HCI Preliminary Study and Implementation for a LoRa based SAR System

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***Abstract*— The subject of this paper is the study and implementation of a Long Range (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, or disease in the autism spectrum, 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. In this paper, aspects of the human-computer interaction were taken into consideration in contrast to the majority of the related papers, and the proposed system is evaluated using heuristic evaluation and questionnaires.**

Keywords—IoT; LoRa; LPWAN; UX; HCI

I. 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. Furthermore, according to a study, about half of children with Autism Spectrum Disorder (ASD) have attempted to elude parental control at least once and eventually go missing while walking.

In this context, the 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. The technologies are ranging from gait and behavior analysis to GPS trackers that assist in the localization of the missing. As a result, such systems have some requirements that should be met to operate 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. This class is called Low Power Wide Area Networks (LPWAN) and the main characteristics of this class is the low energy consumption, the long-range communication, and the low cost. One of the most important 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 a HCI standing point, such systems have a lot of parameters that affect the user experience, because 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.

Many systems have been proposed for SAR systems. In [1] the authors studied a LoRa based system, and in [2] have studied a LoRa based system focusing on localization algorithms for LoRa. In contrast to the above works, in this paper, we focus on the human-computer interaction aspects of such a system. The authors of [3] employ IoT in conjunction with an Unmanned Aerial Vehicle (UAV) for SAR missions. Specifically, the usage of UAVs provides supporting information to rescuers. In this paper, the focus is given on wearable device-based localization monitoring, without the costly UAV technology employed. In [4] the authors provide a study on the feasibility of machine learning algorithms used to GPS data to anticipate the potential paths of dementia patients. The authors propose that prediction models for each individual may be generated based on the frequency with which the user wears the wearable device, and therefore GPS data is gathered. In addition, in the [5], the authors built a GPS-based fall detection system to broadcast the position where the individual fell. The primary drawback of the works [4][5] is that, in contrast to LoRa, GPS quickly consumes the battery of the IoT device.

The goal of this research work is to create a SAR system based on LoRa using wearable devices. In contrast to other similar systems, in this paper, a human-centered approach has been followed to understand the stakeholder's requirements and needs, following the *Norman Interaction Model* and *Design Thinking* frameworks. Moreover, heuristic evaluation was conducted, and a small-scale experiment was conducted with a small number of participants and a questionnaire was disseminated to them. It is important to note that the experiment's goal was not the fully understand the users, so the results did not reach statistical significance but to expose some more usability issues to be improved in the next iterations. Also, some mechanisms of energy consumption were integrated from our previous works such as [6]-[10].

The structure of the paper is the following: the next section explains the motivation of the work. Section III gives an overview of the IoT concepts and explains the wireless technology that is used. Section IV gives an overview of the SAR domain, for a better understanding of the reader about the scenario use. Section V provides information about the HCI-based procedure of the implementation. In section VI the system parts and architecture are presented, and in Section VII the evaluation process of the interface is presented. Lastly, the conclusion and future work is presented.

II. Motivation

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 [12] with 15 million nurses providing an estimated 18.2 billion hours of treatment annually. It is projected that 60% of dementia patients will wander [12]. 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 [12]. Having dementia over a longer period, 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 [13]. Thus, we can conclude that it is of paramount importance to monitor the people suffering from such diseases, to find them when they get lost.

Moreover, 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 [14].

According to the 2011 Pathways research survey [15], 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 technologies, 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, tracking systems can likely 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. [14] 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.

III. Internet Of Things

There is a lot of discussions nowadays about various innovations that take place in the field of computer engineering and informatics, one of these being the IoT. IoT is mainly multi-parametric, and for this reason, a plethora of technologies, protocols, and prototypes are used in order to support the notion of IoT. 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 LPWAN.

The LPWAN technologies come to fulfill the gap between short-range communication technologies and cellular technologies, 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. 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. One important LPWAN technology is called LoRa [19].

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. 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.

IV. Search And Rescue

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, in many cases such as in suburban conditions where broadband or cellular wireless technologies are out of range. 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 Gateway 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 a 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, is a satellite-based radio navigation system, that is widely used.

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, when 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 [20]. The [20] 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.

V. System Architecture

In this section, the system architecture is presented. The system consists of 4 main parts: a) End Devices (ED); in this study the wearable is based on Dialog's DA 14861 platform with a LoRa module integrated. b) The Gateway (GW), which is a device responsible for translating the packets transmitted through LoRa to Internet packets and vice versa. The GW relays the LoRa packets to the respective Network Server (NS). c) The NS is a server responsible to supervise and set the network parameters. d) The Application Server (AS). In Figure 1, a typical deployment of LoRa system is presented, showing each LoRa component. Figure 2 shows a DA 14864 wearable device incorporating a LoRa module. Figure 2 shows a LoRa GW that is placed on the University of Patras Campus.

As far as the web application is concerned, the main technical aspect of the application is the web framework called Flask. 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. For the Relational Database Management System (RDMS) the SQLite 3 technology has been used. As far as the maps in the web application are concerned the Leaflet has been used. The Leaflet is an open-source JavaScript library for creating mobile-friendly interactive maps. Figure 3 shows the homepage of the web application.

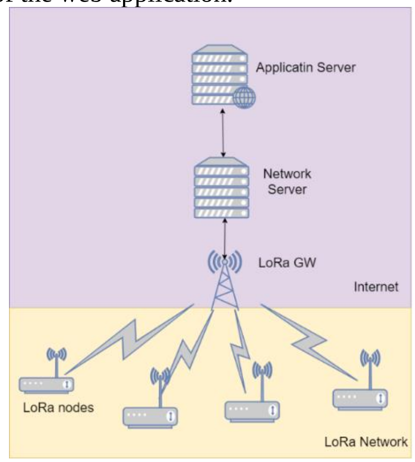

Figure 1. LoRa deployment architecture.

Figure 2. Left: a DA 14861 wearable device, Right: a LoRa GW in the University of Patras campus

The basic scenarios that the system provide to the user are the following: a) The user logs in to the system, b) definition of the allowed region, c) Location monitoring, d) Set the wearable device's state to an emergency/normal state, 7) See past packet information.

Figure 3. The homepage of the web application.

When a user enters the website, the homepage is the first thing that is presented (Figure 3). When the user logs in, a page is showed with a personalized message to the user informing about the last selected wearable device. 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 4. 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.

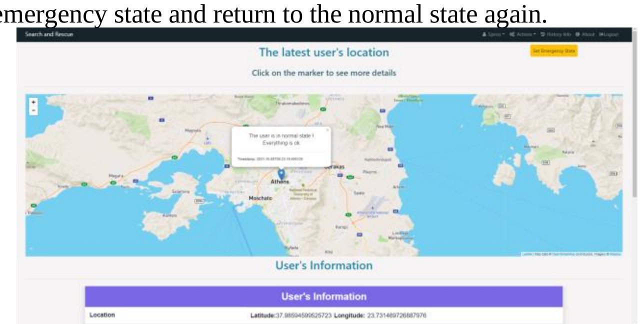

Figure 4. Dashboard

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 5. 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. Furthermore, the user can check the previously added permitted areas through the “Check your permitted areas”. 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 page, the user can see the history of the packets received in a tabular. In the navigational bar the user can spot and click the option “About” where the user can see the Frequently Asked Questions (FAQ). 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.

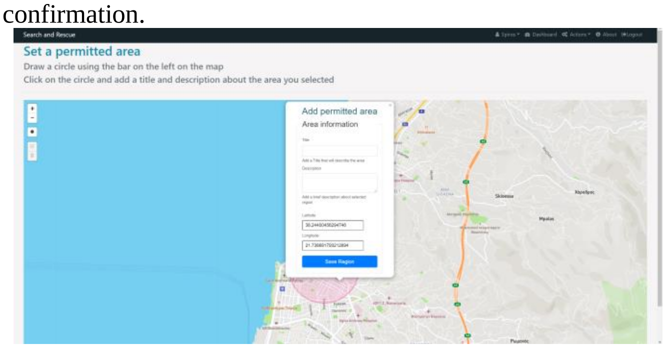

Figure 5. First page in the *"Add new allowed region"* scenario.

VI. HCI Approach And Evaluation

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 target group 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 have control of this system. 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 [21].

Usability criteria

The following ten usability criteria were isolated from work by Nielsen.

- The first principle is the visibility of system status.
- Match between the system and the physical world.
- User control and freedom.
- Consistency and standards.
- Error prevention.
- Recognition rather than recall.
- Flexibility and Efficiency of use.
- Aesthetic and Minimalistic Design.
- Help users recognize, diagnose and recover from errors.
- Help and documentation are the last principles.

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.

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. 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. Table I presents the problems and the heuristics that were violated in each problem.

In May 2021 the evaluation process of the Search and Rescue prototype took place in the office of the Laboratory of Distributed Systems and Telematics at Rio, Patras. The evaluation team consisted of three people: two HCI Master level graduates and one engineer specialist on monitoring systems 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 to achieve the feel of a real functional site.

Evaluators were given a heuristic evaluation sheet that was relevant to the 10 heuristics. 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 problems only needed not to 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.

TABLE I. LIST OF THE ERRORS DURING THE HEURISTIC EVALUATION.

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*

In the Table II an example of the problems found in the heuristic is presented, and particularly the ninth problem is presented. In Figure 4 the screen after the heuristic evaluation is presented.

After the heuristic evaluation, the necessary improvements were made. After this, another iteration was made, but at this time a usability questionnaire was given to each one of 10 random participants, who are frequent internet users that were called to test the prototype online, and then, they answered the questionnaire. This happened in order to test if there are more problems with the interfaces. 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).

TABLE II. PROBLEM NO 9.

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 6). This change bothered all the participants that did not understand what the meaning of the red color was. 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 7

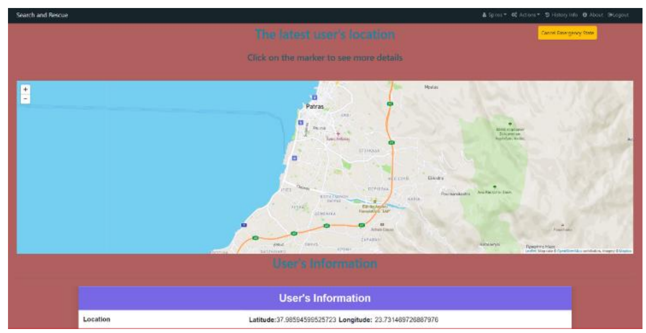

Figure 6. Initial emergency state case.

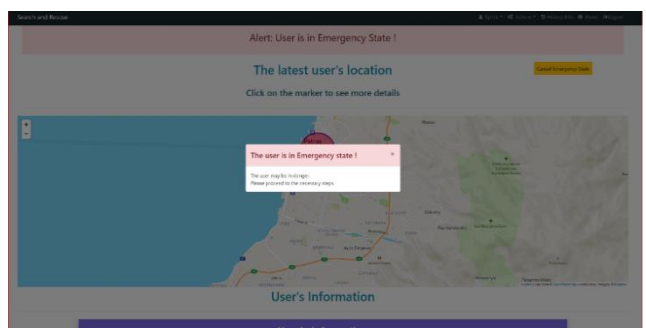

Figure 7. Emergency state alert after evaluation.

The purpose of the work was not to make a statistical analysis but to use the questionnaire as an additional means of evaluation. After all, the number of participants as was mentioned above was small. Considering this situation, the answers that are presented are the most characteristic ones. In the first question, 50% of 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 apart from the three participants from the evaluation process that had an academic background the other participants were high school graduates that use frequently websites and the 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 disagree with a 4 scale score and the other two participants answer strongly agree with a scale of 2.

The fact that 30% of the participants' score was 3 and above reveals in combination with the comments through an evaluation process that i) some users were not familiar with a technical website that is aiming at one certain purpose. The heuristic evaluation process had great results as the majority of the users feel that the system is not complex. Something that arise also from the answer in questions 8 and 9. In question 8 all of the ten responds were neutral while in the question 9 only 70% of the participants strongly agree (5) about how confident they were with the use of the website when only 30% of the answers were divided into neutral and 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. Then we calculated the score of the questionnaire, and the score was 72.5. The general guideline for SUS questionnaires classifies it with grade B, which means that the designed system is good and is also greater than the average grade of 68.

VII. Conclusion and Future Work

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.

For future work, the examination of different wireless technologies such as the Sigfox or 5th Generation networks will be taken into consideration. Also, after the COVID 19 pandemic is over an ethnographic study should be designed in institutions for people suffering from AD or dementia. Finally, another aspect that can be studied and examined is the legal part of the system that concerns people that can not be fully aware of legal concepts, for example, a person who suffers from dementia can not practically agree or disagree if the person that is responsible about the safety has the right to monitor the position and other vital personal information.

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