to the packet. Finally, the system holds the information such as the location of the GWs in the table “loragw”. This information help in the localization algorithm as for the successful estimation the position of the GWs is necessary.

Figure 55 shows the Entity-Relationship Diagram to represent the associations among the tables, and each field of the tables, too. The schematic representation was drawn using the SchemaDisplay python module. SchemaDisplay is based on Graphviz, which is a free and open-source graph visualization program. Graph visualization is a method of expressing structural knowledge in the form of diagrams of abstract graphs and networks. It finds use in networking, bioinformatics, software engineering, database and web architecture, artificial learning, and visual interfaces for other technological domains.

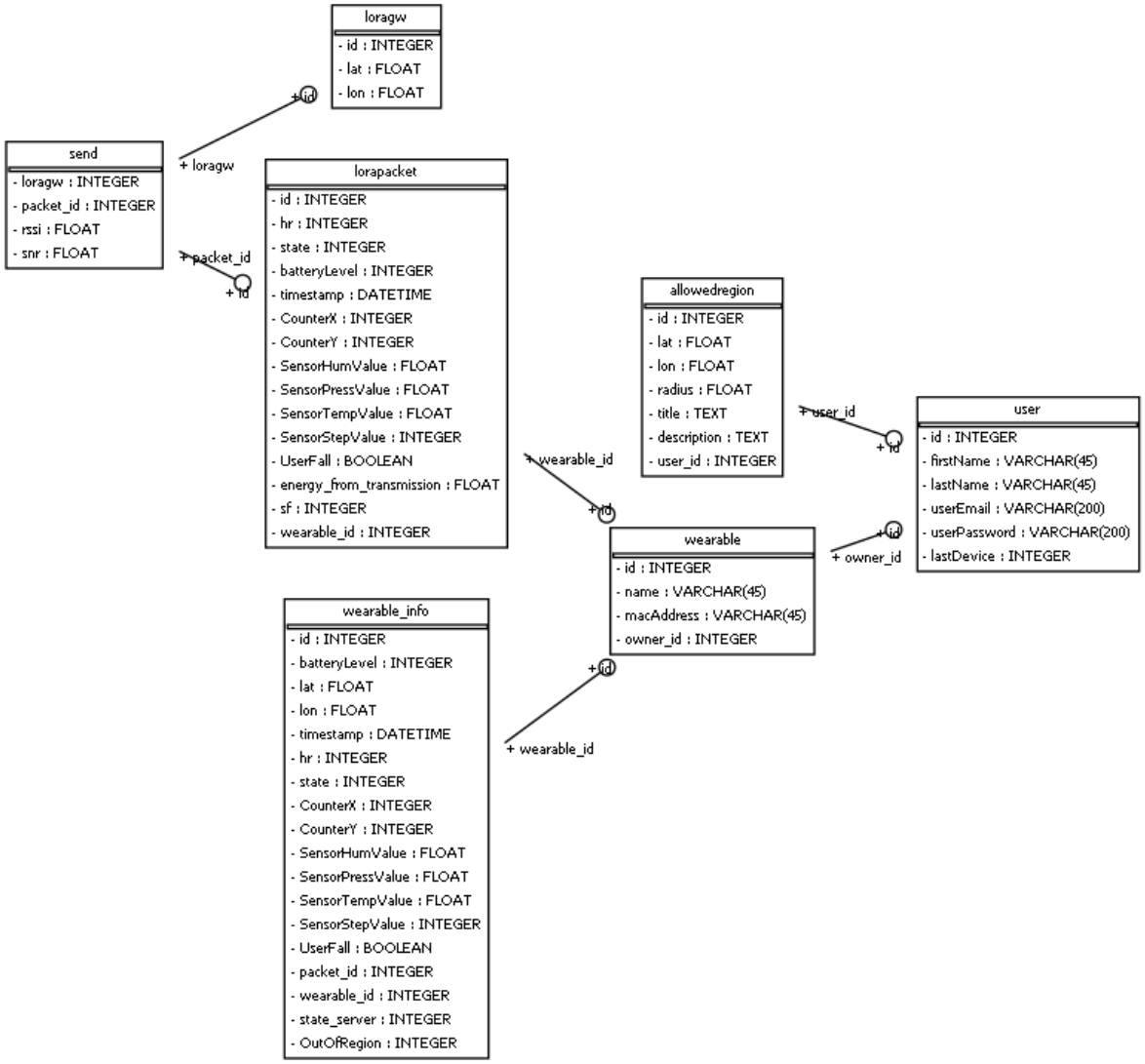


Figure 55 Database Entinty-Relationship Diagram

4.4.3 Project structure

The web application follows a typical Flask-based web application. Specifically, the project directory consists of the essential Visual Studio Code's basic settings folder. As the Flask application may need specific python modules, the thesis' web application was built in a virtual environment. A virtual environment, which is a self-contained directory tree that includes a Python installation for a specific version of Python as well as a variety of additional packages. Different applications, e.g. different web applications, will then use different virtual environments. The necessary files for the virtual environment are in the "env" folder. Furthermore, there are two very common in Flask applications folders, the folders called "static", and "templates". The "static" folder contains files such as the background images and the *.css* files for the styling of the web application. The "template" folder contains the *.html* files that present the skeleton of each web page. Next, the remaining files are the python (*.py*) files that implement the back-end functionalities. Particularly, the python file "*app.py*" implements the initialization features of the web application. The python file "routes.py" contains the URL rules of the web application, and according to the URL the user enters, it is the "routes.py" job to return to the user the appropriate *.html* file. In the python file "models.py" the database structure is defined using the SQLAlchemy python module. SQLAlchemy is a Python SQL toolkit and Object Relational Mapper that provides full SQL power and versatility to application developers. It offers a complete set of well-known enterprise-level persistence patterns, designed for powerful and high-performance database access and adapted into a simple and Pythonic domain language. In the python file called "forms.py", the forms used in the web application are defined, using the WTForms Flask module. In the python files "server.py" and "LoRaLocalization.py" the localization process, the energy consumption mechanisms, and all the helpers concerning these mechanisms and processes are implemented. Finally, in the "*database.db*" the SQLite database is stored.

```
master_site
├─ .vscode
│  └─ settings.json
├─ env
├─ app.py
├─ forms.py
├─ LoRaLocalization.py
├─ models.py
├─ requirements.txt
├─ routes.py
├─ server.py
├─ sqlite_queries
├─ static
│  ├─ img
│  │  ├─ bg.jpg
│  │  ├─ earth.png
│  │  ├─ map_opacity.png
│  │  └─ user_default.png
│  ├─ style.css
│  └─ svm_final_model.joblib.pkl
├─ templates
│  ├─ about.html
│  ├─ base.html
│  ├─ dashboard.html
│  ├─ editProfile.html
│  ├─ history.html
│  ├─ index.html
│  ├─ login.html
│  ├─ middle_page.html
│  ├─ mydevices.html
│  ├─ profile.html
│  ├─ setAllowedRegion.html
│  ├─ showAllowedRegion.html
│  └─ signup.html
└─ database.db
```

Figure 56 Project structure using markdown.

4.4.4 Browsing the Web-Application

When a user enters the website, the homepage is the first thing that is presented. A text presenting the System and the options are presented. the user can login or signup if no account was created before. The home page is presented in Figure 57. On the signup page, the users encounter a form that prompts the user to enter the credentials such as the First Name, Last Name, email, and Password. Having created an account, the user then can log in, through the login page, in which there is a form that asks for the email and the password details. Signup and Login pages are presented in Figure 58 and Figure 59 respectively.

When the user logs in, a page is showed with a personalized message to the user informing about the last selected wearable device. This page is presented in Figure 57. Then the user is redirected to the Dashboard page. On this page the user can find a leaflet map where the latest position of the person has the wearable device, having a tooltip showing the current state of the user (e.g. normal state or emergency state) and the timestamp of the latest LoRa packet. Moreover, below the map, a table is presented where the latest information of the user and the sensor measurements such as the HR, and the pedometer. The Dashboard page is presented in Figure 61, and Figure 62. Also, there is a button with which the user can click it in order to set the wearable device to the emergency state, or to cancel the emergency state and return to the normal state again.

Now, if the user wants to check the details, in the navigation bar choosing the My Profile option in order to see the basic information such as the email and the name, as presented in Figure 63. If changes need to be made, then these changes can be done in the option Edit Profile (Figure 64). Also, the user can manage the registered wearable device through the web page called My Devices (Figure 65). On this page, the user can add a new device by clicking the “Add a new device” button (Figure 66), select a wearable device by clicking the “Select Wearable Device” button (Figure 67) delete a device by clicking “Edit”-> “Delete device”(Figure 69) or change the information of the wearable device, by pressing the “Edit” button in the right of each wearable device entry (Figure 68).

If the user needs to add a new region in which the person suffering from dementia or ASD should move, and if this person exits this region then the emergency state is triggered. The user should click “Actions” ->”Set permitted Area”. On this web page, there is text giving guidelines to the user on how to add a permitted area (Figure 69). Next, there is a map, in which the user can draw a circle, representing the permitted area. Then a tooltip type form is presented in which the user can add a Title and a Description (Figure 70). Furthermore, the user can check the previously added permitted areas through the “Check your permitted areas” (Figure 71). On this page, the user can see in the map the boundaries of the permitted regions and by clicking on the circles the user can see the respective details and information. Also, the user can check the packet history via the “History” webpage. In this webpage, the user can see the history of the packets received in a tabular way (Figure 72). In the navigational bar the user can spot and click the option “About” where the user can see the Frequently Asked Questions (FAQ) (Figure 74). Lastly, the user in order to logout has to click on the logout option in the navigational bar. When the user clicks on the logout option a popup modal is shown that asks for the user’s confirmation (Figure 73).

Figure 57 The Homepage.

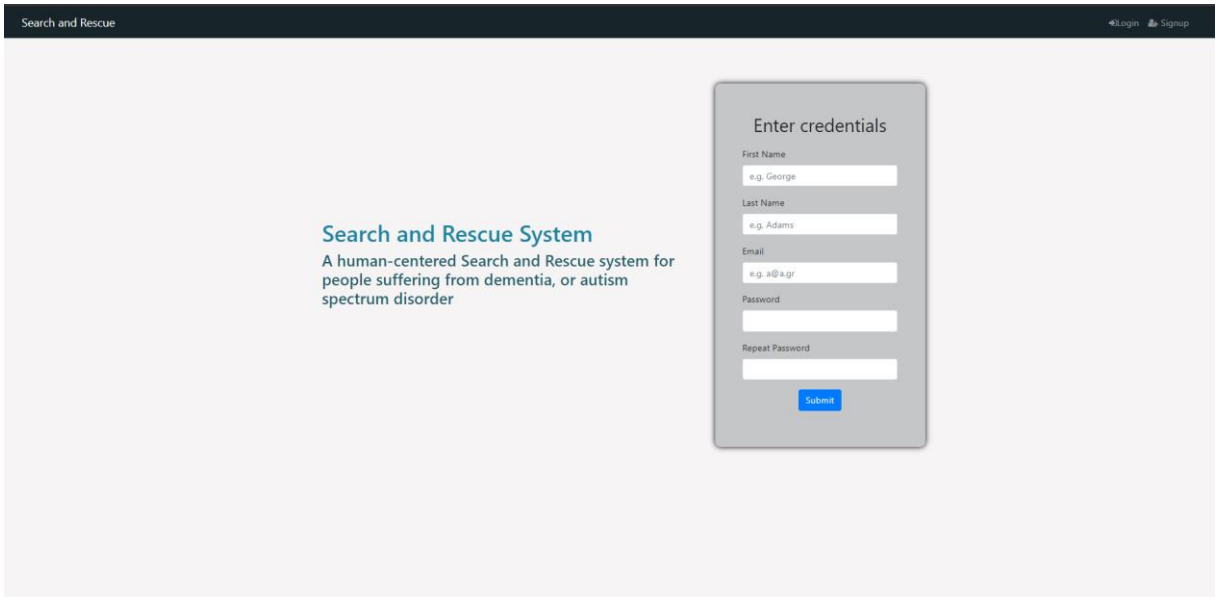


Figure 58 The Signup page

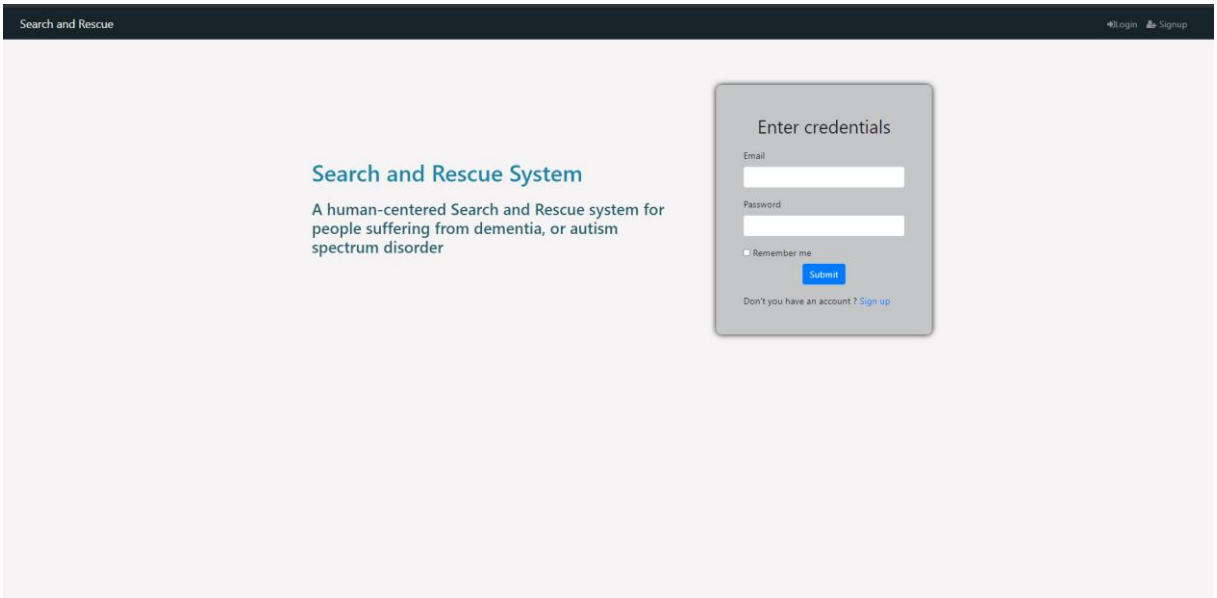


Figure 59 The Login page.

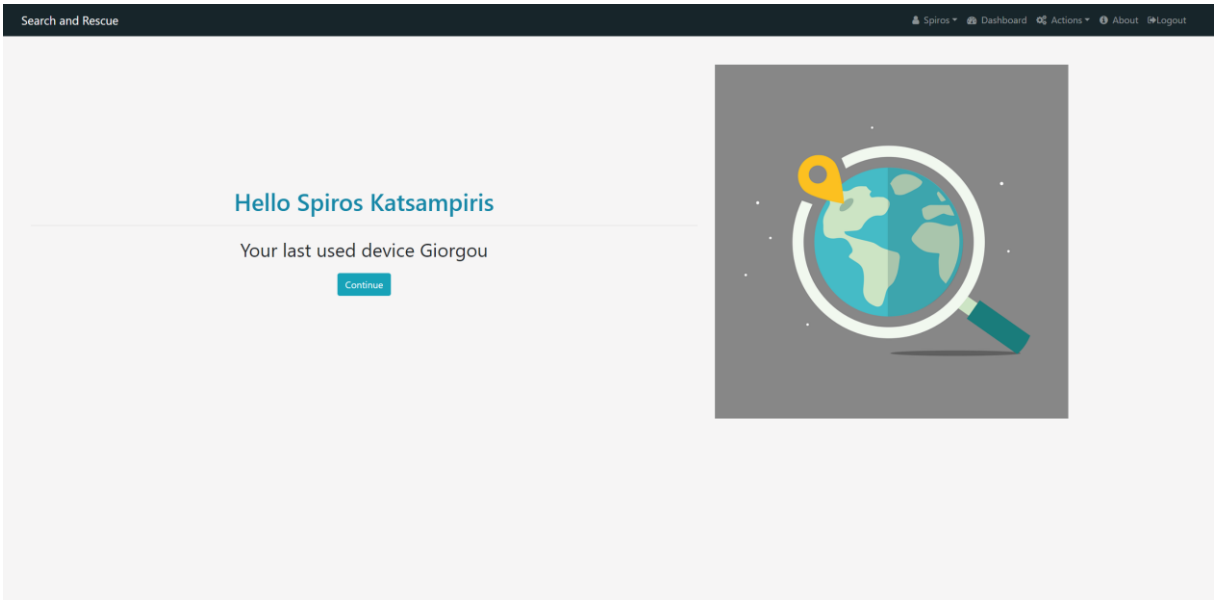


Figure 60 Page showing personalized messages to the user.

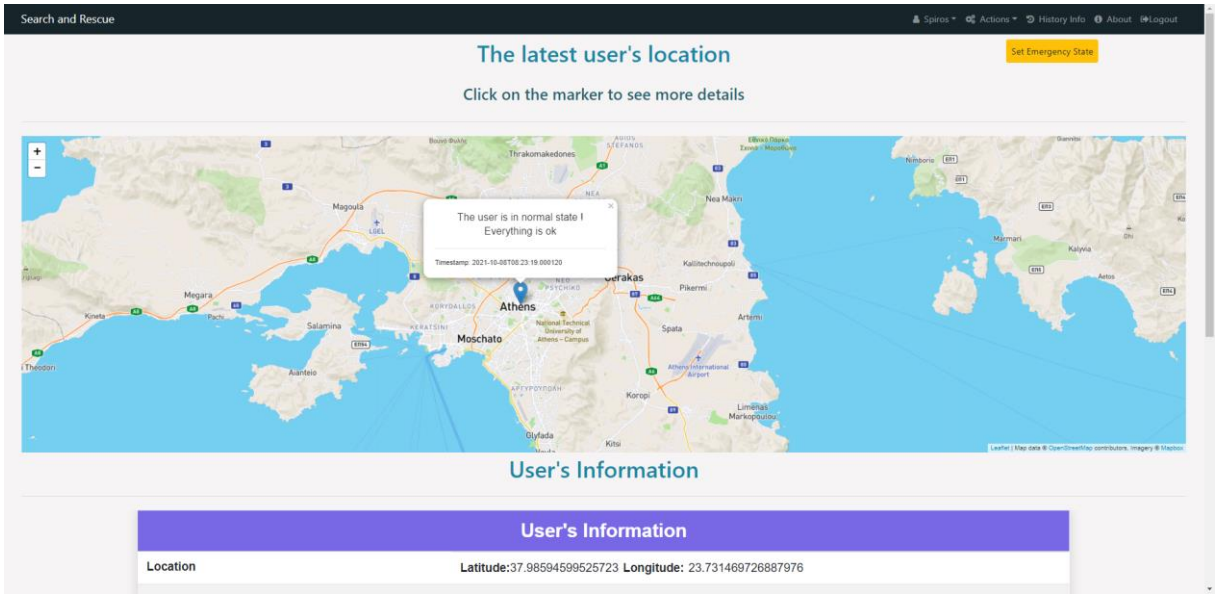


Figure 61 Dashboard page 1.

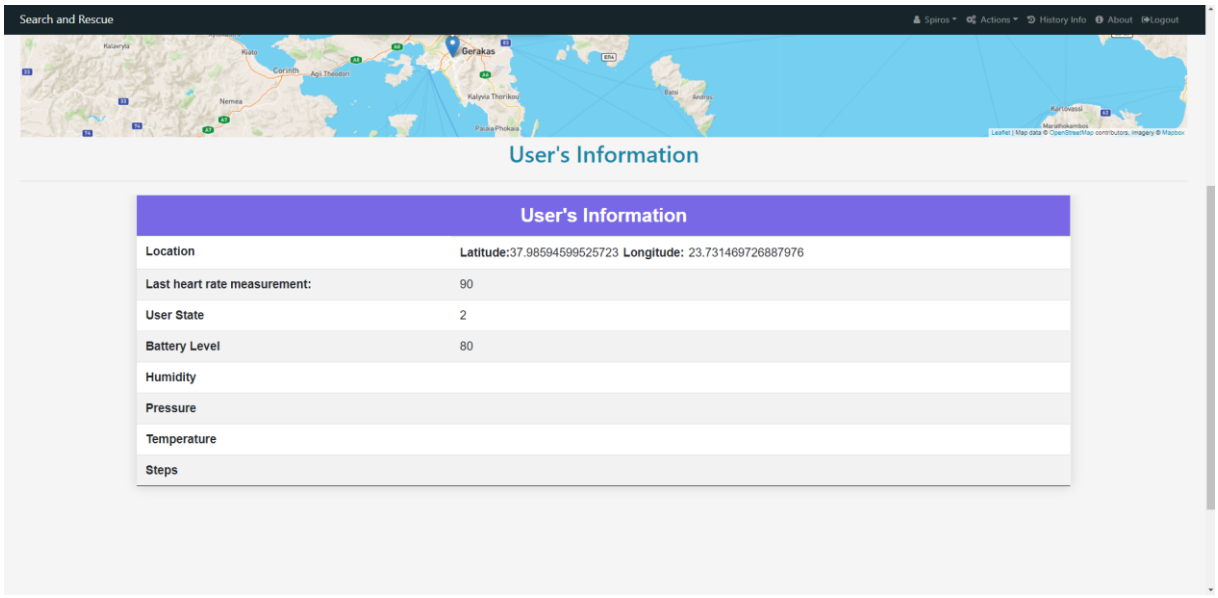


Figure 62 Dashboard page 2.

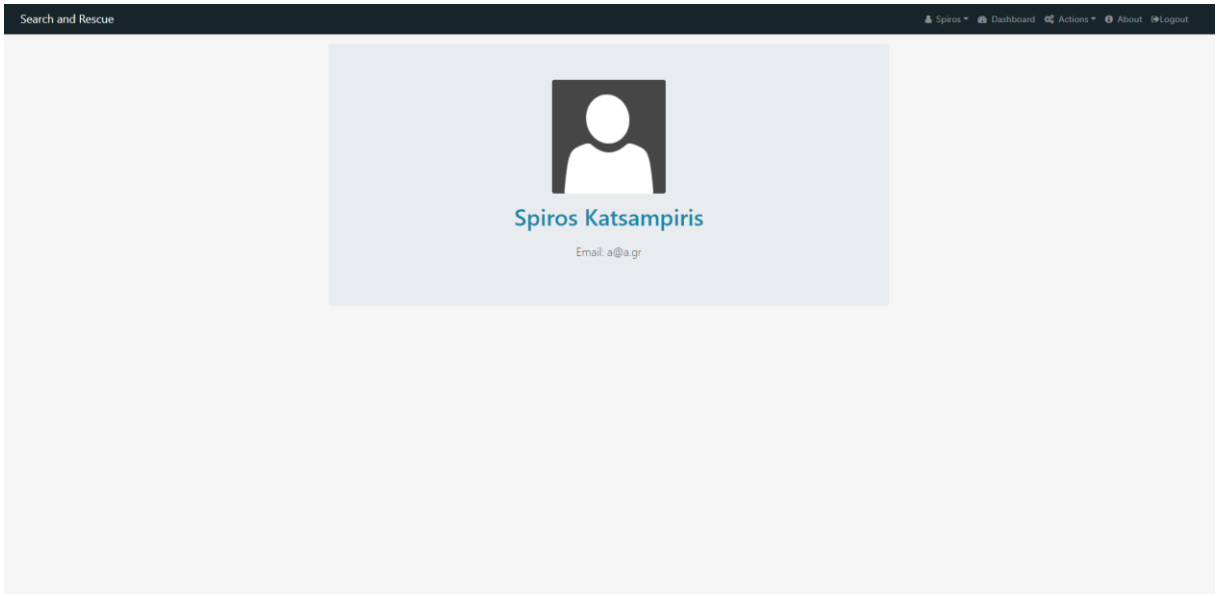


Figure 63 My profile page.

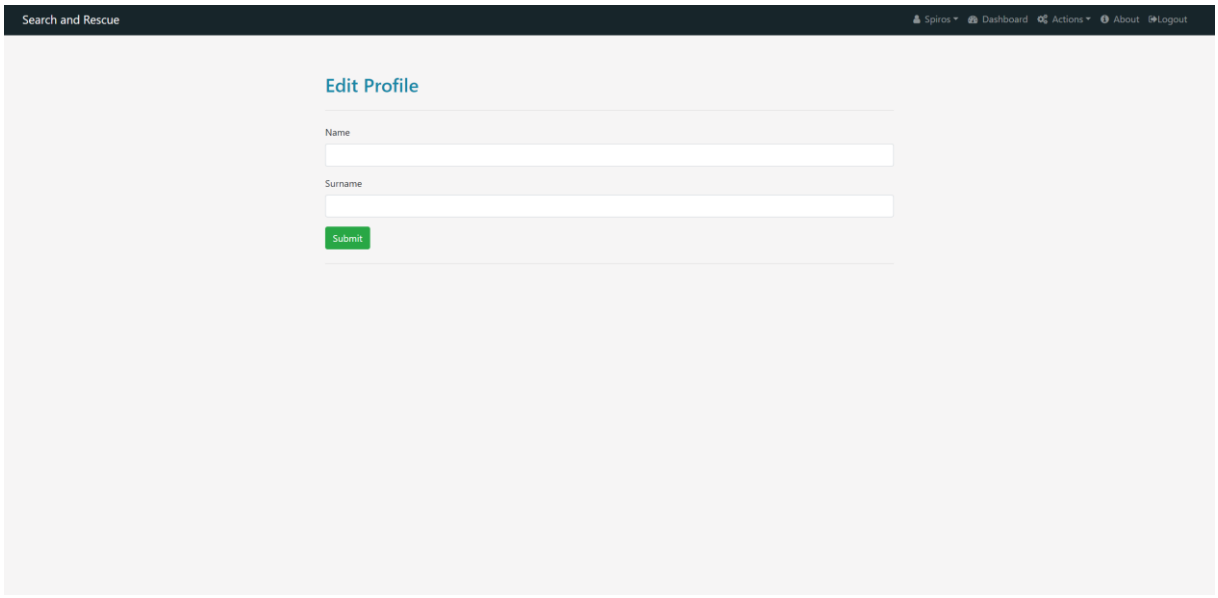


Figure 64 Edit Profile page.

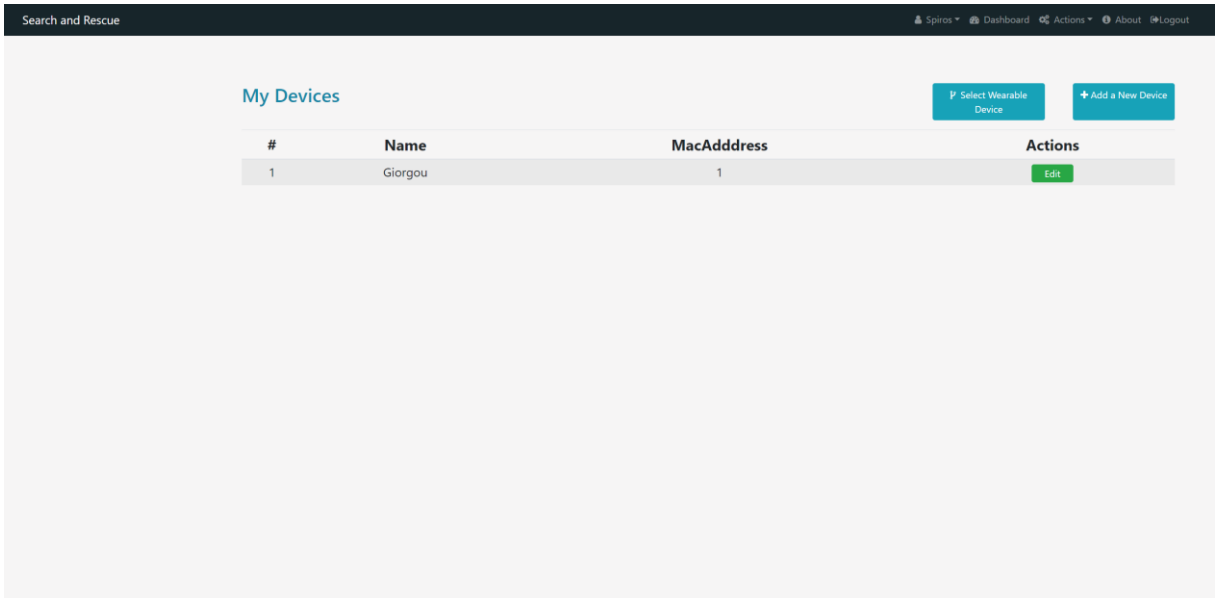


Figure 65 My Devices web page.

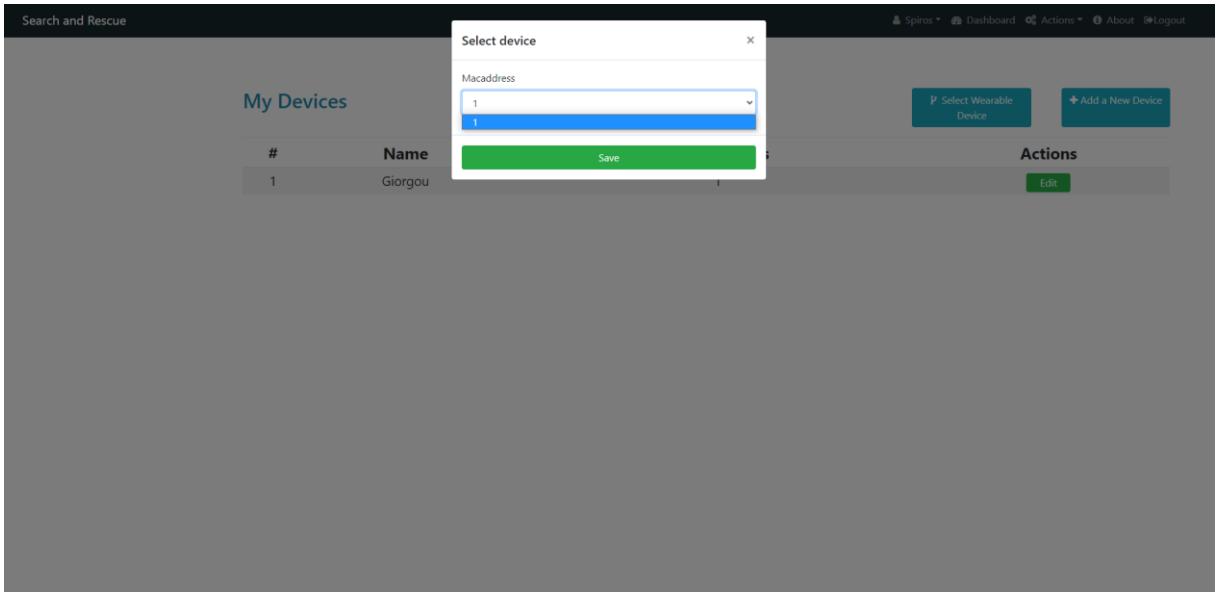


Figure 66 Select a wearable device in My Devices web page.

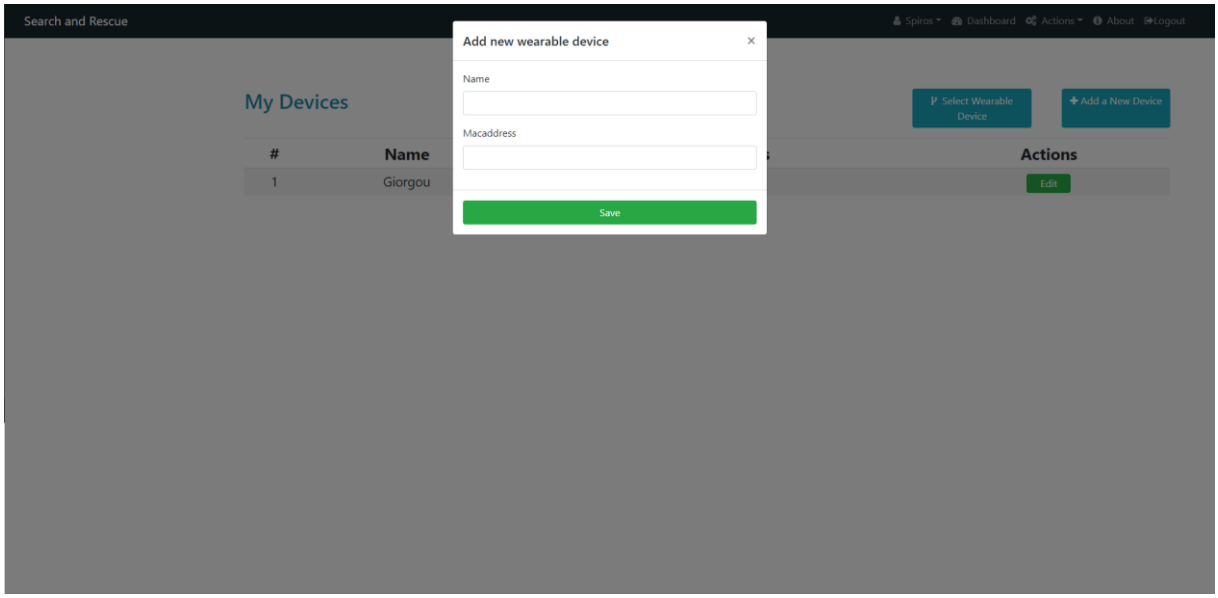


Figure 67 Add a new wearable device in My Devices web page.

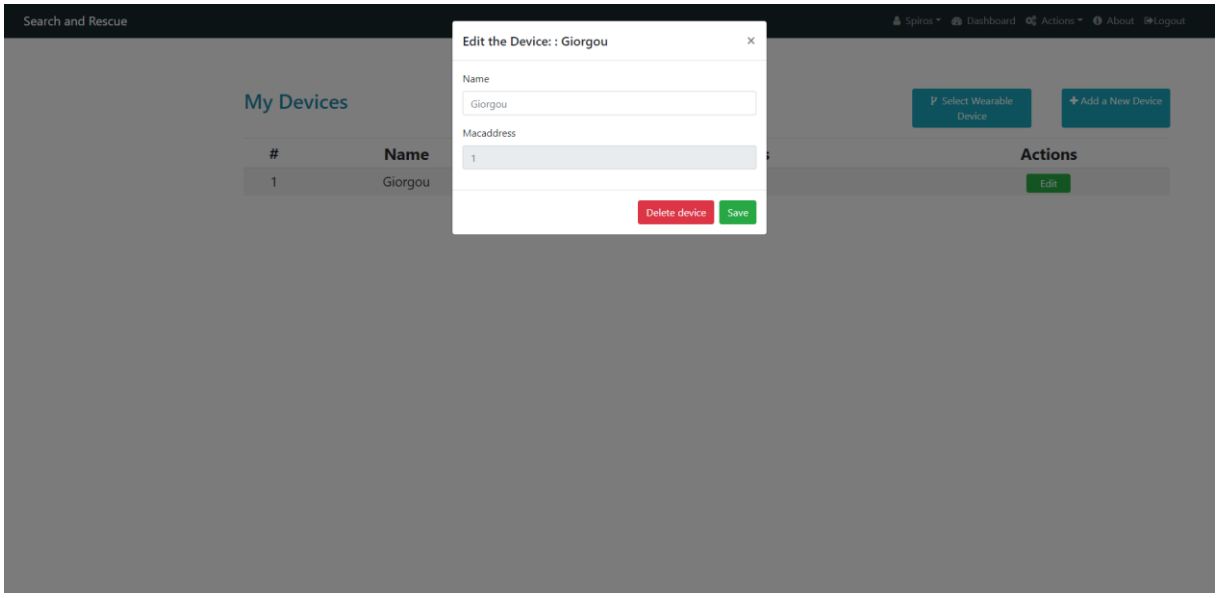


Figure 68 Changing the wearable device's information.

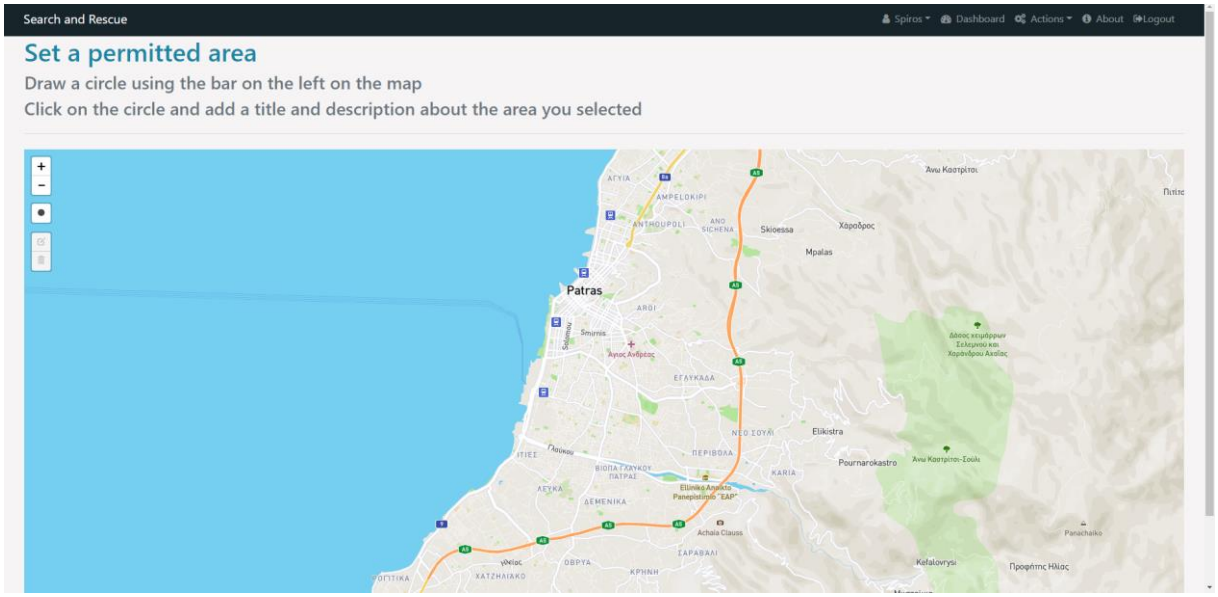


Figure 69 Set a permitted area.

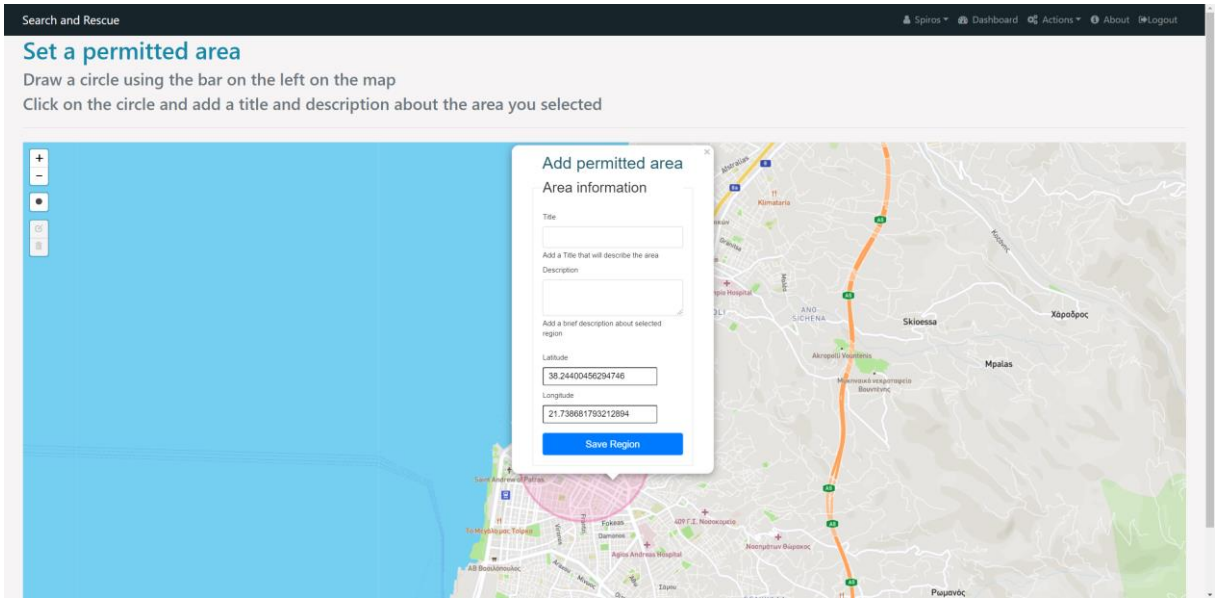


Figure 70 Set a permitted area - Form

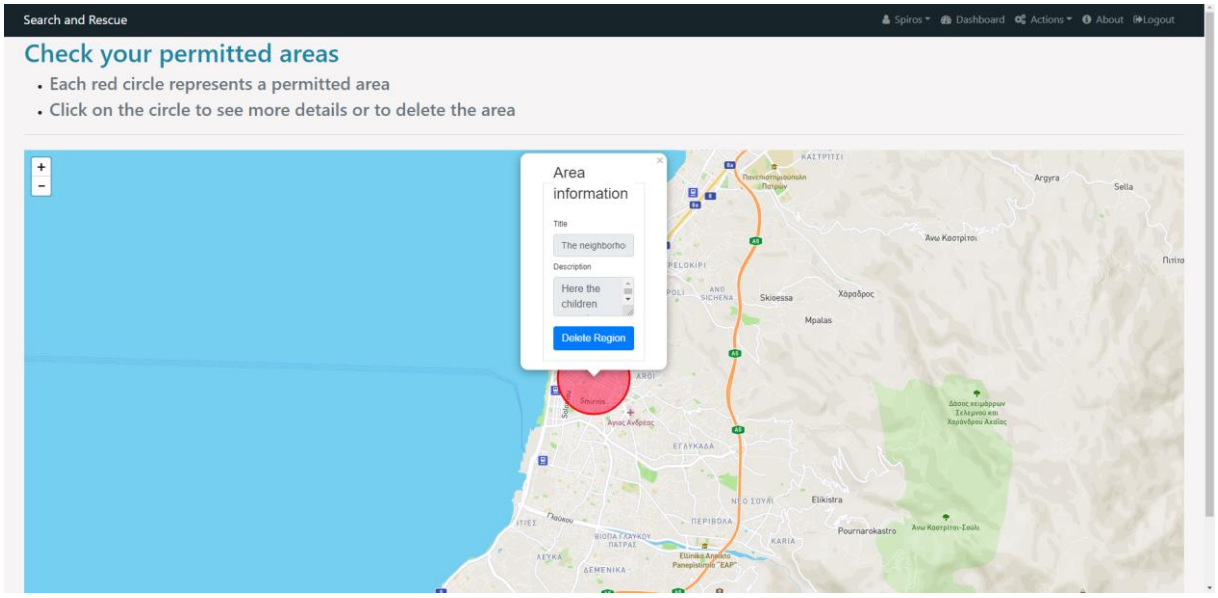


Figure 71 Check the permitted areas.

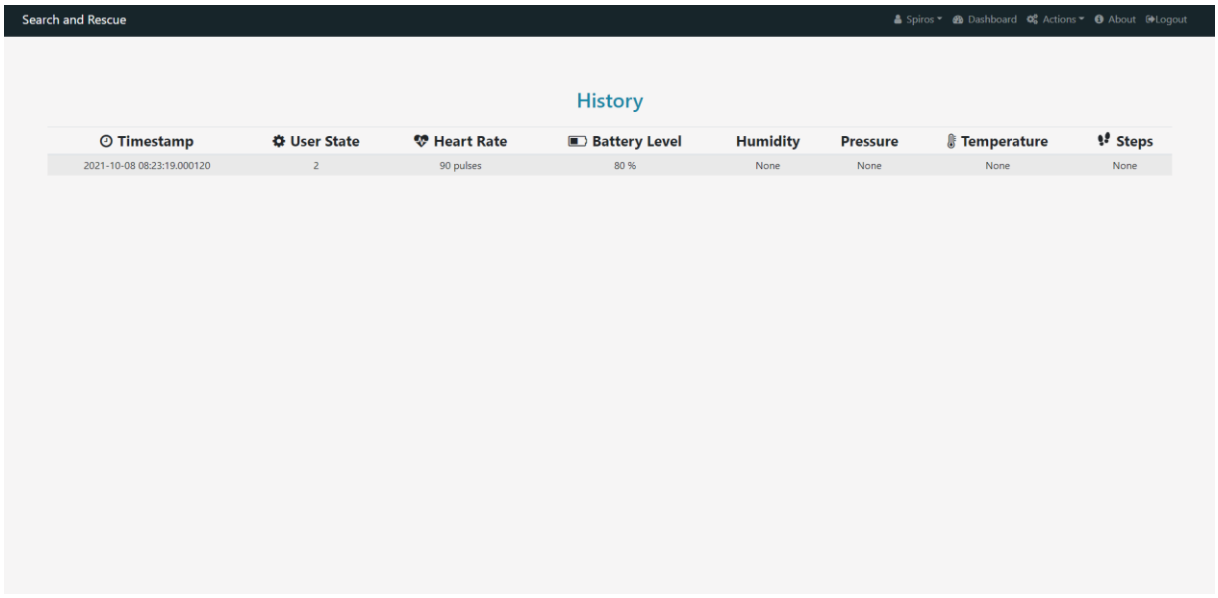


Figure 72 History web page.

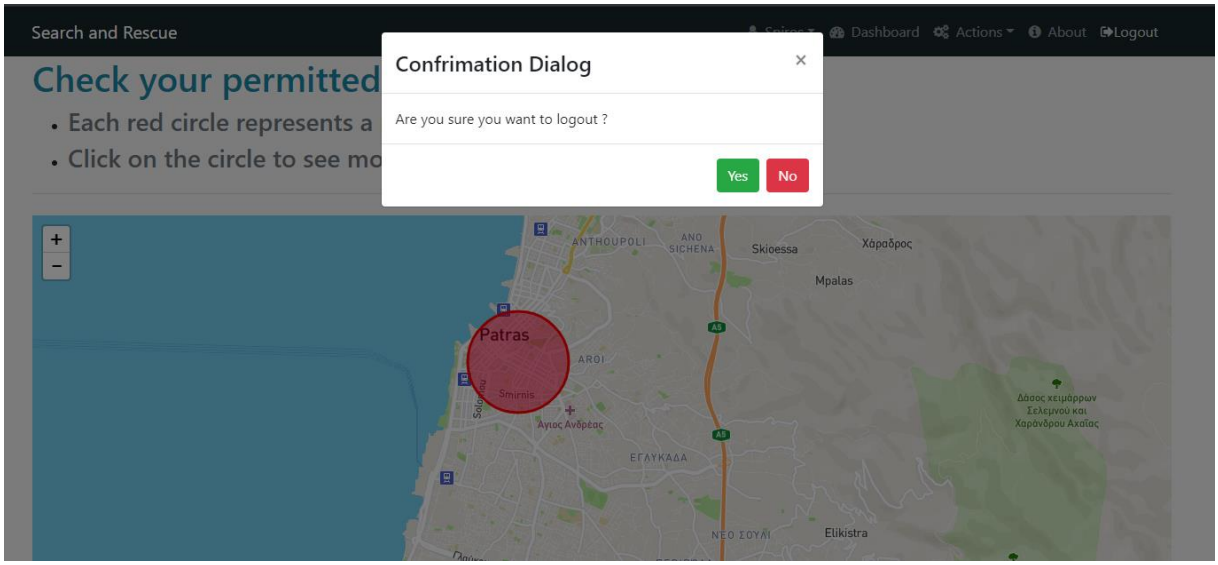


Figure 73 Logout popup Confirmation Dialog.

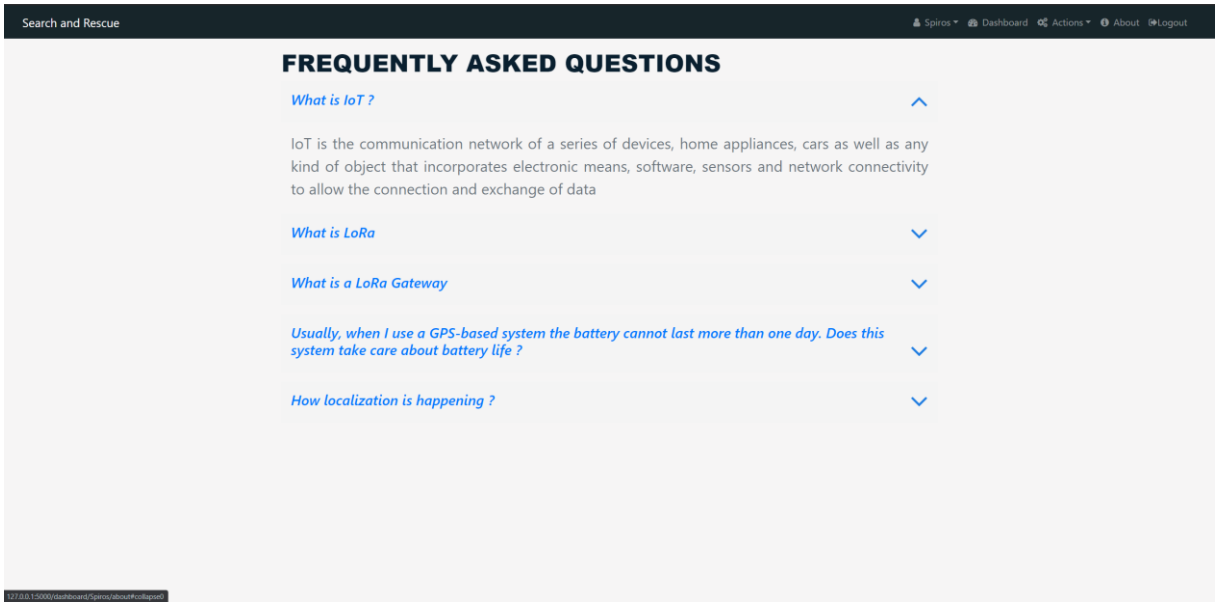


Figure 74 About page.

5

Conclusion and Future Work

"Great is the art of beginning, but greater is the art of ending."

– Henry Wadsworth Longfellow

5.1 Conclusion

As mentioned in the previous sections, the need for an IoT-based SAR system has been understood and explained, in order to save the lives of people that have a high probability to go missing. The benefits of such a system can be of paramount importance for the person that goes missing, for the peace of mind of the caretakers and the people that are responsible for the people such as in the case of people suffering from dementia or ASD. Also, emerging technologies such as the LoRa technology can help to create SAR systems due to many factors, such as it can transmit over long distances and keeps the energy consumption at low levels.

At this point, in this thesis, the concept of SAR operations has been holistically discussed and studied, concluding to many proposals on many levels. Firstly, in order to cope with the energy consumption factor, two energy-efficient mechanisms have been proposed, one is based on the user states, and the second one is based on ML algorithms. After understanding and pinpointing the user's states namely the normal state and the emergency state a mechanism that changes the sensors' and transmission frequency according to these states and according to the battery level of the ED. In all the scenarios that were tested, and with the different ED mobility models the results showed a vital reduction in energy consumption. Finally, a thorough examination of the classification algorithms was presented and the integration in the context of SF assignment was studied. The results were promising showing an open research area.

Secondly, the localization algorithms in LoRa networks have been discussed and the algorithm used in the thesis has been described. Finally, a web application was created that constitutes a working prototype of SAR operations systems. The aforementioned system was created utilizing the Flask web application framework, a very widely-used web framework. Furthermore, the system was created and evaluated following the guidelines of the HCI field. Initially, The concept of personas, scenarios, and the general design phase was presented relative to the proposed web application as well. Two interviews were quoted: one with an expert in the domain and one supervisor from Child's Smile organization. More specifically, the evaluation process was presented step by step with the description of the area and the way in which it took place. One by one all the problems that evaluators pointed out, the heuristics

that were violated as well as the recommendation for a better design implementation were presented. Furthermore, a questionnaire was disseminated and the results were presented.

5.2 Challenges

The implementation of such a system has some major challenges to deal with that can be the distance, the architecture of the system, or the methodology that the HCI follows. Due to long distances and lack of testbeds, one of the issues arising from the long-range contact characteristic of LPWAN is conducting a proper evaluation involving actual experiments. A fair test with wearable devices is necessary to be given to a large number of people. Also, as the LoRa technology doesn't support low latency and high data rates, the user should wear these devices for a long period of time. Furthermore, stabilizing the background variables in an urban setting is challenging such as the path propagation loss, the multi-path effect, etc., and using a different environment (e.g., in a laboratory) does not always capture the real-world scenarios that are necessary. Another problem is that, even in urban areas with numerous GWs, there is still the risk of getting out of range and losing connectivity. Usually, researchers use their own GWs to conduct experiments, but this can be time-consuming and limited in terms of coverage area, and the cost can be very high. Another issue is the number of EDs that a LoRa network can support to the platform and to the end-user, and the collisions that can be occurred if many devices transmit simultaneously. All these factors impose limitations in the HCI research for example ethnography research could be difficult to be used due to the wide-area elements of such systems and technologies.

Also, a better evaluation of the proposed system was not feasible during the COVID 19 pandemic. The task of finding a representative sample in addition to the aforementioned challenges was even more difficult. Not only the limitation of people's interaction during the pandemic was a difficulty for such research, but also the curfews that were in place had imposed more difficulties. This leads to permission denial to move to permisses where people suffering from dementia are living. Even for people with such diseases who do not live in an institution that helps them, was difficult to reach them, as their family had their worries about the transmission of the deadly virus.

As far as the HCI field is concerned, the biggest challenge is the right evaluation method that would give reconmendations through the design of the final version of an application. Designers seek a way to make an application easy to use and efficient wherever its purpose is: an application for food delivery or an application that can save the population at risk. In order to achieve this, they have to evaluate the prototypes of the application in the most reliable way. Another challenge refers to meaningful human control. In any case, the goal is that humans must have control of the system and not let automation take control of their lives. Furthermore, an important challenge is the topic of privacy and ethics. Many of the applications from the HCI world are using data from people like the id for their devices, their geolocation data, their email, passwords, etc. All those elements are considered as personal data and there is a very thin line whereas an application and its creator can use them or he actually violated them to make its application more efficient.

5.3 Future Work

Except for the Search and Rescue system, there is also another try of LoRa networks technology in the domain of IoT services that could assist humans in their everyday life. Other LPWAN technologies that are left to be examined as future work are the NB-IoT, SigFox, etc. Also, with the advent of the 5G technology, new potential will emerge for this kind of application. The heterogenicity

of the 5G combined with the high speed, low latency can accelerate the integration of these applications to more people and increase the reliability of the data transmissions.

Following the completion of the thesis implementation, a large-scale analysis will be conducted to validate the mechanisms presented with actual data from hundreds of users. In addition, future studies will include investigating and improving more sophisticated algorithms and strategies, such as using neural networks in the context of energy conservation, packet loss in LoRa networks, and other metrics. Also, an investigation in the ML framework for LoRa network optimization will be conducted taking care of the TP something that was ignored in this thesis scope and remained intact through the simulation process. In future work, we will use a similar approach to solve the energy conservation dilemma. To begin, the authors will simulate the processes and use datasets produced during the simulation process.

The focus of HCI research is now on health monitoring applications that can be used by mobile phone users. Until today those applications have the form of a personal guide that alerts users about their next medicine when they have scheduled an appointment with their doctor etc. Researchers from the HCI field search ways in which a health mobile application will fit into the daily life of mobile phone users in a real-world case. There are two restrictions in this try: the proximity of the phone as surveys have shown that when a user is at his home 50% of his time the mobile phone is out of his arm’s reach for several reasons (the phone is charging, the user takes a bath, etc). The second restriction has to do with the program of the user and the interruptions from his phone. Mobile proximity and usage are higher in the mornings when people are in their works or take a break for their daily routine drinking a coffee. Also, users seem to be disturbed by alerts and messages from various applications from their phones, and for this reason, they often make use of silent mode. So researchers propose health applications with pleasant alarms that at the same time will measure the phone's proximity to the user and alert the application when he is out of a close range.

Appendix A: Research papers published

Journals

- C. Bouras, A. Gkamas, **S. A. Katsampiris Salgado**, and N. Papachristos, "A Comparative Study of Machine Learning Models for Spreading Factor Selection in LoRa Networks", Journal of Wireless Networks and Broadband Technologies (IJWNBT), IGI Global, 2021.
- C. Bouras, A. Gkamas, and **S. A. Katsampiris Salgado**, "Energy efficient mechanism for LoRa networks," Internet of Things, vol. 13, p. 100360, Mar. 2021, doi: 10.1016/j.iot.2021.100360.

Conferences

- C. Bouras, A. Gkamas, **S. A. Katsampiris Salgado**, and N. Papachristos, "Spreading Factor Selection Mechanism for Transmission over LoRa Networks", in 28th International Conference on Telecommunications (ICT 2021), 2021.
- C. Bouras, A. Gkamas, and **S. A. Katsampiris Salgado**, "Energy Efficient Mechanism over LoRa for Search and Rescue operations", in The 2021 International Symposium on Networks, Computers, and Communications (ISNCC'21), Dubai, United Arab Emirates.
- C. Bouras, A. Gkamas, and **S. A. Katsampiris Salgado**, "Exploring the energy efficiency for Search and Rescue operations over LoRa", in 11th IFIP International Conference on New Technologies, Mobility, and Security (NTMS 2021), Paris, France.
- C. Bouras, A. Gkamas, **S. A. Katsampiris Salgado**, and N. Papachristos, "Spreading Factor Analysis for LoRa networks: A supervised learning approach", in 9th World Conference on Information Systems and Technologies (WorldCIST'21), 2021.

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