A system to facilitate the mobility of visually impaired people

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Abstract. The number of visually impaired persons (VIP) who move around alone is growing day by day. This has increased the concern of responsible persons (relatives) for their well-being. Some solutions have been presented that help both VIP to move more safely and their families to be more relaxed. Our contribution is a prototype called CapTeus, which can alert blind people and give them indications to evade obstacles in their path. In addition, relatives will be able to receive text messages or messages to Telegram. CapTeus has been developed using the Test-Driven Development Methodology for IoT-based Systems. Obstacle recognition has been performed at a maximum of 200cm, and Google's TensorFlow API has been used, obtaining an accuracy to 100%, depending on the obstacle and the distance. The evaluation of this prototype was carried out with VIP in real and controlled scenarios. CapTeus achieved a 96% acceptance rate among users.

Keywords: obstacle recognition, visually impaired, Internet of things, Test-Driven Development

1 Introduction

There are about 2.2 billion people with visual impairment (VIP) in the world. Of these, 14.50% suffer from moderate blindness, 16.69% suffer from moderate to severe blindness and 2.77% are blind [1]. In Ecuador, according to data provided by the National Council for Equality of Disabilities (acronym in Spanish CONADIS), by mid-2022 there were 54,397 VIP, either from birth or due to disease, representing 11.54% of the total number of people with disabilities in Ecuador [2]. The inclusion of these people starts at home, so their families must provide them with some strategy to help them become self-sufficient in their mobilization, without neglecting the safety of the VIP or the peace of mind of them.

VIPs often use white canes or guide dogs in their mobilization, and face adversity along the way. Unfortunately, these resources can be ineffective in adequately alerting them to dangers in their path. Similarly, they are unable to help a VIP recognize obstacles, especially those who are new to the disability or their training. On a path, people may encounter obstacles such as signs, electric lighting poles, fire hydrants or trees, among others [3]. Guide dogs are usually one of the most viable options for the mobilization of VIPs, but there is a possibility that during their trajectory they may coincide with untrained dogs, which may cause the VIP to be at risk due to confrontations between canines [3, 4].

Moreover, the acquisition of a trained guide dog entails a significant upfront expenditure of approximately US$50,000 [5], along with its consequent maintenance and everyday upkeep costs. Nonetheless, the precise outlay is subject to regional disparities in training practices, such that the initial cost of training a guide dog in Ecuador amounts to US$12,000 US dollars, accounting for a training period of no more than one year and an anticipated work span of nearly a dozen years [6]. Therefore, it is necessary to look for accessible, safe and comfortable alternatives for this segment of the population.

Currently, technologies such as the Internet of Things (IoT) make it possible to build intelligent devices, interconnecting physical objects through the Internet. IoT aims to help improve people's lifestyle. For example, VIPs can detect and recognize objects [7], being able to improve their daily life by trying to improve their self-sufficient life [8].

Leveraging IoT technologies, accessible solutions for VIP have been implemented. Vorapatratorn and Teachavorasinskun [9] present a solution consisting of an ear accessory connected to a device that goes on the user's waist. It allows identifying obstacles at 130 cm and alerting the user by emitting vibrations. Vorapatratorn and Teachavorasinskun [9] take into account the recognition of objects so that the user can make the best decisions and avoid them. Another work with similar functions can be considered the work of Kazi et al. [10] developed an smart cane capable of detecting obstacles and recognizing their type. Although the user can have several types of outputs (depending on his or her disability) to guide him or herself, it does not provide for communication with a family member in case of emergency. None of these documents mention the functionality of the device to allow the user to communicate with his/her relatives in case of emergency.

2 Related Works

The inclusion of people with disabilities in society and in the world of work has allowed them to learn to be self-sufficient, and to move around to meet their daily obligations/needs. These changes have increased the concern of academics to develop solutions for these people to move around more safely and for their relatives to remain more at ease when they are away from them. In the case of the visually impaired, some very promising solutions have been developed, although none fully meet the needs of the users. Among those solutions, one can cite the work of Hertel [4], in which they propose the design of a cane device called STIC, which assists the mobility of a VIP by making use of an ultrasonic distance sensor for head level and a laser-based infrared sensor for ground level obstacle detection. Feedback to user on obstacle detection is encoded and transmitted through vibrotactile actuators. Thus, the VIP must learn to perceive the intensity of vibrations to identify the distance of the obstacle in front of it.

On the other hand, Rajesh et al. [11], present a system in which they have used a buzzer and multiple ultrasonic sensors with which they try to give security on the way to the VIP. The sensors are used to detect obstacles and stairs, and the humidity of the ground to issue an alert according to the situation. It also allows to know the location of the blind person using the cell phone, to be used as part of an emergency message that can be sent to the cell phones of the specified numbers.

Another work that combines ultrasonic obstacle detection sensors to make the blind person's trajectory more comfortable is SCBIoT presented by AbdElminaam et al. [12]. In addition to obstacle detection, SCBIoT uses a GPS module to send a periodic mail with the user's location by connecting to the Wi-Fi hotspot of the Android phone. This way you can keep your family members informed. In addition, they incorporate vibrators and a buzzer that try to help and warn the user of any obstacle.

The work of Rajesh et al. [11], the user must learn the meaning of the alerts he receives by vibration and sound. In addition, in the work of AbdElminaam et al. [12]. when trying to keep family members informed by e-mail, it may happen that they are not attentive, and when they check their e-mail it is too late. The works of AbdElminaam et al. [12]. as well as Rajesh et al. [11] are very promising, however it can be considered that users may be distressed by not recognizing the obstacle in front of them, as they only detect them.

In addition to canes to assist VIPs, smart shoes have been developed, such as the work of Nathan el al. [13]. The shoes are equipped with sensors and actuators to detect obstacles and inform VIPs, trying to make them walk autonomously. In addition to an emergency fall notification through a buzzer and speakers (DF Player) so that people nearby can help the VIP, while their relatives are notified through [14]. Likewise, the smart shoe designed by Suneetha et al. [15] offers a possible solution for blind people to walk on the street independently. This shoe, like the one proposed by Nathan et al. [13], has several built-in sensors, a microcontroller and buzzers, with the difference that the one by Suneetha et al. [15] only warns by a buzzer when there is an obstacle in front of the VIP.

Both canes and shoes detect obstacles uniquely, with the exception of Rajesh et al. [11] s work which identifies obstacles as Large, Medium and Small. The limitations of the works retrieved and reviewed in this paper have inspired the authors of this work to propose CapTeus as a prototype that allows to detect and recognize obstacles in the way of the VIP, and is equipped with a panic button (as is the work of Rajesh et al. [11]) to notify in case of emergencies to their relatives via Telegram messages and emails, or text messages when they do not have internet connection.

3 CapTeus: The Proposed System

CapTeus (Latin: *cap*tiosus bal*teus*) is proposed as a viable solution to guide blind people in their daily walks. CapTeus is an economically viable system with high usability acceptance. It was built and tested with real user requirements. Capteus can detect obstacles, recognize them, warn the user about them and guide the user where to go to avoid the obstacle. In addition, in case of emergency, the user carrying the device can press a panic button to inform relatives about the situation via Telegram message and emails, or in case of no internet connection via SMS. CapTeus consists of a device and a mobile application.

3.1 Obstacle Detection Method

Obstacle detection is performed by the reflection of ultrasonic waves transmitted by an ultrasonic sensor. The distance is given by the time it takes for the wave to return multiplied by the speed of sound divided by two.

3.2 Obstacle Recognition Method

Recognizing obstacles through artificial intelligence after encountering and identifying them is vital for a VIP to know what is in front of it when following a path, especially in open environments. This is the reason why this important functionality was implemented in CapTeus. In the realization of CapTeus, the TensorFlow Lite API is used, which is focused on the use of mobile devices, has a comprehensive and flexible ecosystem of tools, libraries and community resources; which allows researchers to innovate with machine learning and developers to create and implement applications with DL technology [16].

3.3 TensorFlow

CapTeus uses TensorFlow for obstacle recognition. It is an open source API for Deep Learning (DL). This API allows building and training neural networks to detect patterns and reason like humans. They are used for object recognition, image classification, among others. TensorFlow is ideal for CapTeus because it covers from mobile devices such as smartphones and tablets to large-scale distributed systems and other computational devices [17].

3.4 Issuance of Notifications for the VIP

CapTeus issues notifications to the VIP by voice. The texts of the notifications are formed based on the obstacle about which the VIP needs to be notified. Once the text is obtained, it is converted to speech using an Android class called Text-to-Speak, which receives the text and the information is obtained as a result through the smartphone's synthesizers [18].

4 Development Methodology of CapTeus

For the development of CapTeus, the Test-Driven Methodology for IoT-based Systems (TDDM4IoTS) [19] has been used, as it is an agile methodology and one of those that best covers the life cycle of the systems in its phases [20]. TDDM4IoTS is a methodology which consists of 11 phases: preliminary analysis, tecnology layer design, detailed requirement analysis, model generation and adaptation, test generation, software generation, model refinement, software refinement, hardware and software deployment, deliverable assessment, maintenance [19]. TDDM4IoTS focuses specifically on the development of IoT-based systems [19, 20].

TDDM4IoTS is a flexible methodology, in which the order of the phases and the phases themselves are not a straitjacket. Developers decide which ones should be executed and in what order [19]. For this, it is necessary to observe the type of project, the experience of the project team in the development of this type of projects, among other aspects.

4.1 Execution of the TDDM4IoTS Phases in the Development of CapTeus

For example, the maintenance phase because CapTeus is a prototype in the testing phase. Also, the model and software refinement phase because it was a system whose requirements were clear and the software code was written manually with clean code best practices.

Preliminary Analysis. In this phase, a coarse-grained analysis was performed to obtain the main functional and non-functional requirements of CapTeus. Technical aspects such as available tools and technologies, expert personnel in the development of this type of systems, time available for its development, including its evaluation, were taken into account to determine whether the development of CapTeus was feasible or not (***technical analysis***). Being a wearable device, it must have a battery to power it, connected to a mobile Internet signal, among other non-functional requirements (***environment analysis***).

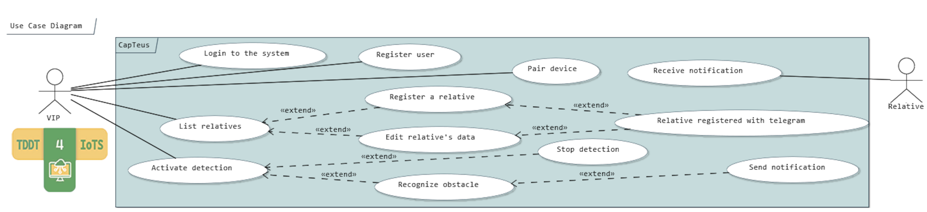

Fig. 1. CapTeus use case diagram.

Requirements analysis. The most important deliverables developed were the following: User registration, registration of a relative or caregiver, device communication with the mobile application, obstacle detection, obstacle recognition, issuance and playback of alerts to the VIP, issuing and Sending Text Message Notification, broadcasting and sending notification by Telegram.

Feasibility analysis. Regarding the tools and technologies required for its development, there are many free tools, with many functionalities that facilitate and accelerate the development of IoTS. The development of CapTeus was done using TDDT4IoTS as a modeling tool, both for the software and the design of the IoT device. To program the operation of the mobile application, Android Studio was used as IDE and Kotlin as programming language, for the SQLite data storage. In terms of economics, its development was feasible, since the only investment that had to be made was around US$50. In addition, the simplicity of the activities that must be performed to keep it operational (on and off, charging its battery, attaching it to the VIP belt), made it operationally feasible.

Technology Layer Design. Considering both software and hardware for fulfilling the functional and nonfunctional requirements of CapTeus, appropriate technologies were sought for alerts in detecting and recognizing obstacles in the VIP trajectory, and sending notifications about the status of the VIP to its family members. These technologies are shown in figure 2, which shows the CapTeus system architecture.

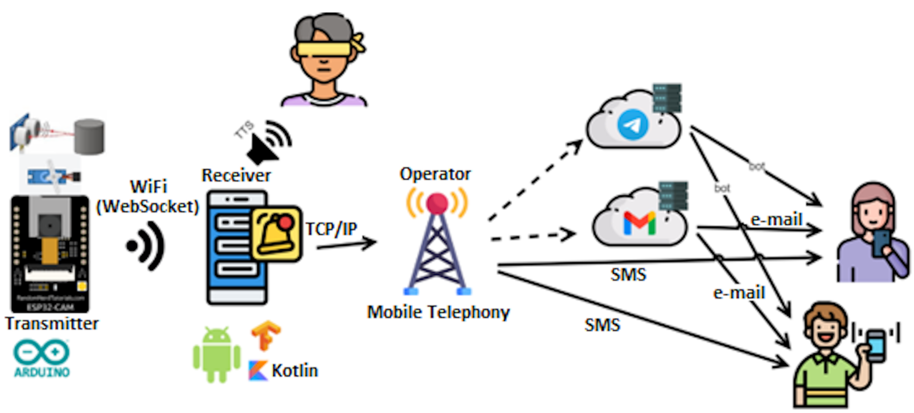

Fig. 2. CapTeus architecture.

Figure 3 shows an interconnection diagram of the CapTeus device components. a) 5-volt battery power supply, b) servo motor to rotate the camera in search of an alternative path, c) Arduino board to program the rest of the device components, d) ultra sound sensor to determine the presence of an obstacle and its distance from the VIP, e) ESP32-CAM camera sensor to capture the image of the obstacles to be processed for recognition, and f) the button that the PIV can press when it is in danger. It is one of the diagrams that have been produced using the TDDT4IoTS tool [21].

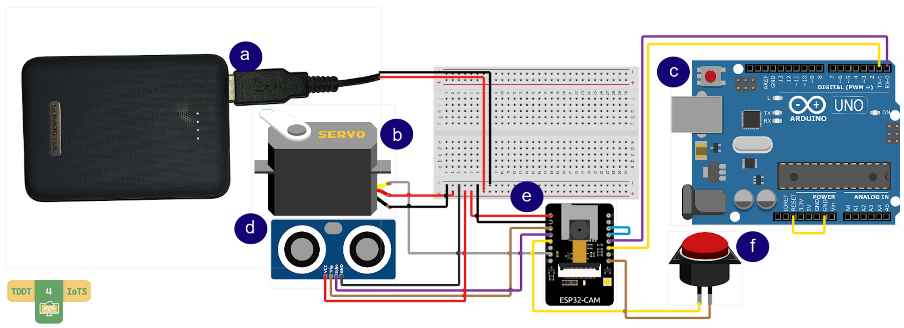

Fig. 3. CapTeus device design.

Detailed Requirement Analysis. CapTeus requirements are identified in more detail. The modeling of the software architecture was performed obtaining the following artifacts: use case diagram, extended use cases, class diagram, among others. These diagrams were created using the same TDDT4IoTS tool.

Model Generation. The CapTeus class diagram was generated after writing the extended (detailed) use cases using SLUML. The class diagram is shown in figure 4.

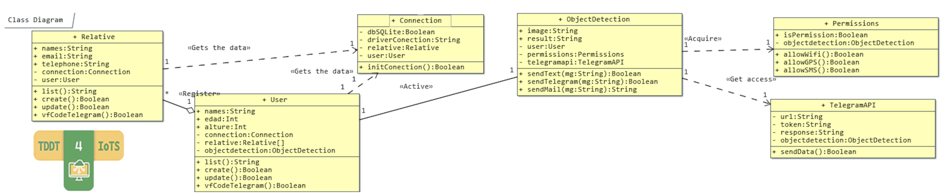

Fig. 4. CapTeus class diagram.

Test Generation. The generation of tests as a phase of TDDM4IoTS allowed assuring the quality of the developed system. Tests applied were of two types:

– Tests performed by the developers: unit tests and integration tests.

– Tests performed by a VIP: usability tests, including functional tests.

Therefore, the tests performed allowed to ensure that the system complies with the functionalities according to the established requirements, for each of the deliverables that were developed in each iteration as specified by TDDM4IoTS.

Software Generation The software for the mobile application was generated 100% percent manually. While the software for programming the Arduino board, about 40% was done using the TDDTT4IoTS tool. For the writing of the code, the generation of a clean code was considered to guarantee its maintainability and scalability.

Model and Software Refinement. Being a project with little breadth and complexity, these two phases were not necessary to be executed, since once the models were generated from the clear functional requirements, and then the software with good clean code practices. In addition, the project team has experience in the development of this type of systems, which helped to accelerate the development of CapTeus.

Hardware and Software Deployment. The hardware and software of the system were deployed in the environment for which it was built. In this case, since it is a wearable system, its operation was tested by placing the device on the belt of a VIP and installing the mobile application on her smartphone, and it was verified that the system works and interacts with the VIP properly.

Deliverable assessment. Once the evaluation by the development team of each deliverable was completed,and finally the integration tests, an assessment was carried out with a group of 27 visually impaired users to assess the performance of the device and the mobile application in different situations.

The assessment by the VIPs was carried out in two groups. The first group (Group 1) in the province of Los Ríos (La Maná and Quevedo), and the second group (Group 2) in the province of Guayas (Guayaquil) in Ecuador. The evaluations with Group 1 were in controlled environments in which some obstacles such as chairs, tables, and people were asked to collaborate as obstacles, and Group 2 in the facilities of the "Fundación Ecuatoriana para Ciegos (FUNECI)" (Ecuadorian Foundation for the Blind). Regarding the acceptance to use or not to use the device, 74% totally agree, 22% agree and 4% showed some objection to use it. It should be noted that the effective distance for successful obstacle recognition is directly proportional to the size of the obstacles.

The more complete the object captured by the camera, the more likely it is to be recognized. At a distance of 150cm, some objects were not recognized correctly. Results were obtained from 20% to 100% of correctly recognized objects. The results are shown in the graph in the figure 5.

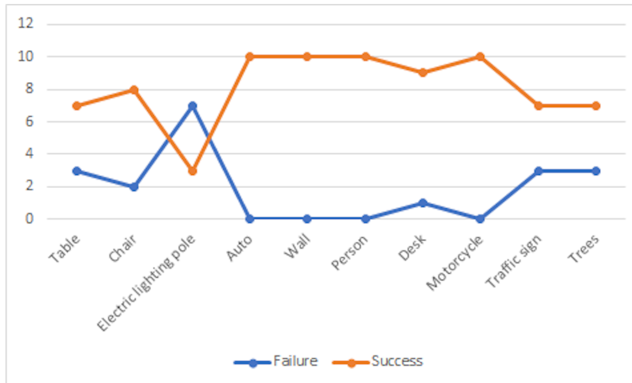

Fig. 5. Success in obstacle recognition.

5 Conclusions and Future Work

A cost-effective and user-friendly system has been proposed in this paper. According to the System Usability Scale (SUS) questionnaire applied to VIPs who used the system, CapTeus achieved an acceptance rate of 70%, with a standard deviation of 7.52. According to Bangor, CapTeus has a good level of acceptance.

Future work includes reducing the size of the CapTeus box. In addition, it is intended to implement sensors to detect obstacles at ground level (unevenness of the street or stairs) and sensors to detect the presence of water (humidity or mud). These sensors could be implemented in a cane or in the VIP's footwear.

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