Introducing the Concept of a Hybrid Navigation System Adapted to Blind Users for Optimal Stress-free Indoor and Outdoor Mobility

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***Abstract*—The most challenging task in the daily life of blind individuals is to navigate safely. This challenge is prevalent in both outdoor and indoor environments. The lack of visual cues when blind people navigate makes reaching destination a very difficult and stressful task to achieve. In our prior research, we established a connection between stress levels and the challenges encountered by visually impaired individuals during outdoor navigation. To address this, we developed an outdoor navigation system capable of initially determining the least stressful route between two points, and subsequently delivering real-time navigation instructions and obstacle detection. This paper introduces a novel concept: a hybrid navigation system designed to help visually impaired people navigate in unfamiliar environments, both indoors and outdoors, enabling them to successfully reach their destination while minimizing stress.**

***Index Terms*—blind people, navigation system, indoor and outdoor imagery, obstacles detection, smart cane, QR code**

I. Introduction

According to the World Health Organization, approximately 285 million people worldwide have a severe visual impairment, of which approximately 47 million are visually impaired [1]. While they cannot see objects, many can perceive light and shadows. Hence, navigation is challenging for blind people, especially in situations lacking suitable accessibility elements. When you are navigating in an outdoor environment, the digital navigation solution such as Google Maps, is based on satellite imagery, aerial photography and GPS signals. These geospatial data inherently lack coverage of interior spaces, necessitating an alternative service to map indoor venues and enable digital navigation within buildings.

Blind people need help to detect and avoid physical obstacles in their path, both indoors and outdoors. Many assistive tools have been developed like white canes and braille compasses that assist the visually impaired to navigate the environment. Moreover, they navigate around, based on their senses and experiences with the aids of guidance canes to detect and avoid obstacles while moving [2]. Technology is a revolutionary force in addressing the challenges faced by people with visual impairments, providing innovative solutions that improve accessibility and independence.

One of the main challenges that blind people encounter in their daily lives is mobility and orientation in both environments outdoor and indoor which impact their social engagement and overall quality of life. This challenge is prevalent in both outdoor and indoor settings. It is particularly noticeable in public places like shopping malls, airports, offices, and other large indoor spaces. Unlike outdoor environments, indoor spaces are not accessible to GPS signals, making reliance on traditional navigation aids impractical. Indoor navigation is challenging due to complex layouts, dynamic obstacles, and unreliable visual cues.

Finding and avoiding obstacles in their path is more challenging when there are no visual cues available. Receiving accurate and up-to-date information becomes more difficult when aiming to arrive at a destination quickly. Because decision-making and continuous spatial awareness demand a higher cognitive load, physical fatigue develops. Also, people get mental tiredness from cognitive fatigue because they are always processing touch and auditory cues to make sense of their environment. Lack of tailored support in unfamiliar indoor spaces worsens challenges, hindering blind individuals' navigation independence and proficiency [3].

While several technologies have emerged to assist individuals with visual impairments, they remain insufficient in fully addressing obstacles, overcoming barriers, and ensuring successful arrival at the intended destination. Therefore, we are proposing a concept of an indoor and outdoor navigation system designed to empower visually impaired users. This system will overcome blind users stress in both environments indoor and outdoor when navigating by providing real time navigation and obstacle detection.

II. Related Work

This section presents the related work divided into two parts. In the first part we list several technologies and systems that have been proposed to address navigation challenges. In the second part we present studies related to stress detection for blind users when navigating.

A. Related work to navigation and localization

1) Wi-Fi-based: The first solution, which was proposed by Hushe and Suryawanshi [4], implements an indoor navigation system that estimates the user's position inside a building and directs the user to attain a destination by using Wi-Fi technology. This will facilitate locating the desired destination in an unfamiliar area, representing a small stride toward improving accessibility to modern technology for individuals with disabilities in our society. The user scan and identifies the available Wi-Fi network with the most strength then the application shows the current location, and the user can select the destination from the available options.

This approach can lead to two different results:

- Wi-Fi found: an image of the default map is displayed.
- Wi-Fi not found: the user's current location on the map is displayed. When a destination is chosen, the app shows the route in both speech and text

On the one hand, this approach is convenient in terms of efficiency, low cost, easy implementation, and providing text-to-speech directions for visually impaired people. On the other hand, in terms of limitations, if a designated access point is faulty or absent or encounters network configuration issues, it can lead to inaccuracies in determining the user's position, and it does not implement object detection.

2) CamNav versus BLE technologies: Kunhoth *et al.* [5] developed a robust solution that accurately estimates the coordinates of users using different systems: a system based on computer-vision, called CamNav, and a Bluetooth Low Energy (BLE) system. This solution aims to enable dynamic real-time tracking in indoor areas at any given moment. The study, involving ten blindfolded participants, was conducted to evaluate and compare the efficiency of the two navigation systems separately in terms of time spent navigating and errors that occurred while navigating.

CamNav is a system based on computer-vision that utilizes a deep learning model to identify and acknowledge geographical positions. This technology detects scenes and objects by matching the captured images with the pre-trained existing dataset. CamNav uses an Android application to capture the images and provide instructions for the user. The experiments conducted with the help of the 10 blindfolded people showed that CamNav has several advantages and limitations.

Among the advantages is improved accuracy, as indicated by decreased average errors in terms of the number of steps. It provides detailed information about the current location and surroundings, including information about doors and walls. This benefit, however, comes at a cost: users may experience a delay in receiving instructions, forcing them to wait a few seconds to comprehend the necessary information. Furthermore, the user's walking speed influences CamNav's performance and accuracy, since quicker speeds potentially result in blurred pictures, thus damaging the overall user experience. Another significant limitation is that users must maintain their mobile device in a fixed orientation, straight or pointing downward, for accurate location recognition. However, some users struggle to maintain the precise smartphone orientation for extended periods, posing a major usability challenge.

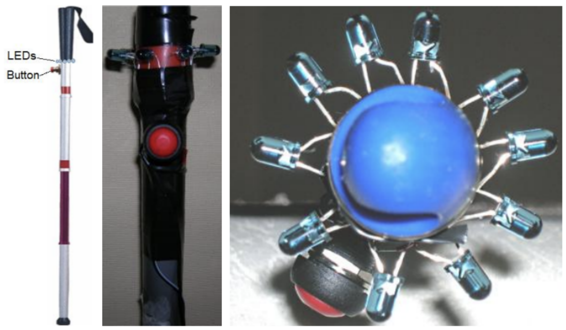
Bluetooth Low Energy (BLE): Bluetooth Low Energy technology-based solutions consist of an Android application and employ BLE beacons to estimate the user's proximity. The BLE beacons are hardware devices connected to the walls or ceilings of the location. To estimate the user's position, the recorded Received Signal Strength (RSS) from BLE beacons using a smartphone or a radio frequency signal receiver is compared to the RSS stored in the database.

A BLE navigation system offers substantial advantages in terms of increased user speed and reduced navigation time. However, challenges arise in the accuracy of position estimation, as the system may encounter difficulties in providing precise instructions at junctions, leading to potential user misguidance. The system's limitation becomes evident when users bump into walls or doors, highlighting its occasional inaccuracy in determining the user's exact position. Nevertheless, BLE beacons demonstrate effectiveness in navigating straight paths within corridors, offering valuable location information.

3) Wiimotes and Infrared LED system: Guerrero *et al.* [6] have come up with a solution that can determine a person's position and direction of movement. With the use of this data, the system computes the user's trajectory, identify potential obstacles along the way and offer navigational assistance. The main components of the system are an augmented white cane, a computer, a smartphone and two infrared cameras.

The cane emerged as the optimal item for augmentation to depict the user's position, following the Augmented Objects Development Process (AODeP) methodology applied to various candidate objects. Developers predefine the boundaries of the environment and render all objects within it. Subsequently, the system creates an XML specification detailing the environment's configuration. Analyzing this XML file enables the generation of a comprehensive room map, facilitating recognition of the user's surroundings. The system employs a common-sense strategy for message delivery.

By pressing a button on the cane, users can initiate this system and request navigational information. The infrared LEDs built into the cane, as shown in Fig. 1a, are then turned on. The software application identify the user's position among a list of possible obstacles in the surrounding area. Figure 1b shows the infrared camera built into the Wiimotes that is used to detect the user's position and movement. These devices incorporate a dedicated microchip to manage the Bluetooth antenna, which transmits at 2.1 Mbits/s. The application then will use such information the generated XML file of the obstacles identified in the area to generate navigation voice messages that are delivered by the smartphone. Figure 2 illustrates the flow of Wiimote and infrared LED system. The length and width of the room, the relative positions of each Wiimote, the angle at which the controls were fixed to the walls, and the relative positions of each object are a few of the data elements that must be included in the XML file.



(a) Smart cane with infrared LED system.

(b) Wiimote component.

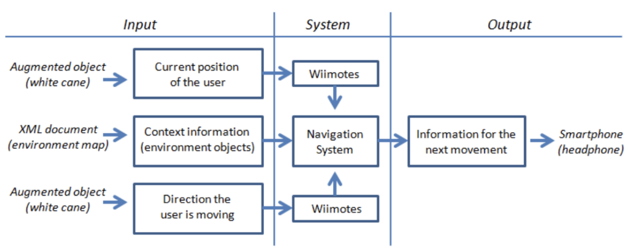


Fig. 2: Flow of Wiimote and Infrared LED system.

Based on the evaluation process, in which five blindfolded volunteers participated in the system trial, several advantages and disadvantages were found. To begin with the positive aspects of this system, we can say the system is accurate sufficiently to navigate blind people in indoor environments. Moreover, this model is user-centric and feasible in terms of cost and availability. On the flip side, it presents some limitations, including the fact that the information that is provided to them only offers background data to assist them in choosing the best route on their own and does not specify the route that should be taken. The system's primary drawback is the use of Bluetooth, which has a low communication threshold, even though it has the potential to manage large areas. Nevertheless, all it takes to overcome this restriction is Wi-Fi communication. Another limitation is that the map needs to be updated whenever an object in the surrounding area is moved. That being said, this might be used in locations that do not undergo frequent changes.

4) Ultra-Wide Band: Alnafessah *et al.* [7] have proposed a solution to aid Arabic-speaking blind individuals and save their time while navigating to desired destinations due to the lack of such systems in the Arabic world. The proposed system aims to integrate UWB technology and smartphones for guiding blind people from their current position to desired destination.

This system has four main functionalities: mapping, positioning, interface, and navigation. The mapping component is responsible for constructing and reading the map using a building XML representation in the localization server for a high degree of accuracy and another XML representation on the user's smartphones since the application needs to represent the map in a relatively small size. The positioning component places and sets tags in desired locations within the building. The interface component has two interfaces: a data interface for the localization server and a graphical user interface on the user's smartphones. The GUI is a voice-based system where the user listens to the voice commands and interacts by touching the screen either short or long touches and dragging to the left or right. The navigation component is responsible for finding the best route using the setup Ubisense tags and keeping track of the user until he arrives at the desired destination. Figure 3 gives on overview of the UWB system.

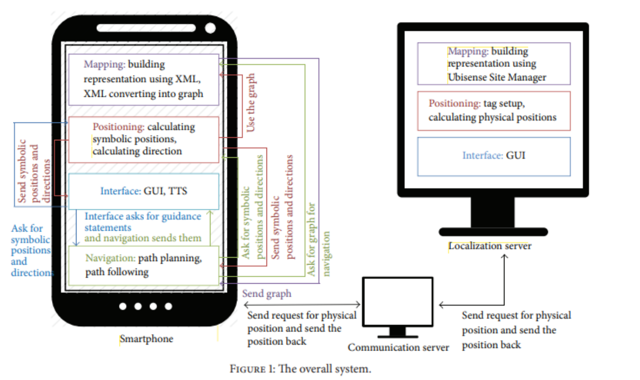


Fig. 3: UWB system overview.

To implement these functions, three main apps need development: one for the localization server, one for the communication server, and one for smartphones. The localization server is based on Ubisense's real-time location system (RLTM). To track objects Ubisense uses tags and location software. Ubisense sensors use UWB pulses to find the tags and locate them and Ubisense software manages the tags and sensors in the network. The communication server is an intermediary layer between the localization server and the smartphone since it needs to be connected to the Ubisense using Wi-Fi. Both the localization server and communication server must be connected to the same LAN. This system has achieved 100% user satisfaction in terms of touch interface and guidance statements. The system needs obstacle avoidance for efficiency and should integrate speech recognition for better user interaction.

5) LED Light and Geomagnetic Sensors: In [8] the authors proposed an indoor navigation system for blind people using visible light communication and geomagnetic correction methods. Visible light communication is a method that uses light visible to the human eye and a visible light ID system. The main components of this system are LED lights, a smartphone with an integrated receiver, headphones, and indoor map data that is expressed using a geographic coordinate system.

First, users use the touch interface to long-press on the smartphone screen to initiate voice navigation. The smartphone requests comprehensive ground location information from the location base and, upon receiving that data, notifies the user of the target along with its corresponding number. When a user enters a destination number using voice recognition, the smartphone requests a route based on location and informs the user of the whole route. While traveling, a visible light ID is transmitted from the LED light using visible light communication and is received by the smartphone receiver. The smartphone acquires a visible light ID via Bluetooth, receives real-time location information using Wi-Fi, and calculates the driving direction and distance. Guidance will be delivered to the user using the data provided. If the user deviates from the route, he will be immediately notified with the route changes. This process is repeated until the goal is reached. Figure 4 sequence diagram outlines the interaction between the user and the system, as well as between the various components.

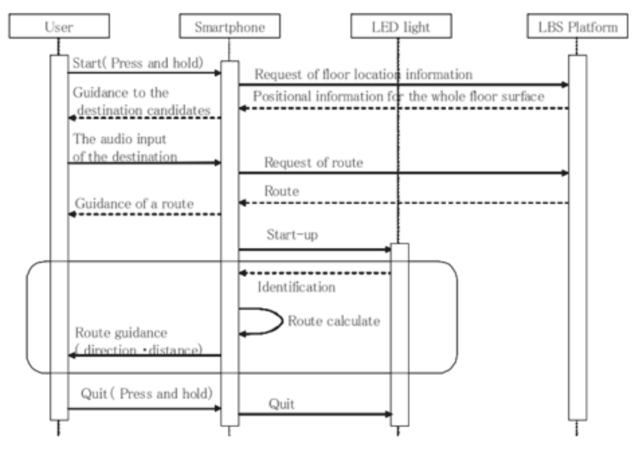


Fig. 4: Sequence diagram for navigation system using LED light and geomagnetic sensors.

According to the test results, which were done on 3 blind people and 3 people with low vision, the primary drawback arises when the smartphone is worn around a person's neck, resulting in more swinging motion than expected. Consequently, there is a deviation between the obtained geomagnetic value and the corrected value for the intended position, leading to inaccuracies. Another main disadvantage is the absence of obstacle detection. Moreover, due to floor modifications or the presence of magnetic materials in the actual space, there is a chance that circumstances will arise where the magnetic field changes and the correction is rendered ineffective.

B. Related work to stress detection

Kalimeri *et al.* [9] developed an approach for blind people stress detection when navigating in an indoor environment. The approach uses the signals of the electroencephalogram (EEG) by the EmotivEpoc+ equipment, the signals of the Electrodermal Activity (EDA), and blood volume pulse (BVP) by the Empatica E4 equipment. They conducted an experiment using an indoor route which included five different environments representative of a variety of a distinct indoor mobility challenges. Participants had to navigate through automated doors, navigate within an open space, use an elevator, ascend large spiral staircase and walk through other obstacles. The route took on average 5 minutes to walk (a range of 4–8 minutes) and was approximately 200 meters in length.

Massot *et al.* [10] used a wearable equipment called EmoSense on blind pedestrians observe the Autonomic Nervous System (ANS) in an ambulatory, non-laboratory settings experiment. EmoSense is a small device that can be mount on wrist, can be connected to various sensors and allows the measurement of physiological signals of the sympathetic and parasympathetic systems, such as heart rate, skin resistance responses and the temperature of the skin. Signals were recorded and analyzed to objectively assess stress levels among blind individuals navigating the city, aiming for a more precise understanding through localization. The goal is to confirm the psychology hypothesis regarding the impact of urban environments on stress and vigilance levels among the blind.

Moreno *et al.* [11] investigated the modulation of the autonomic nervous system on the heart of blind and normal vision subjects. Patients were submitted to Heart Rate Variability (HRV) analysis throughout three periods:resting, intervention and recovery. Intervention period consisted of short walking, handling objects and engaging in cognitive exercises through educational games while wearing sleep masks.

III. Comparative Analysis of Relevant Research for Navigation

As we showed in the previous section, various innovative solutions have been proposed to address the indoor navigation challenges faced by visually impaired individuals. These include WiFi-based systems, computer-vision and BLE technologies, Wiimotes with infrared LED systems, Ultra-Wide Band integration, and LED light with geomagnetic sensors. Each approach presents distinct advantages and limitations, such as accuracy, real-time tracking, user-friendliness, and cost considerations. Additionally, it is noteworthy that some systems lack features like obstacle detection, potentially impacting their overall effectiveness. While certain countries have mandated accessibility aids for the blind in public spaces, the adequacy of these measures poses a crucial question. This emphasizes the need for ongoing assessment and improvement to ensure full support for the visually impaired community.

In what follows, tables compare different approaches discussed in the related work section, considering various criteria

First, the Table I focuses on the ability to detect and avoid obstacles, as well as the effectiveness of the different approaches presented. There are few ready-made solutions for obstacle management, and at best, they are only moderately effective. Only CamNav and Wiimote are in that case, whereas the four other solutions cannot deal with obstacle and for BLE and LED light exhibit a low efficiency.

TABLE I: Comparing obstacle detection and avoidance, as well as the effectiveness of the considered solutions

Existing solution	Object detection	Object avoidance	Efficiency
Wi-Fi-based	No	No	Medium
BLE	No	No	Low
CamNav	Yes	Yes	Medium
Wiimote	Yes	Yes	Medium
UWB	No	No	Medium
LED light	No	No	Low

Table II allows to identify whether a solution can go from a prototype to a tool used on a large scale by blind people. Regarding feasibility and cost, on the one hand almost all solutions are possible, only CamNav seem to be more difficult to deploy, and on the other hand their respective costs range from low up to high. One can notice that the cost of CamNav is not defined, which is a second drawback in addition to its difficulty of implementation. Finally, Table III shows that there is no solution without any drawback, each one at least one problem that will affect its performance.

TABLE II: Comparing feasibility and cost of the solutions

Existing solution	Feasibility	Cost
Wi-Fi-based	High	Low
BLE	High	Medium
CamNav	Low	N/A
Wiimote	High	Medium
UWB	High	High
LED light	Low	High

TABLE III: Comparing feasibility and cost of the solutions

Existing solution	Disadvantages or problems
Wi-Fi-based	Faulty or absent AP Network configuration issues
BLE	Provision of imprecise instructions at junctions
CamNav	Delay Difficulty in maintening fixed position
Wiimote	No routing from x to y Inapplicable for dynamic locations
UWB	Absence of speech recognition
LED light	Position divergence

IV. Introducing our Navigation System Concept

Our goal is to develop a tech solution using sensor, mapping, and AI advancements for real-time guidance and spatial awareness, reducing stress during navigation indoors and outdoors.

TABLE IV: Means of biosignals values for each sector.

	Heart beats	Muscle activity	Skin conductance
Sector 1	99	510.8	325.3
Sector 2	101	510.9	364.7
Sector 3	102	510.8	372.8

TABLE V: Mean of stress levels for each sector

	Sector 1	Sector 2	Sector 3
Stress level	1.8	4	5.6

A. *Stress detection in indoor and outdoor environments*

Our earlier efforts concentrated on identifying and detecting stress experienced by blind users during outdoor navigation.

In [12], we introduced a prototype comprising a white cane integrated with a network of biosensors for experimentation and the collection of biological data related to stress. The prototype underwent testing with 6 users, revealing a correlation between unexpected situations and signal peaks in various biosignal measures. Moreover, Fig. 5 presents the heart rate variability observed among three users, showing that, as expected, the rate changes depending on the situations encountered during navigation. More recently, in [13], we implemented updates to the prototype to enhance experimental efficiency. Additionally, we restructured the previous experimental path into three sectors, prompting users to assess their stress levels on a scale from 1 to 10 for each sector. These sectors are of roughly equal lengths, with sector 3 presenting the highest density of obstacles, attributed to its location in the city center where our experiments were conducted. The mean values of biosignals, as presented in Table IV, indicate an increasing difficulty along the path, corroborated by the average stress levels reported by users across the three sectors.

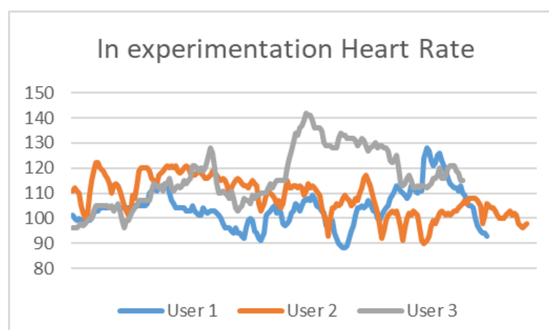


Fig. 5: Heart rate variability of the users observed in the experimentation done in [12].

Our experiments have shown that stress can be detected and is co-related to obstacles detected along the path of blind persons when navigating. For indoor environments, stress detection employs the same approach and features as outdoor settings, which implies using the same white cane integrated with the same network of biosensors used in outdoor environment to experiment and collect biological data related to stress while blind users navigate in indoor environments.

B. Navigation in indoor and outdoor environments

For the outdoor environment, based on the experimentation results, we have built an outdoor navigation system that, in an initial step, can identify the least stressful route among multiple possible routes to take between two points. After identifying the least stressful route, the system redirects the blind person in real time, using voice directions and detects obstacles in real time using machine learning techniques.

As for indoor navigation, the process begins with uploading an indoor floor plan image to a content management system (CMS). The CMS uses a third party API to convert the image into a map. An automatic labeling process is then launched to create a set of default indicators at the center of each detected room. Afterwards, the CMS user is provided with a set of visual representations in form of QR codes. Each QR code will represent a localization point inside the indoor environment.

On the other hand, a mobile indoor navigation app is used to assist the user in the navigation. It follows a simple navigation process: Users start by scanning the main QR code to load the indoor environment into their app. Once the QR code is scanned, the app connects to a database using a web API, retrieves map data to construct a virtual indoor environment forming the basis of the augmented reality (AR) voice-assisted framework. The user is then presented with the list of available destinations, from which he is recommended to choose his destination. Upon selecting his target, the user is prompted with an AR voice-interpreted guiding line, that virtually links his phone to the desired destination. The AR voice-guided line directs the user to their destination. As the destination nears, the AR lines vanish intuitively. The simple navigation process provides a user-friendly experience that makes it efficient and accessible to blind users.

For additional safety, the application integrates obstacle detection and avoidance via sensors on the user's white cane, providing verbal warnings when needed. Upon reaching the destination successfully, users are prompted to share their feedback and rate their experience. This valuable input contributes to analyze the stress at each way-point in the route and refining the app's route recommendations for future use, ensuring an improved and reliable navigation system for all users. Figure 6 represents the schematic of the indoor navigation system.

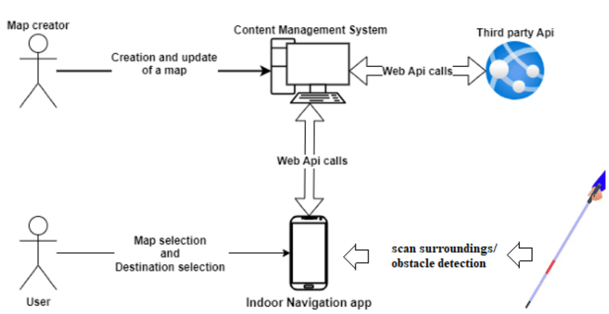


Fig. 6: Schematic of the proposed indoor navigation system.

V. Conclusion and Future Work

In a first previous work we have identified a relation between stress and obstacles while blind persons navigate outdoor. Afterward, in a second work, we have built an outdoor navigation system capable of identifying the least stressful route between two points, offering real-time navigation directions, and detecting obstacles. In this paper we have introduced the concept of an indoor and outdoor navigation system. Outdoors, this system will incorporate the existing functions of the already developed outdoor navigation system. The paper proposes adaptations for indoor navigation coupled with stress detection. Following implementation, the system will be evaluated and tested in both indoor and outdoor environments. Insights gained from this evaluation will inform updates aimed at enhancing the system accuracy and functionality across both indoor and outdoor environments.

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