Improving pedestrian's crosswalk accessibility through digital fencing

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Abstract. One of the major challenges for visually impaired people is to walk safely in any urban landscape. Modern cities are using passive solutions, like audible signals, to promote the security of that pedestrians. However, these solutions may be insufficient to provide the relevant information about the traffic flow, and the length of the crosswalk among many other questions. Smart crosswalks can improve the access to such information by providing a way for the user to share data with them. This paper addresses this question by presenting the VALLPASS project that aims to develop a smart pedestrians crosswalk that, besides other design requirements, aims to promote accessibility by sharing local traffic data with the user. Besides that, pedestrian security will be tackled by defining a digital protecting fence based on the user location obtained from the RSSI values between two beacons and the user's smartphone. Details behind its operation and the overall functionality of a custom-made app will be provided.

Keywords: Pedestrians crosswalks accessibility· Digital fencing · Bluetooth

1 Introduction

According to the latest national censuses, in Portugal, there are about 890,000 people with vision difficulties, among which, around 27,000 are completely blind [1]. The lack, or significant deprivation of the sense of sight, translates into challenges that some people must overcome and that are normally not perceived by the rest of the population. Among the various domains of social life in which these difficulties can be felt, this article focuses on those that relate to mobility in typical urban environments. In this context, public transportation plays an important role in providing ways for visually impaired, or blind persons, to travel independently. However, to take the bus, train or just move around the city on foot, it is necessary to walk through streets where, usually, both people and vehicles coexist. The sharing of space between cars and people poses safety challenges that must be taken into account in order to avoid accidents that often end in fatalities. Security is even more critical on crosswalks since these are places where the probability of collision between vehicles and pedestrians is substantially higher. Knowing when and where it is safe to cross a given road is fundamental. Moreover, that information must be easily perceived by any pedestrian. In most cases, being able to see or hear greatly simplifies the process of crossing a road since, besides being able to easily grasp the traffic conditions, existent road signs, colour or graphic codes require visual perception.

At the present, in Portugal, there is a normative that promotes the inclusion of passive solutions to help visually impaired persons to walk safely [2]. In particular, the addition of floor tactile clues to facilitate the location of the crosswalk. Other accessible pedestrian signals (APS), including audible signals and crosswalk tactile contrasts, are also conveniences that greatly help the visually impaired navigate in urban scenarios. However, even if this normative can be seen as a positive point toward the democratization of road access, passive solutions, such as the ones enumerated above, lacks vital information to help the user in unfamiliar environments. Indeed, it is worth noticing that memory and familiarity with the surrounding environment is a fundamental assets used for navigation. When in familiar places, visually impaired people generally know the layout and memorize the location of obstacles. For example, the number of lanes, the crosswalk extension or even the traffic pattern. However, when in unusual places or with high and complex traffic variability, prior knowledge is unavailable or inapplicable. Moreover, even audible clues that exist in some crosswalks may not be easily perceived due to several causes such as the traffic and surrounding noise. That is why efforts are carried out aiming at the integration of active accessibility strategies into crosswalks. In particular, the development of smart pedestrian crosswalks, aiming to increase traffic safety and improve accessibility is being targeted by both commercial companies and academia.

It is within this framework that the VALLPASS project, funded by the Portuguese program Norte2020 under the grant NORTE-01-0247-FEDER-113439, is being carried out since July of 2021 and with a predicted end date of June of 2023. This project aims to develop a pedestrian crosswalk that could be integrated into the smart cities paradigm. In addition, it intends to include active systems that could promote an increase in crosswalks safety targeting a broader pedestrian universe of users which includes visually impaired persons.

The aim of this paper is to describe the overall approach that will be taken in order to increase the smart pedestrian crosswalk accessibility to visually challenged pedestrians. Details regarding the solution envisaged will be provided in Section 3. Before that, an overview of related work is presented in Section 2. The closing section will be devoted to presenting the main conclusions of the paper and pointing out further work directions.

2 Related Work

This section will be devoted to describing the most common approaches found in the literature that deal with the problem of crosswalks accessibility improvement for visually impaired pedestrians. The solutions are found to fall into one of the following three categories: global positioning using GNSS/GPS, image processing and wearable sensors. Regarding the former, the use GNSS/GPS allows gathering both the global pedestrian location and where he or she is heading. This information, in conjunction with the map with the crosswalk locations, will be used to steer the person in the urban landscape. However, the use of GNSS/GPS as a guidance system must take into consideration the overall system precision which is around five meters under open sky [3]. Besides this error margin, satellite signals can be shadowed by bridges and buildings. Some of those drawbacks can be bypassed by using hybrid approaches that merge more than just one technology. For example, [4] from the University of Minnesota, designed a smartphone application that combines a digital map of the intersections and the user location obtained from GPS. For the cases where the GPS signal is weak, they placed Bluetooth beacons to improve the information on the user's location. After arriving near the crosswalk, the application exchange messages with the traffic light controller, through Wi-Fi or LTE, asking how long the user have to wait until is safe to cross the road. This information will then be relayed to the user using audio messages. It is worth pointing out that this approach requires the location of Bluetooth beacons since, in general, they are not integrated into the conventional crosswalk signalling system. Moreover, it relies on the availability of an API to query the traffic system about its status which is not usually the case.

Another paper that explores the use of GPS for increasing the security of visually challenged persons was published by [5]. The authors have developed an application, named Virtual Guide Dog (VGD), which resorts to a GPS-based localization method to check when the user is near an intersection. If this is the case, the app will ask the pedestrian if he or she wants to cross the road and, if this is the case, the app will give orientations to steer the user. When the user is in position, the app connects via Bluetooth to the traffic light controller and acts as the physical process of pressing the crosswalk button. When it is safe to cross, the application indicates the user to start traversing. This solution suffers from the same issues as the previous by relying on third-party technology to operate.

Other researchers approached this question through computer vision and image processing [6–8]. In particular, using real-time video obtained from smartphone cameras or wearable devices, they are able to determine the crosswalk location and status giving information to the user if it is safe to cross. The problem with this kind of solution is that they need a fast image processing device and software that could be able to guide the user in real-time Moreover, at night the camera may not be able to correctly detect the crosswalk.

Kiyoung et al. [9] presented the Crossing Assistance System (CAS) where a location is performed through machine learning using the Received Signal

Strength Indication (RSSI) from eight Bluetooth beacons located at a four-corner car intersection with four crosswalks (two beacons at each side of a crosswalk). In particular, a smartphone app takes the measured RSSI of each beacon and then the machine learning algorithm computes the user location. In this setup, the beacons send data every half second and the smartphone app is built in order to receive two RSSI signals per second provided by the eight beacons. According to the authors, the algorithm only requires three seconds to process the data and provide the user location. However, their work doesn't implement any guidance system but they mention it as a potential future work. In addition, Bluetooth beacons must be installed on third party systems which can be challenging.

Still, in the artificial vision area, [10, 11] put forward a real-time crosswalk detection algorithm in conjunction with adaptive extraction and consistency analysis in order to detect crosswalks at urban intersections. This algorithm ingests real-time video taken from custom made goggles that the user must wear [12]. The use of wearables always poses problems that span from the need to acquire a specific item that, due to its particular application and target audience, can be very expensive or even not within the person's sense of fashion and personal style.

The approaches described above require the integration with third-party technology, the installation of beacons or the purchase of specific hardware. In the following section, the integrated solution defined in the VALLPASS project will be explained and how it tackles the drawbacks of the above-mentioned solutions.

3 The VALLPASS accessibility approach

The VALLPASS project consortium is headed by the company VALLED and has as technological partners the research centres CeDRI and MORE. VALLED is a company based in Bragança, a city in the northeast part of Portugal, and focuses on the development of products related to street lighting, water pumping systems and solutions based on photovoltaic systems. On the other hand, CeDRI is a research centre that develops its activities within the areas of digitalization and intelligent robotics. Located also in Bragança, CeDRI is a multidisciplinary research unit fostered by the Polytechnic Institute of Bragança that promotes and applies technological solutions in the industry. The consortium is completed with the MORE collab centre, also from Bragança, which provides scientific, technological and innovation consulting services to companies in both the public and private sectors.

In short, the main objective of the VALLPASS project is to develop and build a smart pedestrian crosswalk solution able to improve the security of pedestrians and, at the same time, be compatible with the *smart cities* ecosystem.

Besides its ability to react to the environment adapting to both pedestrians and traffic, accessibility of visually impaired persons is also a major concern of the design requirements. In practice, visually handicapped persons may find the general location of crosswalks based on traffic noise or tactile cues. However, after getting its position, it is fundamental to "read" the traffic noise signature to know the moment when the street is secure to be crossed. This task is especially complex when the person is in unfamiliar environments where details regarding traffic flow patterns and crosswalk length among many other variables are unknown.

It is in this context that this work is being carried out. In particular, this paper addresses the architecture of a protection digital fencing system based on Bluetooth signals that will be integrated into the VALLPASS smart crosswalk solution. This digital fencing will be able to steer the pedestrian toward the crosswalk centre and provide acoustic, voice or vibration codes according to the actual degree of security for traversing the road. The main idea is presented in Figure 1.

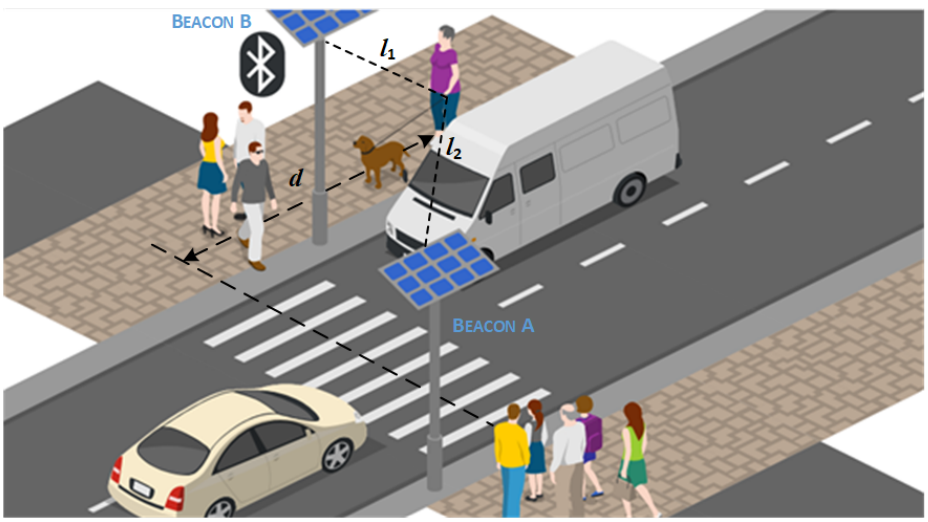

Fig. 1. User localization using two Bluetooth beacons embedded on the VALLPASS smart pedestrian crosswalk.

In the situation illustrated in the figure, two VALLPASS units are installed sideways of a crosswalk. Each one of the VALLPASS elements includes a Class 1 Bluetooth beacon that provides an RF signature able to be detected to a distance of up to 100 m. Assuming that a given pedestrian has a smartphone with the VALLPASS mobility application installed, the RSSI of each Bluetooth beacon will be decoded by the software and the relative position of the pedestrian, regarding the crosswalk, is estimated.

It is worth noticing that, in practice, location by triangulation requires, at least, three points. However, in a typical crosswalk application, only two VALLPASS units will be available. Hence, there is an intrinsic uncertainty if the pedestrian is upstream or downstream of the crosswalk. However, this issue is not fundamentally a problem since the location algorithm will be concerned with the relative peak power and disregard if the pedestrian is approaching the centre of the crosswalk from the left or from the right. Moreover, positioning is not the main objective of this system. Indeed, pedestrian positioning can be fine-tuned by himself with the help of the tactile cues embedded on the sidewalk. Being able to provide accurate information on the actual crosswalk and traffic status while providing decision support regarding the most secure time interval to cross the road is the key feature of the VALLPASS accessibility system.

In theory, the estimated distance D in meters between two Bluetooth devices using the RSSI value can be computed from:

$$D = 10^{\frac{P - RSSI}{10\eta}} \tag{1}$$

where $RSSI$ is a measure of signal strength expressed in dBm, P is the measured signal strength observed at a distance of one meter between the two devices and η is an attenuation constant that depends on environmental factors.

Using this approach, the distance l_1 between "Beacon B" of Figure 1 and the user smartphone can be estimated. In the same way, the distance l_2 between "Beacon A" and the user's handheld device can also be inferred. Once the distance between the pedestrian and each of the two beacons is found, the distance of the user to the centre of the crosswalk can be estimated.

Drawing a circle for each beacon with a radius equal to its distance to the user, two intersecting points can be obtained. Figure 2 present this concept.

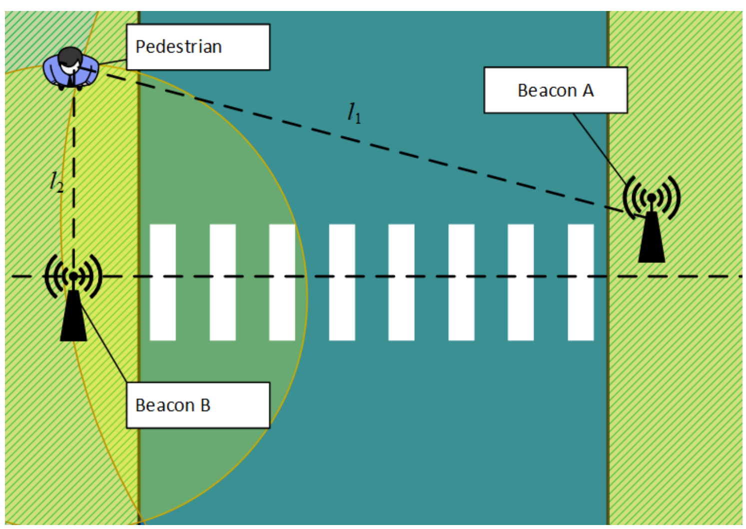

Fig. 2. Pedestrian localization from the distances estimation to each beacon.

Besides the RSSI, each VALLPASS element share with the application its ID and global position. This will be used to narrow down the location uncertainty. In practice, non-linearities and other problems due to RF signal reflections must be considered. Ongoing experimental results will soon reveal the best way to perform the data filtering and analysis.

Finally, and before the concluding remarks, a word about the smartphone app. Since the software is targeting visually impaired users, graphical information is irrelevant. As can be seen from Figure 3, the device will accept voice commands in order to, for example, raise or lower the sound volume, provide status information about the crosswalk, traffic information and so on.

Fig. 3. Smartphone front-end for the VALLPASS accessibility portal.

Moreover, the use of the Braille alphabet encoded using the smartphone vibration actuator will be equated in order for the application to silently communicate with the user and vice-versa. This is not a new idea and has already been presented in the literature [13]. However, at least to the best of our knowledge, there is no commercial product available that explores this concept.

4 Conclusion

Modern societies are inclusive by definition and promoting life quality of all persons should not be a question of numbers. At the present, where societal digitalization is accelerating, efforts must be made to use that technology to further improve the urban mobility and accessibility of persons with disabilities. It is framed on this idea that the VALLPASS project seeks to develop a smart pedestrian crosswalk that has security as a major concern. One of the key concepts of this solution is the inclusion of active security measures targeting visually impaired persons.

This accessibility module will be based on the information exchanged between the user's smartphone or equivalent device and the VALLPASS units. A rough estimation of the user location, relative to a given set of VALLPASS units, will be obtained from the RSSI values of a Bluetooth beacon relative to the user device. The RSSI values will be used to compute the relative distance of the user to the crosswalk centre. After "locking" into a pair of VALLPASS units, the user will be able to query the system to get information on when to cross the road. This data exchange will be performed by a custom-made app that will execute voice commands. Communication between the user and the app through Haptic approaches using the smartphone touchscreen and vibration actuator will also be explored.

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