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Smart Canes as Multifunctional Aids: Enhancing Navigation, Gaming, and Social Connectivity for the Visually Impaired

Par

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RESUMÉ

Les personnes souffrant de déficience visuelle rencontrent d'importants obstacles lors de la navigation, que ce soit en intérieur ou en extérieur. Reconnaitre et éviter des obstacles, qu'ils soient fixes ou en mouvement, pose des difficultés considérables, contribuant à une confiance diminuée et à une mobilité restreinte. Pour répondre aux défis auxquels sont confrontées les personnes malvoyantes, cette thèse introduit une solution novatrice sous la forme d'une canne intelligente, visant à améliorer leur mobilité et leur indépendance.

En exploitant diverses technologies, la canne intelligente proposée intègre des capteurs et des algorithmes intelligents pour fournir des retours en temps réel et une assistance à la navigation. Notre travail de recherche examine la littérature actuelle sur les systèmes de navigation en intérieure et les techniques utilisées dans les cannes intelligentes pour aider les utilisateurs à effectuer certaines tâches.

De plus, le travail fait référence à diverses études connexes sur les technologies d'assistance pour les personnes souffrant de handicap, telles qu'un script numérique pour les sourds-aveugles et les malvoyants, et un bâton blanc assisté par téléphone intelligent pour les aveugles. Cette recherche présente une architecture de canne intelligente innovante visant à autonomiser les personnes malvoyantes. Elle intègre de nombreux capteurs et offre une connectivité aux médias sociaux pour améliorer l'accessibilité et encourager l'activité physique. La canne intelligente intègre des algorithmes développés pour le comptage des pas, la détection des mouvements et la mesure de la proximité. Son architecture complète comprend des couches pour la plateforme, les communications, les capteurs, le calcul et l'interface utilisateur, fournissant une assistance complète. Les composants matériels comprennent l'interaction audio-tactile, la commande d'entrée, le microphone, le stockage local, le comptage des pas, l'intégration cloud et la batterie rechargeable. Les composants logiciels comprennent l'API de discussion Facebook, l'API Facebook Python, la bibliothèque fbchat et l'intégration de la bibliothèque de reconnaissance vocale. Ce faisant, la canne intelligente proposée offre une solution holistique pour améliorer la mobilité, l'accessibilité et l'engagement social, contribuant à une société plus inclusive et améliorant le bien-être de la communauté malvoyante. La configuration expérimentale utilisée pour tester le système de canne intelligente et les rapports sur ses performances sont également présentés. La section méthodologie décrit les objectifs de l'expérience, la compréhension des objectifs du jeu, l'évaluation de la qualité du tutoriel, l'engagement du gameplay et l'ergonomie du contrôleur. Ces résultats fournissent des informations sur les performances et l'utilisabilité du système. La discussion approfondit la méthodologie d'expérimentation, l'analyse de la compréhension des objectifs du jeu, l'évaluation de la qualité du tutoriel, l'évaluation de l'engagement du gameplay et l'évaluation ergonomique du contrôleur de la canne intelligente. Les résultats et conclusions de l'étude sont présentés, ainsi que des suggestions pour les orientations futures en matière de recherche et de développement.

Mots clés : Canne Intelligente, Technologie Assistive, Déficience Visuelle, Systèmes de Navigation, Connectivité Sociale, Intégration de Jeux, Aides à la Mobilité, Retour Sensoriel, Interface Utilisateur.

ABSTRACT

Individuals with visual impairment encounter significant hurdles during navigation, both indoors and outdoors. Negotiating obstacles, whether stationary or in motion, poses considerable difficulty, contributing to diminished confidence and restricted mobility. Addressing the challenges faced by visually impaired individuals, this thesis introduces a novel solution in the form of a smart cane, aimed at enhancing their mobility and independence. Leveraging advanced technology, the smart cane integrates sensors and intelligent algorithms to provide real-time feedback and navigation assistance. The research delves into the current literature surrounding indoor navigation systems and the techniques used in Smart Canes to aid users in performing tasks.

In addition, the work references various related studies on assistive technologies for individuals with disabilities, such as a digital script for the deaf-blind and visually impaired and a smart phone-assisted blind stick. This research introduces an innovative smart cane architecture aimed at empowering visually impaired individuals. It integrates advanced sensors and social media connectivity to enhance accessibility and encourage physical activity. The smart cane incorporates developed algorithms for step counting, swing detection, and proximity measurement. Its comprehensive architecture includes layers for platform, communications, sensors, calculation, and user interface, providing comprehensive assistance. Hardware components feature audio-tactile interaction, input command, microphone, local storage, step count, cloud integration, and rechargeable battery. Software components include Facebook Chat API, Python Facebook API, fbchat library, and Speech Recognition library integration. The proposed smart cane offers a holistic solution to improve mobility, accessibility, and social engagement, contributing to a more inclusive society and enhancing the well-being of the visually impaired community. The experimental setup used to test the Smart Cane system and reports on its performance is also reported. The methodology section outlines the objectives of the experiment, understanding of game objectives, tutorial quality rating, gameplay engagement, and the ergonomics of the controller. These results provide insights into the performance and usability of the system. The discussion elaborates on the experimentation methodology, analysis of understanding game objectives, tutorial quality assessment, evaluation of gameplay engagement, and ergonomic evaluation of the Smart Cane controller. This aims to interpret the results and draw meaningful conclusions from the experiment. The findings and conclusions drawn from the study are presented, along with suggestions for future directions in research and development.

Keywords: Smart Cane, Assistive Technology, Visual Impairment, Navigation Systems, Social Connectivity, Gaming Integration, Mobility Aids, Sensory Feedback, User Interface, Accessibility

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LIST OF ABBREVIATIONS

Internet of Things	**IoT**
World Health Organization	**WHO**
Artificial Intelligence	**AI**
Radio Frequency Identification	**RFID**
Global System for Mobile Communication	**GSM**
Global Positioning System	**GPS**
Global Navigation Satellite System	**GNSS**
Internal rate of return	**IRR**
Inertial Measurement Unit	**IMU**
Wireless Sensor Network	**WSN**
Received Signal Strength Indicator	**RSSI**
Link quality indication	**LQI**
Received Signal Strength	**RSS**
Multi-Trilateration Algorithm	**MTA**
Graphical User Interface	**GUI**
Time of Arrival	**TOA**
Smart Environment Explorer	**SEE**
Text-to-Speech	**TTS**
Virtual impairment	**VI**
Light Emitting Diode	**LED**
Operating System	**OS**
Speech-to-Text	**STT**

Augmented Objects Development Process	**AODeP**
Radiofrequency	**RF**
Ripple-inspired Fingertip Interactor	**SRFI**
Cloud Computing	**CC**
Bluetooth low energy	**BLE**
Long-range Wide Area Network	**LoRaWAN**
Support Vector Machines	**SVM**
Application Program Interface	**API**
Nonvisual Desktop Access	**NVDA**
Job Access with Speech	**JAWS**
Machine Learning	**ML**

LIST OF APPENDICES

DEDICATION

*To my revered parents, **Ahmed Messaoudi** and **Latifa Mouelhi**,*

Your enduring support and wisdom continue to be my profound source of motivation.

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this dissertation would not have been possible without the divine guidance of the Almighty, to whom I owe all my capabilities and successes, the omnipresent support of **Allah**. His presence has been the cornerstone of my resilience and achievements throughout my academic journey.

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Each of you has played a pivotal role in this academic endeavor, and for that, I am eternally grateful.

GENERAL INTRODUCTION

The number of visually impaired individuals is steadily rising, presenting a growing concern for society. These individuals face a myriad of challenges in their daily lives, primarily related to navigating their environments. Simple activities that sighted people perform effortlessly, such as walking down a street, crossing a road, or even finding a bus stop, can become daunting tasks for those with visual impairments. These challenges not only impede their mobility but also significantly impact their confidence and sense of independence.

Navigating outdoor environments poses particular difficulties. For instance, uneven sidewalks, unexpected obstacles, and a lack of clear auditory cues can make it extremely challenging for visually impaired individuals to move around safely. Furthermore, urban areas with heavy traffic and complex layouts add to the difficulty, making it essential for these individuals to remain constantly vigilant to avoid accidents and injuries. This constant need for caution can be mentally exhausting and emotionally taxing, further limiting their ability to participate fully in community and social activities.

By 2050, vision loss is expected to surge by 55% around the globe, driven by aging populations and increasing prevalence of chronic eye conditions. This significant rise underscores the urgent need for enhanced eye care services and preventive measures to mitigate the impact on individuals and healthcare systems globally.

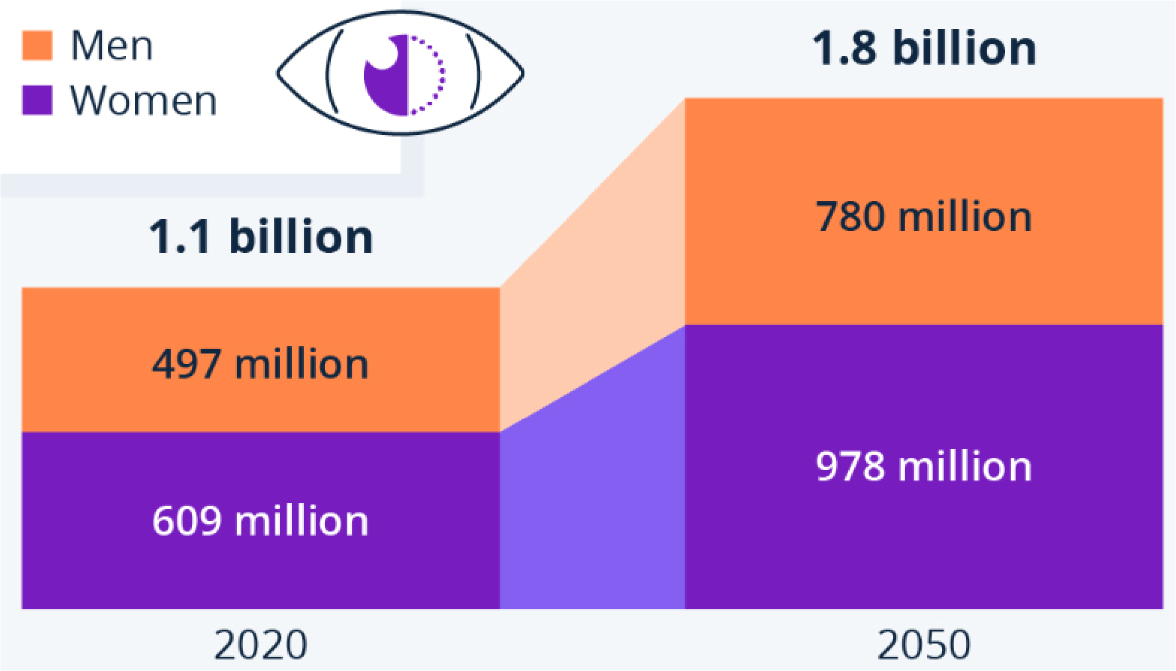


Figure 1. Expected Number of vision loss by 2050 among men and women (Anna, 2024)

Over the past few years, in Canada, individuals above 60 have been facing more problems of vision loss such that their ratio from 1/5 in 2007 has increased to ¼ in 2019. Aging is also one of the most prevalent factors that causes vision loss. Consequently, it is expected to see correlative growth in the prevalence of vision loss alongside the increasing number of senior citizens in Canada. The increase in vision loss in context to the age of Canadian individual is shown in Figure 2 below.

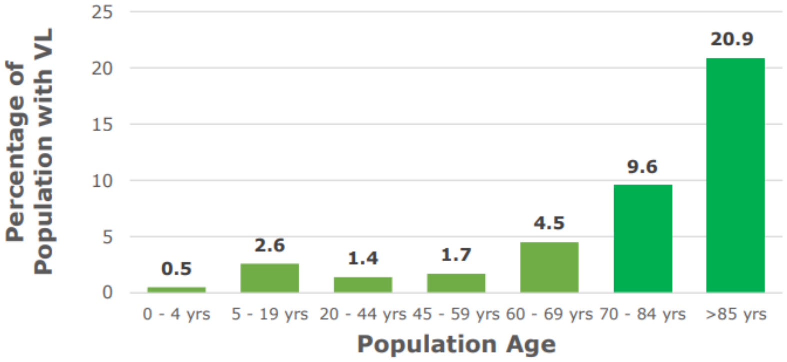


Figure 2. Prevalence of VL in Canada by Age (Summary Report, 2024)

In Canada in 2019, out of the 1.2 million individuals with visual loss (VL), 738,400 (61.3%) had mild VL, 417,600 (34.6%) had moderate VL, and 49,500 (4.1%) were blind (Summary Report, 2024). The proportion of people with mild or severe VL declines with age, whereas the proportion of individuals with moderate VL increases as shown in Figure 3.

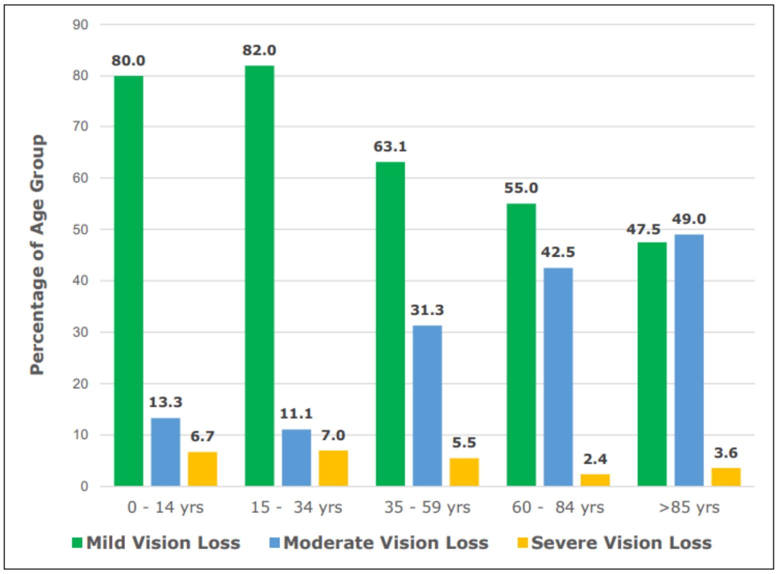


Figure 3. Prevalence of VL in Canada by Severity (Summary Report, 2024)

The indoor environment is not without its challenges either. Visually impaired people often struggle with tasks that require spatial awareness and object recognition, such as finding items in a store, reading labels, or using public transportation systems. These everyday challenges highlight the urgent need for innovative assistive technologies that can help bridge the gap and provide greater autonomy to visually impaired individuals.

As the visually impaired population continues to grow, the development and deployment of effective assistive technologies become increasingly important. These technologies can range from sophisticated navigation systems that use GPS and real-time data to guide users safely, to wearable devices that provide sensory feedback about the surrounding environment. Other advancements, such as smartphone applications that can read text aloud or describe scenes, are also crucial in aiding visually impaired individuals.

The goal of these technologies is not only to enhance safety and mobility but also to boost the confidence and independence of visually impaired individuals. By providing reliable tools that can assist them in navigating both indoor and outdoor environments, we can improve their overall quality of life and ensure they can participate more fully in society. This growing need for assistive technology underscores the importance of continued research, development, and investment in solutions that address the unique challenges faced by the visually impaired community.

The integration of assistive technology with entertainment and accessibility devices marks a promising frontier in innovation. This thesis introduces a pioneering concept: the creation of a smart cane that doubles as a gaming console. Therefore, this groundbreaking device not only serves as a mobility aid but also enhances the recreational and social experiences of its users through integrated gaming features. This smart cane has been designed to offer a compact yet powerful solution capable of processing games and interpreting sensor data from its built-in hand gesture sensor and accelerometer. The proposed smart cane ensures a seamless integration of gaming functionalities while preserving the device's mobility-enhancing features. With the inclusion of a hand gesture sensor and accelerometer, users can interact with games through intuitive gestures and motions, elevating the immersive gaming experience. This concept marks a significant advancement towards dismantling barriers for individuals with disabilities, providing them with a fresh avenue to engage with technology and entertainment without the constraints imposed by traditional devices.

RESEARCH MOTIVATION

In contemporary society, technology plays an increasingly vital role in enhancing the quality of life for individuals with disabilities. However, while strides have been made in both assistive technology and entertainment devices, the convergence of these realms remains largely untapped. By amalgamating the functionalities of a smart cane with those of a gaming console, this concept endeavors to bridge this divide by offering a multifaceted solution that caters to a spectrum of user needs.

At the heart of this innovation lies the various embedded platforms such as Raspberry Pi 5, Arduino, ESP32, Jetson Nano, Banana Pi, UP board, etc., but Raspberry Pi and Arduino serve as versatile platforms that balance computational prowess with compactness. These two microcomputers empower the smart cane to process complex gaming applications while adeptly managing sensor inputs to deliver a seamless user experience. Furthermore, their open-source nature fosters a collaborative ecosystem, facilitating continual enhancement and customization to meet evolving user demands.

Raspberry Pi and Arduino’s open-source nature further enhances their appeal, fostering a collaborative ecosystem where developers and users can contribute to continual improvements and customizations. This adaptability is crucial in meeting the evolving needs of users, allowing for tailored solutions that can grow and adapt over time. The integration of gaming functionalities with assistive technology not only aims to provide entertainment but also to enhance cognitive and motor skills, thereby contributing to a more enriching and inclusive experience for individuals with disabilities.

In essence, this research endeavors to bridge the gap between assistive and entertainment technologies, creating a unified, innovative solution that enhances the quality of life for users by addressing both practical and recreational needs. The smart cane concept stands as a testament to the transformative potential of technology, paving the way for a future where assistive devices are not only functional but also engaging and empowering.

PROBLEM STATEMENT

Inclusivity stands as a central tenet of this concept. Traditional assistive devices often prioritize functionality over user experience, resulting in devices that are utilitarian but lack engagement. By integrating gaming features, the smart cane transcends its conventional role, morphing into a dynamic tool that fosters recreation, social interaction, and personal empowerment. Through this innovative approach, individuals with disabilities are emboldened to explore new realms, challenge societal norms, and redefine the boundaries of accessibility. This thesis explores three key areas of research aimed at addressing the mobility needs of the visually impaired.

Functional Integration:

- Investigating the seamless incorporation of gaming features into the smart cane, ensuring that the device remains both practical and engaging.
- Analyzing how the combined functionalities can enhance the daily lives of users, providing both navigational assistance and recreational opportunities.

Technological Advancements:

- Leveraging the capabilities of embedded platforms such as Raspberry Pi and Arduino to balance computational power with compactness and efficiency.
- Exploring the collaborative potential of open-source technologies to facilitate continuous improvement and customization.

User-Centric Design:

- Prioritizing user experience in the design process to create an intuitive and enjoyable interface.
- Ensuring that the smart cane is adaptable to the diverse needs of individuals with disabilities, promoting inclusivity and personal empowerment.

Through this comprehensive research, the aim is to create a smart cane that not only meets the functional needs of the visually impaired but also enriches their lives by providing opportunities for recreation and social interaction. This endeavor strives to set a new standard for assistive technology, where devices are designed with both utility and user engagement in mind, ultimately contributing to a more inclusive and empowering society.

Chapter 1 conducts a comprehensive review of various navigation-assistive tools and technologies designed to aid visually impaired individuals in their everyday movements. By examining various techniques and state-of-the-art assistive technologies, this chapter seeks to shed light on the advancements and challenges in this field.

In Chapter 2, the focus shifts to the development of an Autonomous Smart White Cane Navigation System tailored for indoor usage. Recognizing the limitations of traditional white canes, this chapter introduces a technological solution, a Smart Cane device that leverages cloud computing and IoT wireless scanners to facilitate indoor navigation for visually impaired individuals.

In Chapter 3, a novel social media integration of the Smart Cane is shown, along with a new step counter algorithm intended to further empower those who are visually impaired. This chapter examines how technology may improve accessibility, promote physical activity, and increase social engagement for the visually impaired population by integrating modern sensors with social media.

Chapter 4 provides detailed problem under study in this research revolves around the development and evaluation of a Smart Cane system for indoor navigation. Indoor navigation systems play a crucial role in assisting visually impaired individuals in navigating complex indoor environments efficiently and safely. The specific focus of this study is on enhancing the functionality and usability of Smart Canes to improve the independence and quality of life for visually impaired individuals.

RESEARCH OBJECTIVES

The general objective of this work is to design, implement, and assess the effectiveness of a Smart Cane system that integrates advanced technologies to facilitate indoor navigation. By leveraging techniques such as triangulation principles, object detection, and route determination, the aim is to create a system that enhances the user experience and provides accurate navigation assistance in indoor settings.

The specific objectives of this research include:

- Investigating the current literature on indoor navigation systems to understand the principles and techniques employed in similar systems.
- Designing and implementing a Smart Cane system that incorporates innovative features to improve navigation efficiency.
- Conducting experiments to evaluate the system's performance in terms of understanding game objectives, tutorial quality, gameplay engagement, and ergonomic evaluation of the controller.
- Analyzing the results of the experimentation to draw conclusions regarding the system's effectiveness and identifying areas for future research and development.

RESEARCH QUESTIONS

The research questions guiding this study include:

- R1Q: How can advanced technologies be integrated into Smart Cane systems to enhance indoor navigation for visually impaired individuals?

- RQ2: What are the key factors influencing the usability and effectiveness of Smart Cane systems in indoor environments?
- RQ3: How do users perceive the Smart Cane system in terms of game objectives understanding, tutorial quality, gameplay engagement, and ergonomic controller evaluation?

METHODOLOGY

The methodology of this paper follows the approach discussed in previous related literature “Autonomous Smart White Cane Navigation System for Indoor Usage” (Messaoudi, Menelas and Mcheick, 2020), “Integration of Smart Cane with Social Media: Design of a New Step Counter Algorithm for Cane (Messaoudi, Menelas and Mcheick, 2024)”, and “Innovating Accessibility: A Smart Cane Game Console Integration”. Each of the papers mentioned above follows the methodology starting from a literature review and user requirements evaluation. The development phase includes the designing as well as prototype building tailored to the particular aims such as navigation assistance, social media integration, and gaming features. In all of the above papers, user testing and iterative refinement play a significantly important role in improving usability as well as effectiveness. Both qualitative and quantitative data analysis approaches have been employed to assess user satisfaction along with the system's performance. Eventually, these methodologies contribute to the technological advancement tailored for all the individuals who are suffering from visual impairments with a focus on enhancing navigation assistance, gaming experience as well as social engagement.

Following a similar approach, this research employs an experimental analysis to assess the performance and usability of the Smart Cane system. By conducting systematic experiments and analysis, the study aims to provide valuable insights into the design and implementation of assistive technologies for indoor navigation.

This sets the stage for a comprehensive exploration of the development and evaluation of a Smart Cane system for indoor navigation, focusing on enhancing the independence and mobility of visually impaired individuals in indoor settings. Through a systematic approach, this research aims to contribute to the advancement of assistive technologies and improve the quality of life for individuals with visual impairments.

Additionally, visually impaired individuals will be engaged in usability testing to gather direct feedback on the Smart Cane’s interface and functionality. This will involve assessing user satisfaction, ease of use, and the overall user experience to ensure that the Smart Cane meets the practical needs and preferences of its users. Through this systematic approach, the research aims to contribute to the advancement of assistive technologies and improve the quality of life for individuals with visual impairments by providing a reliable and engaging solution for indoor navigation.

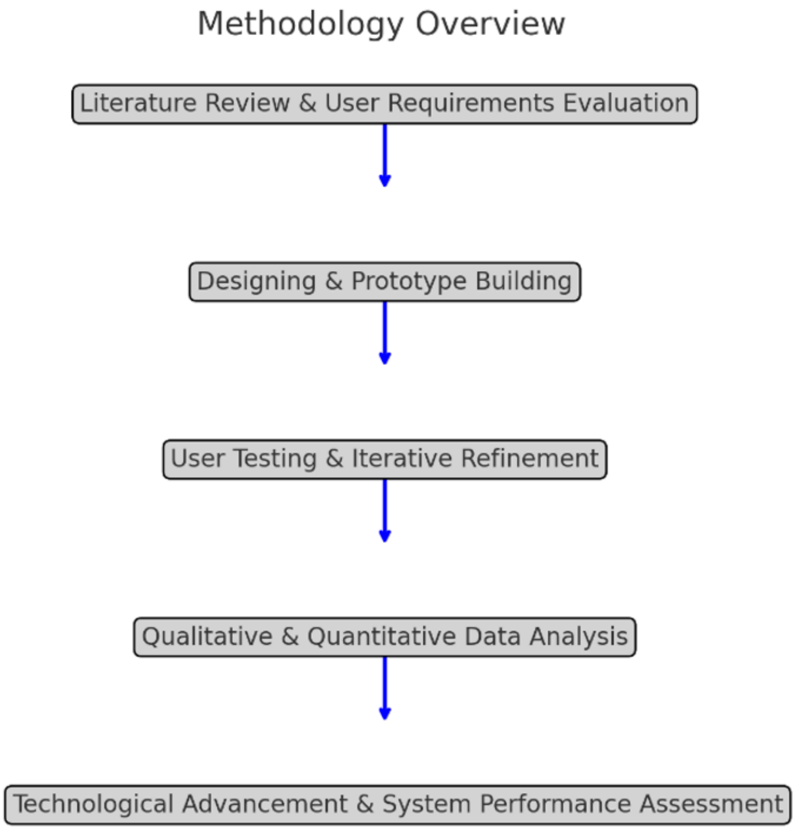


Figure 4. Methodological Overview

CHAPTER 1

REVIEW OF NAVIGATION ASSISTIVE TOOLS AND TECHNOLOGIES FOR THE VISUALLY IMPAIRED

Messaoudi, M. D., Menelas, B. A. J., & Mcheick, H. (2022). Review of navigation assistive tools and technologies for the visually impaired. Sensors, 22(20), 7888.

Résumé : Les personnes malvoyantes souffrent énormément lors de leurs déplacements d'un endroit à un autre. Elles rencontrent des difficultés pour se déplacer à l'extérieur et pour se protéger des objets en mouvement ou immobiles, et elles manquent également de confiance en raison de leur mobilité restreinte. En raison de l'augmentation rapide du nombre de personnes malvoyantes ces dernières années, le développement de dispositifs d'assistance est devenu un domaine de recherche significatif. Cette étude de revue présente plusieurs technologies qui ont été proposées pour aider les personnes malvoyantes dans leur mobilité et expose l'état de l'art des récentes technologies d'assistance qui facilitent leur vie quotidienne. Elle analyse également de manière exhaustive plusieurs technologies d'assistance à la mobilité pour les environnements intérieurs et extérieurs, et décrit les différentes méthodes de localisation et de retour d'information pour les personnes malvoyantes utilisant des outils d'assistance basés sur les technologies récentes. Les outils de navigation utilisés par les personnes malvoyantes sont discutés en détail dans les sections suivantes. Enfin, une analyse détaillée des différentes méthodes est également réalisée, avec des recommandations pour l'avenir.

Abstract: The visually impaired suffer greatly while moving from one place to another. They face challenges in going outdoors and in protecting themselves from moving and stationary objects, and they also lack confidence due to restricted mobility. Due to the recent rapid rise in the number of visually impaired persons, the development of assistive devices has emerged as a significant research field. This review study introduces several techniques to help the visually impaired with their mobility and presents the state-of-the-art of recent assistive technologies that facilitate their everyday life. It also analyses comprehensive multiple mobility assistive technologies for indoor and outdoor environments and describes the different location and feedback methods for the visually impaired using assistive tools based on recent technologies. The navigation tools used for the visually impaired are discussed in detail in subsequent sections. Finally, a detailed analysis of various methods is also carried out, with future recommendations.

INTRODUCTION

Vision-based methods are a specialized method of allowing people to observe and infer knowledge elicited from the environment. The environment may not only be restricted indoors but may extend outdoors as well. A visually impaired person usually faces several challenges for safe and independent movement both indoors and outdoors. These challenges may be more considerable while navigating through an outdoor environment if a person is unfamiliar with the new background and context due to reduced and contracted vision. To overcome mobility restrictions such as walking, shopping, playing, or moving in an outdoor environment, many assistive tools and technologies have been proposed as wearable devices, allowing users to interact with the environment without triggering any risk. These assistive tools improve the quality of life of the visually impaired and make them sufficiently capable to navigate indoors and outdoors (Zafar et al., 2022).

Statistics published by the World Health Organization have revealed that one-sixth of the world population is visually impaired, and that figure is sharply increasing (Giudice et al., 2008). Becoming visually impaired or blind does not imply that a person cannot travel to and from locations at any time they desire. These individuals with visual deficits and diseases require support to complete everyday tasks, which include walking and investigating new areas, just as an average person without disabilities does. Insecure and ineffective navigating ranks among the most significant barriers to freedom for visually impaired and blind persons and assisting these visually impaired users is an important research area. Traditionally, guide dogs and white canes have served as travel assistants. However, they can only partially provide independent and safe mobility. Recent advances in technologies, however, have broadened the spectrum of solutions. From solutions based on radars in the mid-20th century to the current Artificial Intelligence (A.I.), emerging assistive techniques have played a vital role in designing wearable devices for the visually impaired. State-of-the-art techniques in these primary wearable assistive devices incorporate Global Systems for GSM mobile communication along with G.P.S tools and techniques that automatically identify the location of the wearer and transfer that location to their guardian device (Surendran et al., 2018).

Similarly, Electronic Travel Aids are based on sensors such as infrared, ultrasonic, Radio Frequency Identification (RFID), and G.P.S. to perceive the environment, process the information, and detect objects (Dos Santos et al., 2021b). Further, many persons are unable to play video games because of visual impairments and have restricted accessibility while interacting with video games and taking part in various educational, social, and physical activities (Sekhavat et al., 2022). Game-based approaches to training in navigation systems in unfamiliar environments can help the players build a reliable spatial cognitive map of the surroundings, while audio cues processed by sonification can help players recognize objects in the gaming environment. For example, verbal notifications can help players grasp their location and tell them which task must be accomplished. On the other hand, non-verbal cues can indicate the meta-level of knowledge regarding the target object's location, direction, and distance to build spatial cognitive maps (Theil et al., 2023).

While considering the popularity of smart devices among the visually impaired, an optimized solution using a smartphone does not yet exist (Huang et al., 2022, Al-kafaji et al., 2020, Simões et al., 2020). This review study addresses various solutions that allow visually impaired users to walk more confidently across a street. Moreover, smartphone-based solutions are extended to both indoor and outdoor environments. However, no efficient solution for a real-time indoor navigation system exists yet either. A comparison of current navigation systems is shown in Table 1, which also allows a subjective evaluation of the technologies based on user needs.

Table 1 : Comparison of Existing Technologies Based on Different Technologies

Technology	**Technique**	**Indoor**	**Outdoor**	**Requirement of Infrastructure**

Direct Sensing	RFID	✓	✓	✓
	Bluetooth	✓	✓	✓
	I.R.R.	✓	-	✓
	Barcodes	✓	✓	✓
Dead Reckoning	IMU	✓	✓	-
Triangulation	From direct sensing	✓	✓	✓
	GNSS	-	✓	-
	Fingerprint	✓	✓	-
Pattern Recognition	Markers	✓	✓	-
	Natural Elements	✓	✓	-
	3D Sensing	✓	✓	-

In contrast with the indoor environment, the GPS-based navigation systems consume more power in the outdoor environment than proposed technologies such as Zigbee and Bluetooth (Vijayalakshmi et al., 2022). Bluetooth is not comparable with ZigBee due to its power consumption. If an application is operated for an extended period on a battery, e.g., using G.P.S., Bluetooth will not be adequate. Bluetooth design recommends one watt of power consumption. Still, when combined with wireless G.P.S. applications, the power consumption of both Bluetooth and ZigBee is between 10 and 100 milliwatts (mW), which is 100 times less than previous Bluetooth designs (Gupta and Singh, 2021). With Wireless Sensor Network (WSN) technology, tracking and navigation have become more accessible and convenient. In fact, WSN has progressed as a dominant field of research. Thus, multiple tools and technologies have been proposed in the literature and incorporated into natural environments to assist visually impaired users. Similarly, several surveys and reviews have summarized state-of-the-art assistive technologies for visually impaired users. These technologies provide a broad spectrum of techniques that could further progress (Walle et al., 2022, Tapu et al., 2020, Elmannai and Elleithy, 2017).

Various experiments conducted by researchers used an audio screen linked with N.V.D.A.D.A. screen reading software. The audio screen allowed a blind user to move the fingers, pen, or mouse on the picture shown on the screen and hear information about the part they touched. The user could explore the maps of countries, colors of the rainbow, and cartoon characters. The audio screen allowed the user to hear the description of the text (font, size, and color) The audio screen was further divided into two output modes. The first was "pitch stereo grey," which was helpful in the description of images, maps, and diagrams. The second one was "HSV Colors," which described the variations in colors of photographs (Halimah et al., 2008).

Multiple articles were reviewed in detail while formulating this survey article. The obstacle recognition method, feedback methods, and navigation technologies for the visually impaired are briefly explained in Section 2. Different navigation and feedback tools are discussed in Section 3, while Section 4 contains discussions about the papers. Section 5 concludes the research survey, provides future directions for researchers, and presents the pros and cons from the perspective of visually impaired users.

NAVIGATION TECHNOLOGIES FOR THE VISUALLY IMPAIRED

1.1.1 LOCATION METHODS

Several indoor and outdoor orientation and navigation-based solutions exist commercially for the visually impaired, which are also in active research and development. This section briefly explains multiple wireless navigation methods, including ZigBee, Bluetooth, Wi-Fi, and GPS-based ultrasonic sensors. Moreover, several approaches have been applied for utilizing Wi-Fi hotspots for indoor localization and navigation. Wi-Fi-based strategies incorporate Received Signal Strength Indicator (RSSI) localization methods for measuring the signal strength and calculating the geographical location using G.P.S using Triangulation (Plikynas et al., 2020). The following subsections discus and analyze the processes and their applications.

1.1.1.1 TRIANGULATION

Almost every direct-sensing technique aims to locate the user by sensing a unique identifier. However, some systems also employ various identifiers and incorporate computational triangulation approaches to determine the user’s location. These methods/techniques determine such a location using triangulation-based sensors installed in specified areas. The tags frequently incorporated for the localization of users include RFID, ultrasound, Bluetooth, and infrared (Fernandes et al., 2019).

1.1.1.2 TRILATERATION

Trilateration is a method used to measure a point location by utilizing the geometry of triangles, circles, or spheres. The triangulation uses the measurement of the angle to determine location, while trilateration uses the measurement of distance. To provide accurate global surface and geographical locations, Land Surveys and G.P.S use this method.

1.1.2 INNOVATION AND LOCALIZATION TECHNOLOGIES

1.1.2.1 TRIANGULATION USING GPS-BASED SYSTEM

The Global Positioning System (G.P.S.), which operates 27 satellites orbiting the earth, is mainly used for outdoor navigation. The satellites are positioned at any point on the planet, which is covered by at least four satellites at any particular time. Each satellite sends positional information about itself (ephemeris) and all other satellites (almanac). The G.P.S receiver determines its distance from several satellites using data from the ephemeris that employs the triangulation principle, by which the time the data are sent is compared to the time it is received. Thus, at least three satellites are needed to complete the process. However, more satellites allow better precision. This method requires the G.P.S receiver to be well exposed to the satellite, which prevents indoor locations.

G.P.S systems are widely used for outdoor navigation (Ramadhan, 2018). The main disadvantage of G.P.S. localization is that the G.P.S. signal strongly degrades inside buildings, between tall buildings, or in dense forest areas (such as parks) (Katzschmann et al., 2018). G.P.S. is inadequate for visually impaired individuals because of its low precision. It also becomes challenging to use such systems in locations with unknown obstacles. Technologies that use these G.P.S systems, such as guide canes and Braille signs, are not viable options for visually impaired individuals to find their way in new outdoor environments (Cecílio et al., 2015). A G.P.S. position or location is measured based on distance from other objects or points with known sites. The area of each of the satellites is already known with accuracy, and a G.P.S. receiver measures the distance from an object with the help of the satellites (Villanueva et al., 2011).

1.1.2.2 TRIANGULATION USING THE ZIGBEE-BASED SYSTEM

ZigBee (Gonçalo and Helena, 2009) is a wireless navigation technology for the visually impaired that can be used in indoor/outdoor navigation systems. It has high accuracy in location, wide-coverage, simple infrastructure, reduced cost, quick real-time navigation, and lower power consumption. ZigBee Triangulation is based on IEEE 802.15.4, which uses the 868 MHz band in Europe, the 915 MHz band in North America, and the 2.4 GHz band (Karchňák et al., 2015).

This triangulation process is used to transmit signals at long distances among the devices within the wireless mesh networks as shown in Figure 1. This process is known to have a low data transfer rate, low cost, and short-latency time compared to other Wi-Fi standards. As per the IEEE standards of 802.15.4, “Link quality indication (L.Q.I.)” is taken as the process to specify the link quality and is exploited to derive the “Received Signal Strength (RSS)” (Jeamwatthanachai et al., 2019).

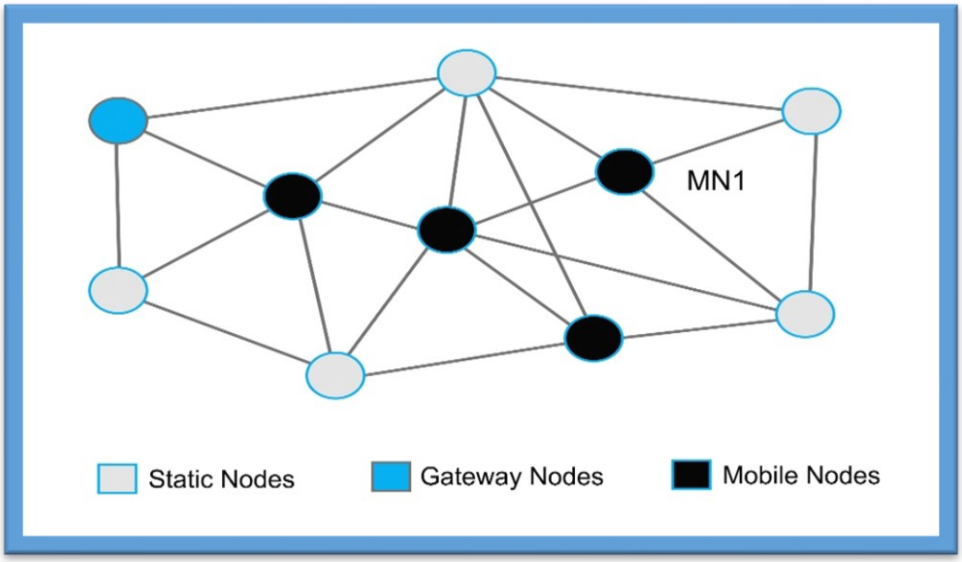


Figure 5. ZigBee Triangulation Mesh Network

Xiao et al. (Xiao et al., 2016) designed the structure of a multi-sensor-based innovative system that gives a “high monitoring accuracy” for users’ status and position. The ZigBee-based system consists of multiple sensors, such as an ultrasound transmitter and receptor, temperature sensors (LM35), a tilt-compensated compass, “liquid propane gas (Figaro LPM2610)”, and stick and accelerometer. Moreover, “ZigBee wireless protocols” were also used for XM2110 modules. The user’s navigation and tracking were deployed and executed with a “multi-trilateration algorithm (M.T.A.).” Navigation accuracy came out to be 3.9 cm in a real-time scenario.

1.1.2.3 TRIANGULATION USING A BLUETOOTH-BASED SYSTEM

Another category for wireless systems is based on the Bluetooth Triangulation (Freitas et al., 2008) method, as it is an easy method already deployed in mobile phones, cameras, handheld devices, and gadgets that can be connected over a shorter distance. It is low cost, has a reduced weight and reduced size, and provides power savings. However, Bluetooth can only communicate over a shorter distance and has limitations when used in an application that involves communication over long distances as shown in Figure 2 (Andò et al., 2015) .

The Bluetooth triangulation method was used where Bluetooth module WT-12 was first proposed by Bluegiga; this module is considered Class 2 Bluetooth, with a range of 10 m and an in-built chip antenna (Zhuang et al., 2016). In this study the module was combined with the evaluation board, which was used as an inquiry generator for each Bluetooth receiver. In addition, a G.U.I (Graphical User Interface) was developed to calculate and estimate the RSSI designed to record every value from the register of the Bluetooth Module after the inquiry cycle. Furthermore, M.A.C. addresses of every Bluetooth module with their location on a 15 × 15 grid were also entered before the testing. In the whole process, the inquiry cycle ran 25 times on each spot, for which the coordinates were changed manually after each run (Chaccour et al., 2015, Kanwal et al., 2015, Li et al., 2018).

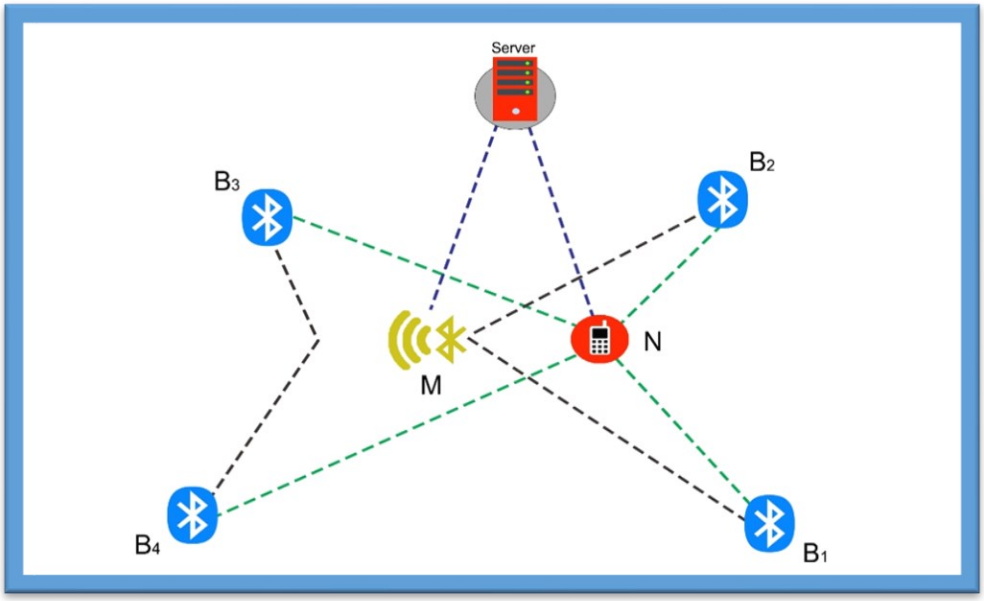


Figure 6.Bluetooth Triangulation

In a study by Andò et al. (Andò et al., 2015), the proposed method allows people with disabilities to navigate in an indoor environment. The study measured the system performance based on the W.S.N. system, which enhances the lives of the visually impaired, wheelchair users, the deaf, or persons with other physical disabilities by helping to locate them and their surroundings and navigate them to their destination. The system's structure comprises a smartphone and wireless technology of Bluetooth and a routing engine for navigating persons, and RSS and WASP for facilitating communication through a smartphone. The Bluetooth-based navigation system showed an efficiency of about 90% in a study carried out with ten users.

1.1.2.4 TRIANGULATION USING A WI-FI-BASED SYSTEM

A Wi-Fi-based navigation (Lim et al., 2007) system enables device connection anytime, anywhere, at home, work, shopping malls, and in hospitals. It is compatible with different systems, from medical devices to printers and tablets. While using Wi-Fi has advantages over other systems, one drawback of this technology is its high-power consumption. It also takes some time to establish a connection, which may create problems, especially for blind persons (Sthapit et al., 2018).

The authors in (Elmannai and Elleithy, 2017) presented a better system for indoor navigation of blind persons. Initially designed for locating nurses and doctors or other patients in a hospital, it can also be used to find blind persons, as the technology is based on a Wi-Fi system. The system is comprised of two kinds of navigation or localization systems, one used for nurses or doctors and the other for patients. The position of patients is located on their call button, a transceiver module, a small USB stick equipped with TCM 310, and a computer, and is identified through the trilateration technique. The nurse's navigation prototype, in contrast, is comprised of mobile phones, Wi-Fi, and alarms. The nurse's position is established using the "time of arrival (TOA)" method. The results for position precision among patients and nurses came out to be 3 m and 2 m, respectively.

In (Kanan et al., 2016), Wi-Fi triangulation was used to help blind people move about places near their location. In this article, the system was designed to assist in detecting and locating indoor areas so that no human or manual assistance is required to reach any location. The system mainly uses Wi-Fi signals. Wi-Fi was set up in various malls, buildings, and commercial places that had many strong Wi-Fi access Internet points to help the blind and the visually impaired navigate those indoor locations. The primary purpose of the proposed design was to identify the locations within the building and colleges, all of which was completed using the Wi-Fi triangulation approach. As the Wi-Fi is fixed within the buildings at each point, it becomes helpful for the signals to be transmitted from the Wi-Fi access points, which can be accessed via a smartphone or any other smart gadget helping to navigate as shown in Figure 3.

For further assistance in the localization of blind persons, a navigational map was created. With its help, a site is mentioned by detecting the Wi-Fi spot in a specified place which is further shown up by the point/dot that can be understood easily. Using this dot, a place can be navigated to efficiently. However, the important thing is to design an exact map of the place .

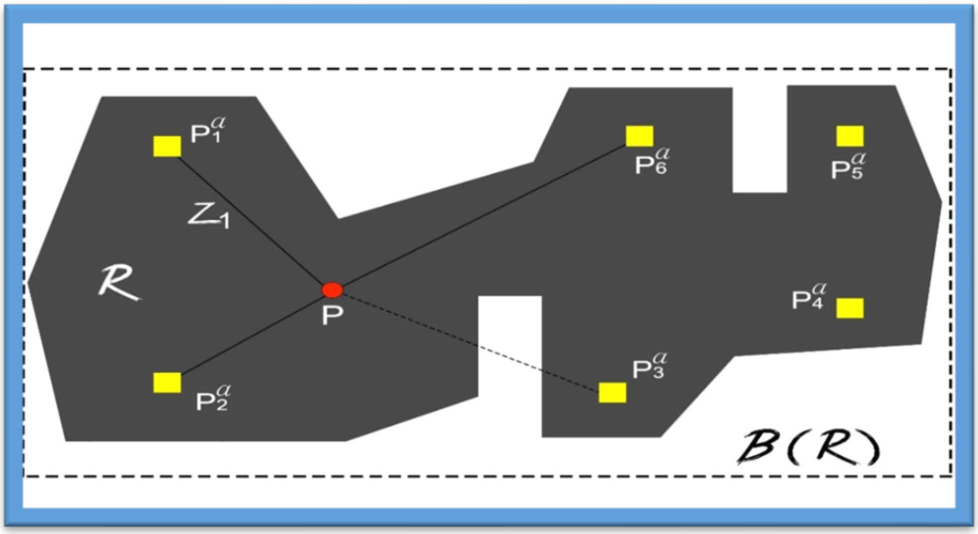


Figure 7 : Navigation Using Wi-Fi Triangulation

1.1.3 OBSTACLES RECOGNITION METHOD

Many methods are used to detect obstacles. These methods can be explained as follows.

1.1.3.1 THE TECHNOLOGY OF A CAMERA-BASED IMAGE PROCESSING NAVIGATION SYSTEM

This real-time technology alerts the visually impaired to any dynamic or static obstacles within a range of meters; it works without smartphones and uses a camera to detect background motion. This system requires no previous knowledge of the obstacle size, position, or shape (Gomes et al., 2018). While the camera-based image processing system is a good choice, its drawbacks are its high processing power, which makes it costly and challenging to use. The camera takes real-time images, which are processed to detect obstacles within a range of some meters quickly. In (Marco and Farinella, 2018), the authors explained how cutting-edge machine vision methodologies offer tools to assist with basic human needs such as psychological capacity, individual movement, and activities of daily living. They also discussed how data preprocessing, pattern classification, and computer vision work along with robotic systems to offer these methods. Users will gain knowledge of new computer vision methods for assisting mental abilities, strategies for assessing behaviour, and of the development of sophisticated rehabilitative solutions that mimic human movement and engagement using intelligent displays with interactive virtual technologies. The researcher's goal was to examine the vision replacement perspective that focuses on image processing and computer vision (Patel et al., 2022). This article's main objective was to investigate gadgets that use detectors and codes. The report showed that a few assistive devices are sold commercially.–The perceptions and financial benefits of blind people influence the most generally available types of technology.

Another mobile camera-based navigation system for the visually impaired was proposed in (Caldini et al., 2015). This system uses pre-stored images of the floor to guide people in finding the obstacle-free route by comparing current floor images with pre-stored images and checking for introduced obstacles. Table 2 provides detailed information on camera-based image processing navigation systems with proposed models.

Table 2 : Summary of Various Camera-Based Navigation Technologies

Ref Paper	**Title**	**Proposed Model**
(Andò et al., 2015)	RGB-D camera-based navigation for the visually impaired	This system considers local and global frame localization and uses a feedback vest to deliver the navigational cues.
(Zhuang et al., 2016)	Visual odometry and mapping for autonomous flight using an RGB-D camera	This model is comprised of an rgb-d camera that provides a 3D point cloud. i.m.y. offers an initial orientation where the point cloud is downsampled to a 3D voxel grid display to the global frame using an odometry algorithm.
(Chaccour et al., 2015)	Enabling Independent Navigation for the visually impaired through a Wearable Vision-Based Feedback System	This model consists of a feedback module, a camera, and an embedded computer. It identifies a safe motion trajectory and communicates this safer route information with the user through a sequence of vibrations.

1.1.3.2 APPROACH OF ULTRASONIC SENSOR-BASED NAVIGATION SYSTEMS FOR BLINDS

Ultrasonic sensor-based technology is the last wireless category to be discussed within the scope of this paper. This technology is based on “ultrasound waves”. The distance between the ultrasonic transmitter and reflector is calculated based on the “arrival and reflected” time. The drawback of this technology is the “short communication range,”, and the inclusion of L.O.S. among obstacles and sensors is considered essential (Wang et al., 2017).

In (Caldini et al., 2015), a “smart environment explorer (SEE)”-based stick system was designed and proposed for blind people. The system guides the visually impaired and helps enhance the ability for “space consciousness.” In addition, the proposed system helps estimate the position of the blind person or of any user. It helps identify any hurdle in their way. The method comprises an ultrasonic sensor, accelerometer, camera, G.P.S., wheel encoder, smartphone, and routing protocol. It makes use of the “reduced inertial sensor system (R.I.S.S.)-G.P.S.-linear Kalman filter (L.K.F) algorithm” for tracking estimation. The initial results of the system have proved successful for blind people in walking, tracking, and detecting traffic lights, even for very short-range tracking. Table 3 incorporates the study of different algorithms used in wireless technology for the visually impaired.

Table 3 : Summary of Various Navigation Techniques

Ref Paper	Objective	Wireless Technology	Algorithm
(Cecílio et al., 2015)	Navigation	Bluetooth	Distributed Indoor Navigation
(Li et al., 2018)	Navigation	RFID	User positioning and Tags
(Karchňák et al., 2015)	Route planning and navigation	Wi-Fi	Wi-Fi-based positioning
(Kanwal et al., 2015)	Navigation	Infrared L.E.D.	Obstacle detection
(Lim et al., 2007)	Obstacle detection and navigation	Ultrasonic sensor	RISS-GPS-LKF

1.1.3.3 TECHNOLOGY OF THE SPEECH-TO-TEXT-BASED NAVIGATION SYSTEM

Using various computational devices, speech-to-text-based navigation systems are developed technologies that make blind or visually impaired persons recognize and translate the verbal/spoken language into text. The S.T. technology is also known as “automatic speech recognition (A.S.R.)” and “Computer Speech Recognition (C.S.R.)”.

1.1.3.4 TECHNOLOGY OF THE TEXT-TO-SPEECH-BASED NAVIGATION SYSTEM

Text-to-Speech (TTS) technology (Luo et al., 2021) is the process where the electronic device is made to render the text from any document or image into speech. For this purpose, the natural language processing phenomenon is used. Several examples of text-reading applications include label reading, the BrickPi reader, voice stick, or pen reading. In addition to that, the finger-reading technique has also been developed under TTS technology. Table 4 provides initial information on audio assistance and speech recognition inputs and their costs and limitations.

Table 4 : Summary of Various Audio-Assisted and Speech Recognition-Based Navigation Technologies

Audio Assistance and Speech Recognition	
Voice Input	The systems such as Google Assistant and Siri take your voice as input to provide a precise output
Cost-Efficient	The visually impaired person only needs a smartphone installed with Speech Recognition assistance that will guide him in a human-like voice
Limitation	Speech Recognition and Assistance needs a stable wireless connection to provide you with voice output.

1.1.4 METHODS FOR INFORMING THE VISUALLY IMPAIRED

Several assistive methods assist the visually impaired in conveying environmental information. The most common feedback is audio and vibration; the audio methods can be further classified into generic audio and bone conduction. The authors of (Yusro et al., 2014) examined a variety of cellphone technologies targeting persons with visual impairments. According to their research, interest in developing and designing methods to assist and enhance persons who are VI is growing. They looked at several assistive technology options and considered this study to be a future attempt to handle various technology tools in a cohesive system that gives the necessary assistance for persons with VI, even though the tools are rarely integrated and are aimed at multiple programs. They advised creating a solid system that can coordinate a variety of programs that offer the best assistance and support possible for persons with VI, including those who are blind or have low vision.

1.1.4.1 HAPTIC FEEDBACK

A commercialized product called WeWalk helps the VI detect obstacles above the chest level by utilizing an ultra-sonic sensor (Karkar and Al-Maadeed, 2018). This can also be connected to a cane using Bluetooth with the help of the mobile application. The communication with the user uses haptic feedback to make them aware of the surroundings. Another commercially available product, SmartCane (Phung et al., 2016), uses light and ultrasonic sensors to inform the VI user about the environment and uses audio and haptic feedback/vibration to warn the user of the surroundings. In (Singh et al., 2014), the author presented a technology to assist the VI person that uses haptic feedback. This unit detects obstacles above the knee via ultra-sonic sensors. In (Bosse, 1977), the author presented another technology for VI users that uses haptic feedback/vibration to warn the VI person of the obstacle.

Haptic feedback can be divided into three categories: vibrotactile, shape-changing, and kinesthetic feedback.

Vibrotactile

This feedback can be used on various body parts such as the shoulder (Kay, 1980), heads (Ross and Lightman, 2005), waists (Kuc, 2002), feet (Ulrich et al., 2001), wrists (Abu-Abdoun et al., 2022), hands (Reed, 1982), etc., which is the most common type of haptic feedback. Direct and indirect mapping can define the relationship between direction and vibration. In indirect mapping, the researchers used a pattern of vibration that indicates the movement, such as in Pocket Navigator (Hoyle and Waters, 2008); two short pulses indicate movement ahead. In mapping, a direct spatial relationship exists between the target direction and location of vibration (Villamizar et al., 2013).

Shape-Changing Feedback

The direction indication can also be carried out using a feedback method called shape-changing, such as the Tactile Handle. This device is based on the shape of a barbell with proximity sensors, actuators, and an embedded micro-controller. This controller is used to match the phalanxes of a finger. The direction is indicated directly by torsion and vibration (Cardin et al., 2007).

Kinesthetic Feedback

The directional cues can also be provided by kinesthetic feedback. In (Akita et al., 2009), the author presented a new indicator for direction. The method of kinesthetic perception is based on the hand of haptic direction. This method is called a pseudo-attraction force which uses a nonlinear relationship, and a force sensation is generated between physical and perceived acceleration. Another (Ifukube et al., 1991) way was presented by the author based on the haptic feedback method in which kinesthetic stimuli are provided to help the VI user navigate.

1.1.4.2 GENERIC AUDIO FEEDBACK

In (Shoval et al., 1994), the author presented an assistive aid called the Smart White Cane that uses audio and haptic feedback methods to communicate information to VI users about their surroundings. In this, the ultra-sonic sensors are used to detect the downfalls, potholes, pits, staircases both up and down, low knee-level obstacles and obstacles above the waste. In this, the feedback method of vibration and pre-recorded audio is used.

Systems with 3D Sound

In the system introduced by the author of (Meijer, 1992) for the visually impaired, the user is helped by creating tactile and auditory representation methods that give information about the surroundings through haptic and audio feedback. This device is based on molded headgear and has a stereo camera and earphones.

Sonification Method

Another method used to convey information to the visually impaired is sonification, which is based on non-speech audio and transmits information to the user. It transforms data relations into perceived relations using an acoustic signal (Hub et al., 2003). Sonification can be further divided as follows:

i. Preliminary Parameter Mapping Sonification

This is referred to as a subcategory of sonification which maps the parameters of data into the parameters of sound. This method is widely used (Choudhury et al., 2004). Interaction based on audio for E.T.A. can be considered a specific application for this type of sonification. Parameter Mapping Sonification is based on three elements: data parameters, sound parameters, and a function that is used to map these parameters.

ii. Image Sonification

It is a difficult task to obtain information about distance by using depth images and to use this information to avoid obstacles. In image sonification, the depth images are converted directly into sound. The parameters of pixels are mapped into the sound in the image sonification.

iii. Obstacle Sonification

In this method, the information about the obstacles is transmitted to the VI person. This method has less redundancy as compared to the raw depth images in which images are converted directly to the sound.

1.1.4.3 BONE CONDUCTION FEEDBACK

In (González-Mora et al., 1999), the author used the bone conduction method, which is based on the configuration of an infrared sensor, a compass, an ultrasonic sensor, and a triaxial accelerometer, all of which are mounted on a white cane. The data are collected through the sensor and transmitted to the user's smartphone, and the bone conduction headphones notify the user of the obstacles.

In (Sainarayanan et al., 2007), the author introduced another method based on the conduction feedback. The Smart Cane can detect the obstacles and faces of friends and family members within 10 m. A Bluetooth earpiece based on bone conduction is used to convey information about the obstacles.

TOOLS BASED ON NAVIGATION SYSTEMS FOR THE VISUALLY IMPAIRED

This literature examination has given an insight into the most advanced navigation systems for blind users, categorizing the methods according to the technology involved (Chen et al., 2018). Their studies indicated several disadvantages connected to user involvement and adjustment to the new scheme. Additionally, they considered the issues of comfort, confidence, mobility, and adaptive multi-feedback possibilities for a VI person. Several factors may have contributed to the lack of acceptance of the technology by the blind and visually impaired population and the resistance of the intended users to using them. Due to the ophthalmic-centric nature of the organizations, individuals with vision impairments typically encounter some challenges when viewing museums. The situation is made worse by the frequent inaccessibility of exhibits and replicas from a physical, intellectual, and sensory perspective. This is made worse by the inability to use information for communication technology and ~~or~~ local or global resources for substitute or intensifier communication that can enable different interactions for sighted visitors. The research examines assistive technology applications for the design of multimodal exhibits and links them to visitor experiences. Based on a survey of the literature, this article (Kuriakose et al., 2022) intends to advance the topic of mobility in museums by presenting an overview of the perceptions and needs of blind and visually impaired visitors to museums.

1.1.5 BRAILLE SIGNS TOOLS

Individuals with visual impairments must remember directions, as it is difficult to note them down. If the visually impaired lose their way, the main way forward is to find somebody who can help them. While Braille signs can be a decent solution here, the difficulty with this methodology is that it cannot be used as a routing tool (Vaz et al., 2020). These days, numerous public regions, such as emergency clinics, railroad stations, instructive structures, entryways, lifts, and other aspects of the system, are outfitted with Braille signs to simplify the route for visually impaired individuals. Regardless of how Braille characters can help visually impaired individuals know their area, they do not help to find a path.

1.1.6 SMART CANE TOOLS

Smart canes help the visually impaired navigate their surroundings and detect what appears in front of them, either big or small, which is impossible to detect and identify (the size) with simple walking sticks. A smart guiding cane detects the obstacle, and the microphone produces a sound in the intelligent system deployed in the cane. The cane also helps to detect a dark or bright environment (Dian et al., 2015). For indoor usage, an innovative cane navigation system was proposed (Park et al., 2014) that uses IoT and cloud networks. The intelligent cane navigation system is capable of collecting the data transmitted to the cloud network; an IoT scanner is also attached to the cloud network. The concept is shown in Figure 4.

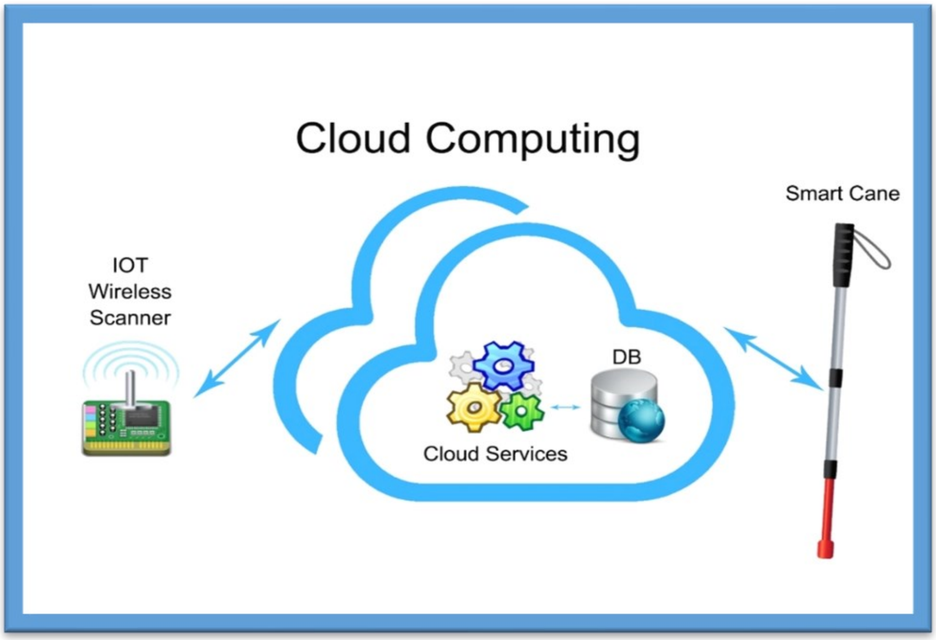


Figure 8 : Smart Cane Navigation System

The Smart Cane Navigation System comprises the camera, microcontrollers, and accelerometers that send audio messages. A cloud service is exploited in the navigation system to assist the user in navigating from one point to another. This navigation system fundamentally assists visually impaired or blind people in navigating and detecting the fastest route. Nearby objects are detected, and users are warned via a sound buzzer and a sonar (Chen et al., 2018). Cloud services acquire the position of the cane and route to the destination, and these data go from the Wi-Fi Arduino board to the cloud. The system then uses a Gaussian model for the triangular-based position estimation. The cloud service is linked to the database that stores the shortest, safest, and longest paths. It outputs three lights: red, when objects are greater than 15 m; yellow, between 5 and 15 m; and green, less than 15 m. Distance is calculated by sound emission and echoes, which is the cheapest way of calculating distance, and a text-to-audio converter warns of possible hurdles or obstacles.

Experiments have shown that this navigation system is quite effective in suggesting the fastest/shortest route to the users and identifying the hurdles or obstacles:

- The system uses a cloud-based approach to navigate different routes. A Wi-Fi Arduino board in this cane connects to a cloud-based system;
- The sound echoes and emissions are used to calculate the distance, and the user obtains a voice-form output;
- The system was seen to be very efficient in detecting hurdles and suggesting the shortest and fastest routes to the visually impaired via a cloud-based approach.

1.1.7 VOICE-OPERATED TOOLS

This outdoor voice-operated navigation system is based on G.P.S., ultrasonic sensors, and voice. This outdoor navigation system provides alerts for the current position of the users and guidance for traveling. The problem with this system is that it failed in obstacle detection and warning alerts (Hairuman and Foong, 2011). Another navigation system uses a microcontroller to detect the obstacles and a feedback system that alerts the users about obstacles through voice and vibration (Messaoudi et al., 2020).

1.1.8 ROSHNI

Roshni is an indoor navigation system that navigates through voice messages by pressing keys on a mobile unit. The position of the users in Roshni is identified by sonar technology by mounting ultrasonic modules at regular intervals on the ceiling. Roshni is portable, free to move anywhere, and unaffected by environmental changes. It needs a detailed interior map of the building that limits it only to indoor navigation (Dian et al., 2015).

Roshni application tools are easy to use, as the system operates by pressing mobile keys and guides the visually impaired using voice messages. Since it remains unaffected by a change in environment, it is easily transportable. The system is limited to indoor locations, and the user must provide a map of the building before the system can be used.

1.1.9 RFID-BASED MAP-READING TOOLS

RFID is the fourth category of wireless technology used to facilitate visually impaired persons for indoor and outdoor activities. This technology is based on the "Internet of Things paradigm" through an IoT physical layer that helps the visually impaired navigate in their surroundings by deploying low-cost, energy-efficient sensors. The short communication range leaves this RFID technology incapable of being deployed in the landscape spatial range. In (Bai et al., 2017), an indoor navigation system for blind and older adults was proposed, based on the RFID technique, to assist disabled people by offering and enabling self-navigation in indoor surroundings. The goal of creating this approach was to handle and manage interior navigation challenges while taking into consideration the accuracy and dynamics of various environments.-The system was composed of two modules for navigation and localization—that is, a server and a wearable module containing a microcontroller, ultrasonic sensor, RFID, Wi-Fi module, and voice control module. The results showed 99% accuracy in experiments. The time the system takes to locate the obstacle is 0.6 s.

Another map-reading system based on RFID provides solutions for visually disabled persons to pass through public places using an RFID tag grid, a Bluetooth interface, a RFID cane reader, and a personal digital assistant (Oladayo and Applications, 2014). This system is costly, however, and there is a chance of collision in heavy traffic. A map-reading system is relatively expensive because of the hardware units it includes, and its limitation is that it is unreliable for areas with heavy traffic.

Another navigation system based on passive RFID proposed in (Barberis et al., 2013) is equipped with a digital compass to assist the visually impaired. The RFID transponders are mounted on the floor, as tactile paving, to build RFID networks. Localization and positioning are equipped with a digital compass, and the guiding directions are given using voice commands. Table 5 incorporates detailed information about RFID-based navigation tools with recommended models for the visually impaired.

Table 5 : Summary of Various RFID-Based Navigation Tools

Ref Paper	Title	Proposed Model
(Yusro et al., 2014)	Mobile audio navigation interfaces for the blind	Drishti system combines the ultrasonic sensor for indoor navigation and G.P.S. for outdoor navigation for blind people.
(Karkar and Al-Maadeed, 2018)	BLI-NAV embedded navigation system for blind people	Comprised of G.P.S. and path detectors, which detect the path and determine the shortest obstacle-free route.
(Phung et al., 2016)	A pocket-PC-based navigational aid for blind individuals	Pocket PC-based Electronic Travel Aid (E.T.A.) warns users of obstacles via audio-based instructions.
(Singh et al., 2014)	A blind navigation system using RFID for indoor environments	A wireless mesh-based navigation system that warns the users about obstacles via a headset with microphone.
(Bosse, 1977)	Design and development of navigation system using RFID technology	This system uses an RFID reader mounted on the end of the stick that reads the transponder tags installed on the tactile paving.

1.1.10 WIRELESS NETWORK-BASED TOOLS

Wireless network-based solutions for navigation and indoor positioning include various approaches, such as cellular communication networks, Wi-Fi networks, ultra-wideband (U.W.B.) sensors, and Bluetooth (Sahoo et al., 2019). The indoor positioning is highly reliable in the wireless network approach and easy to use for blind persons. Table 6 summarises various studies based on the wireless networks for VI people.

Table 6 : Summary of Various Wireless-Network-Based Navigation Tools

Ref Paper	Model Used	Detailed Technology Used
(Ross and Lightman, 2005)	Syndrome-Enabled Unsupervised Learning for Neural Network-Based Polar Decoder and Jointly Optimized Blind Equalizer	1. This neural network-based approach uses a polar decoder to aid CRC-enabled syndrome loss, B.P.P. decoder. 2. This approach has not been evaluated under varying channels.
(Kuc, 2002)	Wireless Sensor Network Based Personnel Positioning Scheme used in Coal Mines with Blind Areas	This model determines the 3D positions by coordinate transformation and corrects the localization errors using real-time personal local with the help of a location engine.
(Ulrich et al., 2001)	A model based on ultrasonic spectacles and waist belts for blind people	This model detects obstacles within 500 cm. It uses a microcontroller-based embedded system to process real-time data gathered using ultrasonic sensors.

1.1.11 AUGMENTED WHITE CANE TOOLS

The augmented white cane-based system is an indoor navigation system specifically designed to help the visual impaired move freely in indoor environments (Santhosh et al., 2010). The prime purpose of the white cane navigation system is to provide real-time navigation information, which helps the users to make decisions appropriately, for example on the route to be followed in an indoor space. The system obtains access to the physical environment, called a micro-navigation system, to provide such information. Possible obstacles should be detected, and the intentional movements of the users should be known to help users decide on movements. The solution uses the interaction among several components. The main components comprising this system are the two infrared cameras. The computer has a software application, in running form, which coordinates the system. A smartphone is needed to deliver the information related to navigation, as shown in Figure 5.

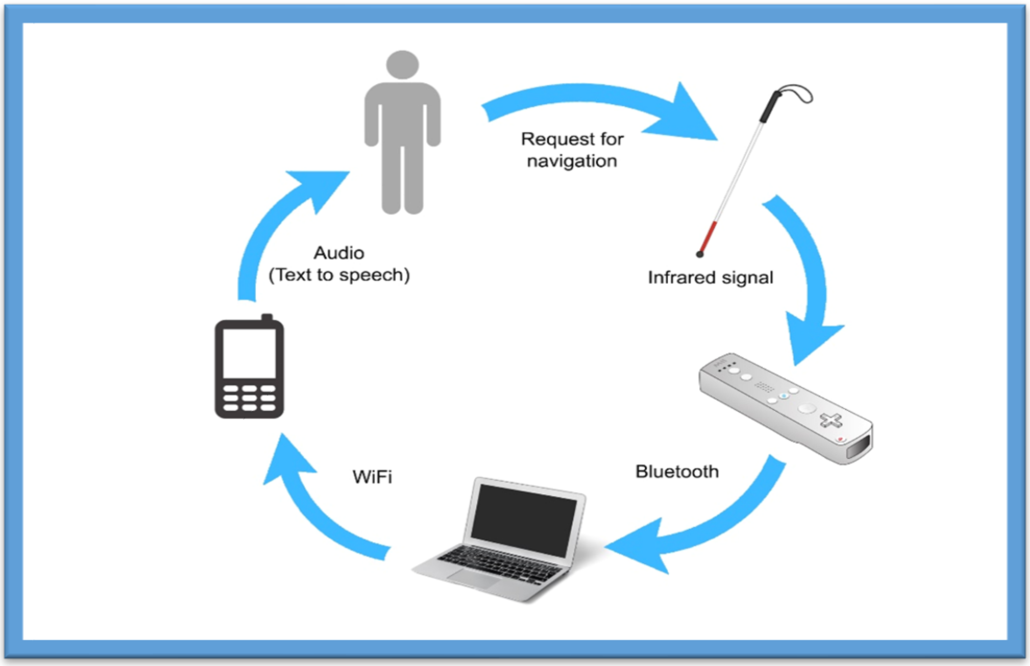


Figure 9 : Augmented White Cane

The white cane helps determine the user's position and movement. It includes several infrared L.E.D.s with a button to activate and deactivate the system. The cane is the most suitable object to represent the position, assisted by an Augmented Objects Development Process (AODeP). To make an object augmented, many requirements can be identified: (1) the object should be able to emit the infrared light that the Wiimote could capture, (2) the user should wear it to obtain his location or position, (3) it should be smaller in size so that it does not hinder the user's movement, and (4) it should minimize the cognitive effort required to use it:

- The white cane provides real-time navigation by studying the physical indoor environment by using a micro-navigation system;
- The two infrared cameras and a software application make indoor navigation more reliable and accurate;
- The whole system takes input through infrared signals to provide proper navigation.

1.1.12 ULTRASONIC SENSOR-BASED TOOLS

This ultrasonic sensor-based system comprises a microcontroller with synthetic speech output and a portable device that guides users to walking points. The principle of reflection of a high frequency is used in this system to detect obstacles. These instructions or guidelines are given in vibro-tactile form for reducing navigation difficulties. The limit of such a system is the blockage of the ultrasound signals by the wall, thus resulting in less accurate navigation. A user's movement is constantly tracked by an RFID unit using an indoor navigation system designed for the visually impaired. The user is given the guidelines and instructions via a tactile compass and wireless connection (Aladren et al., 2014).

1.1.13 BLIND AUDIO GUIDANCE TOOLS

The blind audio guidance system is based on an embedded system, which uses an ultrasonic sensor for measuring the distance, an A.V.R sound system for the audio instructions, and an I.R.R. sensor to detect objects as shown in Figure 6. The primary functions performed by this system are detecting paths and recognizing the environment. Initially, the ultrasonic sensors receive the visual signals and then convert them into auditory information. This system reduces the training time required to use the white cane. However, the issue concerns identifying the users' location globally (Teng et al., 2020). Additionally,

Table 7 provides various blind audio guidance system features relating to Distance Measurement, Audio Instructions, and Hardware Costs.

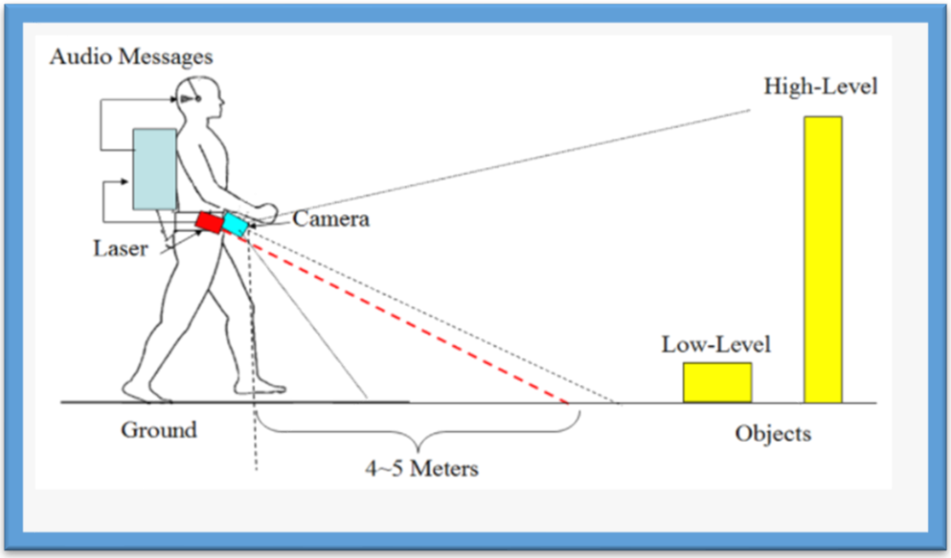


Figure 10 : The Blind Audio Guidance System

Table 7 : Properties of the Blind Guidance System

Blind Audio Guidance System	
Distance Measurement	The ultrasonic sensor facilitates the visually impaired by measuring distances accurately.
Audio Instructions	I.R.R. sensor detects obstacles and provides instant audio instructions to blind people.
Hardware Costs	The system comprises different hardware components that might be a little expensive. However, it remains one of the most reliable systems.

1.1.14 VOICE AND VIBRATION TOOLS

This system is developed using an ultrasonic sensor for the detection of obstacles. People with any visual impairment or blindness are more sensitive to hearing than others, so this navigation system gives alerts via voice and vibration feedback. The system works both outdoors and indoors. The alert mobility of the users and different intensity levels are provided (Liu et al., 2010). Table 8 incorporates the properties of voice and vibration navigation tools used for the visually impaired.

Table 8 : Properties of Voice and Vibration Navigation Tools

Voice and Vibration-Based Navigation System	
Better Obstacle Detection	The ultrasonic sensor accurately detects any obstacles in range of a visually impaired person.
Fast and Reliable Alerts	The ultrasonic sensor provides better navigation with voice and vibration feedback providing proper guidance.
Multipurpose	The system can be used for both indoor and outdoor environments.

1.1.15 RGB-D SENSOR-BASED TOOLS

This navigation system is based upon an RGB-D sensor with range expansion. A consumer RGB-D camera supports range-based floor segmentation to obtain information about the range as shown in Figure 7. The RGB sensor also supports colour sensing and object detection. The user interface is given using sound map information and audio guidelines or instructions (Bhatlawande et al., 2012, dos Santos et al., 2021a) . Table 9 provides information on RGB-D sensor-based navigation tools with their different properties for VI people.

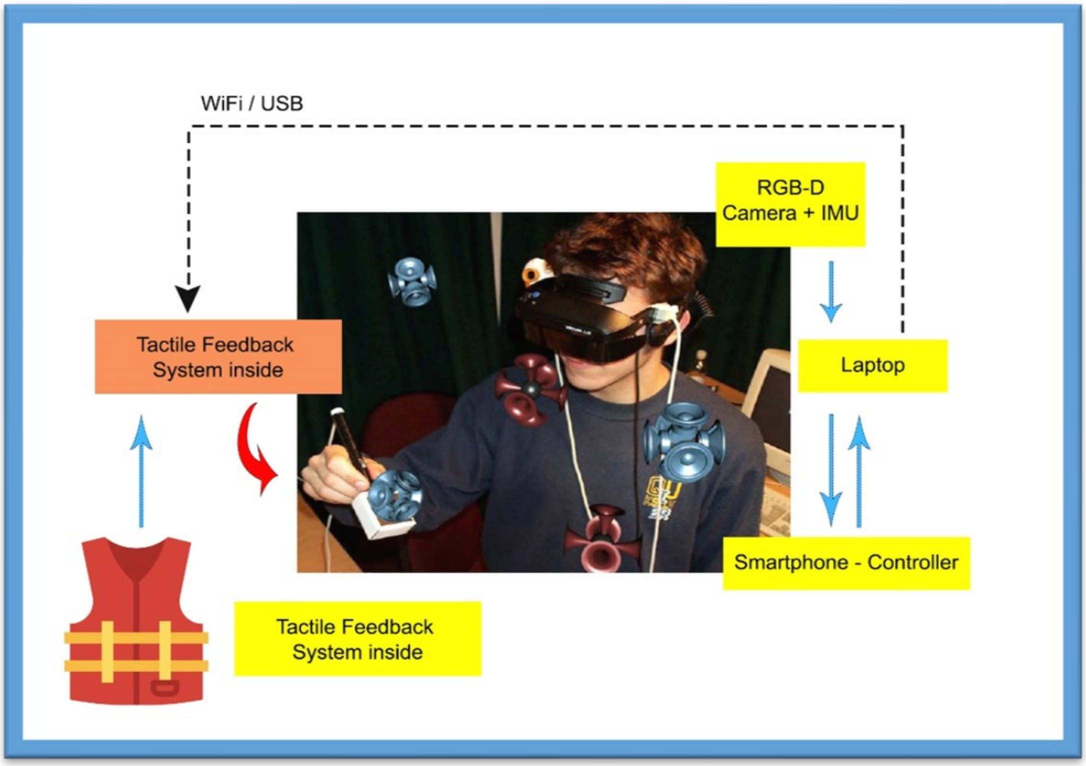


Figure 11 : RGB-D Sensor-Based System

Table 9 : Properties of RGB-D Sensor-Based Navigation Tools

RGB-D Sensor-Based System	
RGB Sensor	RGB sensor facilitates all the visually impaired with color sensing and object detection.
Camera-Based System	The RGB-D camera is used to support range-based floor segmentation.
Expensive	The multiple hardware components, including RGB-D sensors, make it an expensive option for blind people.

1.1.16 CELLULAR NETWORK-BASED TOOLS

A cellular network system allows mobile phones to communicate with others (WI, 2008). According to a research study (Higuchi et al., 2004), a simple way to localize cellular devices is to use the Cell-ID, which operates in most cellular networks. Studies (Caffery and Stuber, 1998, Guerrero et al., 2012) have proposed a hybrid approach that uses a combination of wireless local area networks, Bluetooth, and a cellular communication network to improve indoor navigation and positioning performance. However, such positioning is unstable and has a significant navigation error due to cellular towers and radiofrequency signal range. Table 10 summarizes the information based on different cellular approaches for indoor environments with positioning factors.

Table 10 : Properties of Cellular Network-Based Navigation Tools

Cellular Network-Based System	
Cellular Based Approach	Mobile phone communication makes this system work by using cellular towers to define the location.
Good for Indoors	The system works better in indoor environments.
Poor Positioning	The positioning is not very accurate due to the large signal ranges of cellular towers.

1.1.17 BLUETOOTH-BASED TOOLS

Bluetooth is a commonly used wireless protocol based on the IEEE 802.15.1 standard. The precision of this method is determined by the number of connected Bluetooth cells (Nivishna and Vivek, 2019). A 3D indoor navigation system proposed by Cruz and Ramos (Mahmud et al., 2014) is based on Bluetooth. In this navigation system, pre-installed transmitters are not considered helpful for applications with critical requirements. An approach that combines Bluetooth beacons and Google Tango was proposed in (Grubb et al., 2016). Table 11 provides an overview of Bluetooth-based approaches used for the visually impaired in terms of cost and environment.

Table 11 : Properties of Bluetooth-Based Navigation Tools

Bluetooth-Based Approach	
Bluetooth-Based	The system mainly relies on Bluetooth networks to stay precise.
Not Expensive	The system is cheap as it relies on a Bluetooth network using pre-installed transmitters.
3D Indoor System	An indoor navigation system proposed by Cruz Ramos is also based on Bluetooth.

1.1.18 SYSTEM FOR CONVERTING IMAGES INTO SOUND

Depth sensors generate images that humans usually acquire with their eyes and hands. Different designs convert spatial data into sound, as sound can precisely guide the users. Many approaches in this domain are inspired by auditory substitution devices that encode visual scenes from the video camera and generate sounds as an acoustic representation known as “soundscape”. Rehri et al. (Rehrl et al., 2007) proposed a system that improves navigation without vision. It is a personal guidance system based on the clear advantage of virtual sound guidance over spatial language. The authors argued that it is easy and quick to perceive and understand spatial information.

In Nair et al. (Zhou et al., 2008), a method of image recognition was presented for blind individuals with the help of sound in a simple yet powerful approach that can help blind persons see the world with their ears. Nevertheless, image recognition using the sound process becomes problematic when the complexity of the image increases. At first, the sound is removed using Gaussian blur. In the second step, the edges of images are filtered out by finding the gradients. In the third step, non-maximum suppression is applied to trace along the image edges. After that, threshold values are marked using the canny edge detector. After acquiring complete edge information, the sound is generated.

These different technologies are very effective for blind and the visually impaired and help them feel more confident and self-dependent. They can move, travel, play, and read books more than sighted people do. Technology is growing and is enhancing the ways B.V.I. communicates to the world more confidently.

1.1.19 INFRARED L.E.D.-BASED TOOLS

Next comes the infrared L.E.D. category, suitable for producing periodic signals in indoor environments. The only drawback of this technology is that the “line of sight (L.O.S)” must be accessible among L.E.D. and detectors. Moreover, it is a technology for short-range communication (Rehrl et al., 2005). In this study, a “mid-range portable positioning system” was designed using L.E.D. for the visually impaired. It helps determine orientation, location, and distance to destination for those with weak eyesight and is 100% accurate for the partially blind. The system comprises two techniques: infrared intensity and ultrasound “time of flight T.O.F.”. The ultrasonic T.O.F. structure comprises an ultrasonic transducer, beacon, and infrared L.E.D. circuits.

On the other hand, the receiver includes an ultrasonic sensor, infrared sensor, geomagnetic sensor, and signal processing unit. The prototype also includes beacons of infrared L.E.D. and receivers. The system results showed 90% accuracy for the fully visually impaired in indoor and outdoor environments.

1.1.19.1 TEXT-TO-SPEECH TOOLS

One of the most used and recently developed Text-to-Speech Tools (TTS) is the Google TTS, a screen reader application that Google has designed and that uses Android O.S.S. to read the text out loud over the screen. It supports various languages. This device was built entirely based upon "DeepMind's speech" synthesis expertise. In this tool, the API sends the audio or voice to the person in almost human voice quality (Cloud Text-to-Speech, n.d). OpenCV tools and libraries have been used to capture the image, from which the text is decoded, and the character recognition processes are then completed. The written text is encoded through the machine using O.C.R. technology. The OpenCV library was recommended for its convenience of handling and use compared to the other P.C.C. or electronic devices platforms (Nair et al., 2022). An ultrasonic sensor-based TTS tool was designed to give vibration sensing for the blind to help them to easily recognize and identify a bus name and its number at a bus stop using audio processing techniques. The system was designed using M.A.T.L.A.B. for implementing image capture. Most simulations are performed using O.C.R. in M.A.T.L.A.B. to convert the text into speech (AV et al., 2011). A text-to-voice technique is also presented; most of the commercial G.P.S. devices developed by Inc., such as TomTom Inc., Garmin Inc., etc., use this technique. Real-time performance is achieved based on the spoken navigation instructions (Loomis et al., 2001). An ideal illustration of combining text-to-voice techniques and voice search methods is Siri, which is shown in Figure 8 Siri is available for iOS, an operating system (OS) for Apple's iPhone. It is easy to interact or talk to Siri and receive a response in a human-like voice. This system helps people with low vision and people who are blind or visually impaired to use it in daily life with both voice input and synthesized voice output.

Figure 12 : Siri for iPhone

A Human–Computer Interface (HCI)-based wearable indoor navigation system is presented by (Krishnan et al., 2013). An excellent example of an audio-based system is Google Voice search. To effectively use such systems, proper training is required (Freitas et al., 2008, MN et al., 2019).

1.1.19.2 SPEECH-TO-TEXT TOOLS

Amazon has designed and developed an S.T.T. tool named “Amazon transcribe” that uses the deep learning algorithm known as A.S.R., which converts the voice into text in a matter of seconds and does so precisely. These tools are used by the blind and the visually impaired, and they are also used to translate customer service calls, automate subtitles, and create metadata for media assets to generate the searchable archive (Halimah et al., 2008). I.B.M. Watson has also developed its own S.T.T. tool to convert audio and voice to text form. The developed technology uses the DL AI algorithm, which applies the language structure, grammar, and composition of voice and audio signals to transcribe and convert the human voice/audio into written text (Latha et al., 2019).

Based on multiple tools and techniques incorporated in assistive technologies for visually impaired users, we have identified what is lacking in the current systems. Table 12 shows the complete evaluation and analysis of current systems to help visually impaired users confidently move in their environment.

1.1.20 FEEDBACK TOOLS FOR VI

In this section, different feedback tools for VI people are explained.

1.1.20.1 TACTICAL COMPASS

The feedback for effective and accurate direction in an electronic travel aid for VI is a challenging task. The authors of (Choi et al., 2019) presented a Tactile Compass to guide the VI person during the traveling to address this problem. This compass is a handheld device that guides a VI person continuously by providing directions with the help of a pointing needle. Two lab experiments that tested the system demonstrated that a user can reach the goal with an average deviation of 3.03°.

1.1.20.2 SRFI TOOL

To overcome the information acquisition problem in VI people, the authors of (Nakajima et al., 2013) presented a method based on auditory feedback and a triboelectric nanogenerator. This tool is called a ripple-inspired fingertip interactor (S.R.F.I.) and is self-powered. It assists the VI person by giving feedback to deliver information, and due to its refined structure, it gives high-quality text information to the user. Based on three channels, it can recognise Braille letters and deliver feedback to VI about information acquisition.

1.1.20.3 ROBOTIC SYSTEM BASED ON HAPTIC FEEDBACK

To support VI people in sports, the authors of (Gündüz et al., 2019) introduced a robotic system based on haptic feedback. The runner's position is determined with the help of a drone, and information is delivered with the help of the left lower leg haptic feedback, which guides the user in the desired direction. The system is assessed outdoors to give proper haptic feedback and is tested on three modalities: vibration during the swing, stance, and continuous.

1.1.20.4 AUDIO FEEDBACK-BASED VOICE-ACTIVATED PORTABLE BRAILLE

A portable device named Voice Activated Braille helps give a VI person information about specific characters. Arduino helps direct the VI person. This system can be beneficial for VI by guiding them. It is a partial assistant and helps the VI to read easily.

1.1.20.5 ADAPTIVE AUDITORY FEEDBACK SYSTEM

This system helps a VI person while using the desktop, based on continuous switching between speech and the non-speech feedback. Using this system, a VI person does not need continuous instructions. The results of sixteen experiments that assessed the system revealed that it delivers an efficient performance.

1.1.20.6 OLFACTORY AND HAPTIC FOR VI PERSON

The authors of (Khan and Khusro, 2021) introduced a method based on Olfactory and Haptic for VI people. This method is introduced to help VI in entertainment in education and is designed to offer opportunities to VI for learning and teaching. A 3D system, it can be used to touch a 3D object. Moreover, the smell and sound are released from the olfactory device. This system was assessed by the VI and blind people with the help of a questionnaire.

1.1.20.7 HYBRID METHOD FOR VI

This system guides the VI person in indoor and outdoor environments. A hybrid system based on the sensor and traditional stick, it guides the user with the help of a sensor and auditory feedback.

1.1.20.8 RADAR-BASED HANDHELD DEVICE FOR VI

A handheld device based on radar has been presented for VI people. In this method, the distance received by the radar sensor is converted to tactile-based information, which is mapped into the array based on the vibration actuators. With the help of an information sensor and tactile stimulus, the VI user can be guided around obstacles. Table 12 gives a detailed overview of the navigation application for the visually impaired. The study involves various models and applications with their feasibility and characteristics report and discusses the merits and drawbacks of every application along with the features.

Table 12 : Navigation Applications for Visually Impaired Users

Ref Paper	Name	Components/Application	Device/Application Features	Price/Usability and Wearability/User Feedback	Drawbacks/user acceptance	Specific Characteristics
(Xue et al., 2021)	Maptic	Sensor device, user-friendly feedback capabilities, cell phone	(1) Obstacle detection for upper body Instant navigation guidance	Unknown/Wearable/Instant feedback	Lower body and ground obstacles detection	Object detection
(Huang et al., 2018, Mon et al., 2019)	Microsoft Soundscape	Cell phone, beacons application	(1) Instant navigation guidance Follows preferences	Free/Handheld device/Audio	No obstacle detection	Ease of use
(Warfield, 2020)	WeWalk	Sensor device, cane feedback, smartphone	(1) Detects obstacles (2) Navigation (3) Follows preference. Use of public transportation	Price starts from USD 599/Wearable (weighs about 252 g/0.55 pounds Audio-related and instant feedback	No obstacle detection and number of scenario description when in use	Ease of use Prioritization of user's requirements Availability of application

(Khanna, 2016)	Horus	Headphone with the bone-conducted facility Supports two cameras with an additional battery and powerful GPU.	(1) Detects obstacles (2) Face recognition and reads text (3) Scene detection and description	Price USD 2000/Wearable/Audio related feedback	Navigation guidance not supported	Less power consumption Reliability and voice assistant Accuracy of obstacles
(Chen et al., 2017)	Ray Electronic Mobility Aid	Ultrasonic device	(1) Detect Obstacles	Price USD 395/Handheld weighs 60 g/Audio-related and instant feedback	Navigation guidance not supported	Object classification accuracy Incorporated user feedback Accurate obstacle detection and classification
(Márton, 2020)	UltraCane	Dual Range, Ultrasonic with narrow beam, Cane	(1) Detect Obstacles	Price USD 590/Handheld/instant feedback	Navigation guidance not supported	Power consumption Battery life Ultrasonic Cane
(Dávila et al., 2016)	BlindSquare	Cell Phone	(1) Navigation (2) Follows the interest preference Use the Public transportation	Price USD 39.99/Handheld/Audio feedback enabled	Navigation guidance not supported	Ease of use Availability of application
(Kumpf, 1987)	Envision Glasses	Wearable glasses with additional cameras	(1) Text read (2) Description of scenes (3) Scan Barcodes, Color detections, Help in finding belongings Facial detection helps to make calls, voice commands to share text	Price USD 2099/wearable device weighs 46 g/Audio oriented	No Obstacle detection Navigation guidance not supported	Object classification Bar code scanning Voice supported application Performance
(Li et al., 2022)	Eye See	Helmet with integrated cameras and laser	(1) Read text (2) Obstacle detection Description of people	Unknown/wearable/Audio	Navigation guidance not supported.	Obstacle detection,

						O.C.R. Incorporated, Text to voice conversion.
(Wise et al., 2012)	Nearby Explorer	Cell phone	(1) Navigation (2) Interest preferences support (3) Tracking Objects identification	Free/Handheld/Audio and instant feedback	No obstacle detection	Object identification User's requirement prioritization Tracking history
(Satani et al., 2020)	Seeing Eye G.P.S	Cell phone	(1) Navigation (2) Interest preferences support	Unknown/Handheld/ Audio	No obstacle detection	User preference G.P.S. based navigation
(Chen et al., 2015)	Step-hear	Cell phone	(1) Navigation (2) Uses public transport	Free/Handheld/Audio	No obstacle detection	Availability of application to public G.P.S. based navigation
(Harris, 2015)	InterSection Explorer	Cell phone	Streets information	Free/Handheld/Audio	No obstacle detection Navigation guidance not supported	Predefined routes.
(Tolesa et al., 2022)	LAZARILLO APP	Cell phone	(1) Navigation (2) Uses public transport (3) Interest preferences support	Free/Handheld/Audio	No obstacle detection	Availability of application to public G.P.S. based navigation User requirement prioritization
(English and Childhood, 2000)	Lazzus APP	Cell phone	(1) Navigation (2) Interest preferences support Crossing information	Price USD 29.99/Handheld/Audio	No obstacle detection	User requirement preference

						Predefined crossings on routes.
(Bouchard et al., 2012)	Sunu Band	Sensor's device	Upper detection of body	Price USD 299/Handheld/Instant feedback	Lower body and ground obstacles are not detected	Object detection
(Menelas and Otis, 2012)	Ariadne G.P.S.	Cell phone	(1) Navigation Map explorer	Price USD 4.99/Handheld/Audio	No obstacle detection	Accurate Map Exploration G.P.S. based navigation
(Menelas et al., 2017)	Aira	Cell phone	Sighted person support	Price USD 99 for 120 min/ Handheld/Audio	Expensive to use and privacy concerns	Tightly coupled for security Ease of use
(Ménélas et al., 2010)	Be My Eyes	Cell Phone	Sighted person support	Free/Handheld/Audio	Privacy concerns	Ease of use
(Menelas et al., 2014)	BrainPort	The handheld video camera controller	Detection of objects	Expensive/wearable and handheld/Instant Feedback	No navigation guidance	Accurate detection of objects/obstacles

DISCUSSION

Several research studies were conducted on various navigational systems that have been created over time to assist the visually impaired and blind, but of which only a few remain in use. Although most of the methods make sense in theory, in practice they may be excessively complicated or laborious for the user. This evaluation analysis has been divided into sections according to specific characteristics, including recording methods, smart response to objects, physical hardware, transmission range, detection limit, size, and cost efficiency. These preselected standards described in this study are chosen because they assess system performance. Navigating through various situations is difficult for those with vision impairments, who must be aware of the objects and landscape in the immediate environment, such as people, tables, and dividers. Likewise, the inability to deal with such circumstances itself adversely affects the sense of freedom of the visually impaired, who have little opportunity to find their way in a new environment.

A guide is always needed for the outdoor environment. However, it is not a good solution due to dependency on others. One can request directions for a limited time at some place but asking people for direction every time causes difficulties to move freely.–Numerous tools have been developed and effectively deployed to help impaired individuals avoid obstacles outdoors, such as intelligent canes and seeing-eye dogs, Braille signs, and G.P.S. systems. One approach to navigation systems is the adoption of neural networks. To help the visually impaired to move around, researchers have presented two deep Convolutional Neural Network models. However, this approach is not very efficient in terms of time complexity (Nair et al., 2022).

Some of the approaches for navigation systems have adopted sensory substitution methods, such as one based on LIDARs (Rehrl et al., 2007) or a vibrotactile stimulation (Zhou et al., 2008) applied to the palms of the hand to direct users through a temporal sequence of stimuli. A vibrating belt with time-of-flight distance sensors and cameras was used to acquire better navigation (Kumpf, 1987). An outdoor navigation system based on vision positioning to direct blind people was proposed in (Harris, 2015). Image processing is used for identifying the path and obstacles in the path. An assistive-guide robot called an eye dog has been designed as an alternative to guide dogs for blind people (Tolesa et al., 2022).

In (Nair et al., 2022), the author designed an intelligent blind stick outfitted with an ultrasonic sensor and piezo buzzer that sounds an alarm when the user approaches an obstacle. A fusion of depth and vision sensors was proposed by (Freitas et al., 2008), by which obstacles are detected using corner detection. At the same time, the corresponding distance is calculated using input received from the depth sensor. Further, the main problems for the visually impaired and blind are in finding their way in unfamiliar environments. While they strive to orient themselves in places where they had previously been, places such as shopping malls, train stations, and airports change almost daily. Blind people must orient themselves in a vast place full of distractions such as background music, announcements, various kinds of scents and moving people, etc. They cannot rely totally on their senses in such a place, and they cannot easily find help at any time, for example, by finding a clothing store on the fifth floor.

Although assistive technologies allow the visually impaired to navigate their surroundings freely and confidently, a significant concern that is usually neglected is the power consumption and charging time of such devices. Preferably, images of paths and pedestrians can be stored on mobiles to overcome these problems. Doing so will allow visually impaired users to identify the obstacles and routes automatically, thus consuming less power for capturing and processing. However, this solution takes up memory; shifting from mobile devices to the cloud, therefore, will ease this issue of memory consumption and sharing of updated data between devices (English and Childhood, 2000). Moreover, the fully charged device should last significantly more than 48 h to prevent difficulties with daily charging. Proper training should also be incorporated into the orientation and mobility of the visually impaired, as programs scheduled to train the blind and visually impaired to travel safely help in daily routine tasks and to fit into their community. Considering our previous work on serious games, we think that they may help in the training (Bouchard et al., 2012, Menelas and Otis, 2012, Menelas et al., 2017).

The training sessions helped the students to understand and learn different techniques for street crossings and public transportation with the help of a cane. Visually impaired students who are comfortable with having dog assistance are trained with the help of the application process. This training program is usually applied one-on-one in the student community, home, school, and workplace.

Most instructions and tasks are completed in group discussions and class settings. When organizing the plan for orientation and mobility assistive technologies for the visually impaired, the focus on training should not be neglected.

Some major categories of assistive technologies are:

(1) Public transportation crossing assistive technology, which allows the visually impaired to learn the door-to-door bus service or the public bus transport systems in their area. Training is required to understand assistive maps to reach the bus transport or understand routes according to the needs of the visually impaired user;

(2) Another assistive technology is the Sighted Guide, which allows visually impaired users to practice the skills required for traveling with the aid of a sighted person and gain the ability to train any sighted person to guide them safely through any environment;

(3) Similarly, Safe Travel assistive technology allows visually impaired users to travel safely in an unfamiliar environment. These assistive technologies help in detecting obstacles;

(4) Orientation-based assistive technology allows visually impaired users to become familiar with both indoor and outdoor environments with the help of an experienced

instructor. Haptic and auditory feedbacks may help in guiding users (Ménélas et al., 2010, Menelas et al., 2014, Chapwouo Tchakouté et al., 2018).

(5) Cane Skills assistive technology allows visually impaired users to become familiar with canes and to identify objects without restricting their mobility. Orientation and mobility training for assistive technologies are therefore essential for visually impaired users because, without mobility, a user becomes homebound. With necessary training sessions, a visually impaired user learns the required skills and confidently navigates indoors and outdoors.

The evaluation gives a set of essential guidelines for detailing technological devices and the characteristics that must be incorporated into the methods to improve effectiveness. These criteria are described as follows:

- Basic: a method can be used relatively quickly without additional equipment assistance;
- Minimal cost: an affordable model must be built. Consequently, this design will be inaccessible to most individuals;
- Compactness: a compact size allows the device to be used by those with limited mobility;
- Reliable: the hardware and software requirements for the gadget must be compliant;
- Covering region: This gadget must meet the wireless needs of the individual both indoors as well as outside.

CONCLUSIONS AND FUTURE WORK

Several of the latest assistive technologies for the visually impaired in the fields of computer vision, integrated devices, and mobile platforms have been presented in this paper. Even though many techniques under examination have been in relatively initial phases, most are being incorporated into daily life using state-of technology (i.e., smart devices). The proposed device aims to create an audio input and vibrations in the vicinity of obstructions in outdoor and indoor areas.

Our research review has comprehensively studied visually impaired users' indoor and outdoor assistive navigation methods and has provided an in-depth analysis of multiple tools and techniques used as assistive measures for visually impaired users. It has also covered a detailed investigation of former research and reviews presented in the same domain and rendered highly accessible data for other researchers to evaluate the scope of former studies conducted in the same field. We have investigated multiple algorithms, datasets, and limitations of the former studies. In addition to the state-of-the-art tools and techniques, we have also provided application-based and subjective evaluations of those techniques that allow visually impaired users to navigate confidently indoors and outdoors.

In summary, detailed work is required to provide a reliable and comprehensive technology based on a Machine Learning algorithm. We have also emphasized knowledge transfer from one domain to another, such as driver assistance, automated cars, cane skills, and robot navigation. We also have insisted on training in assistive technology for visually impaired users. We have categorized assistive technologies and individually identified how training in each category could make a difference. However, previous work has ignored other factors involved in assistive technology, such as power consumption, feedback, and wearability. A technology that requires batteries and fast processing also require power consumption solutions relative to the device type. The researcher must determine the feasibility of running real-time obstacle detection through wearable camera devices. Various methods in the literature are “lab-based”, focusing on achieving accurate results rather than dealing with issues of power consumption and device deployment. Therefore, technologies that consume less power and are easy to wear in the future must be incorporated. These techniques should also be efficient enough to allow user to navigate effectively and confidently.

CHAPTER 2

This chapter delves into the advancements and methodologies presented in the seminal work by Messaoudi, Menelas, and Mcheick (2020) titled "Autonomous Smart White Cane Navigation System for Indoor Usage." The paper discusses about assistive technologies, particularly focusing on enhancing the independence and mobility of visually impaired individuals within indoor environments.

A sophisticated smart cane system has been introduced that integrates autonomous navigation capabilities tailored for indoor usage. This innovation is underpinned by a thorough literature review and a comprehensive evaluation of user requirements, ensuring that the system addresses the real-world needs of its users. The development phase, as detailed in the paper, encompasses the design and prototyping of the smart cane, which includes advanced sensor integration and user-friendly interfaces.

A key aspect of the methodology is the iterative process of user testing and refinement. The extensive trials were conducted with visually impaired users, gathering both qualitative and quantitative data to assess the system's usability and effectiveness. This iterative feedback loop was crucial in fine-tuning the smart cane's features, ultimately leading to a more robust and reliable assistive device.

The data analysis performed in this study highlights significant improvements in user navigation efficiency and safety. The mix of qualitative feedback from user experiences and quantitative metrics measuring system performance were employed. This dual approach provides a holistic understanding of the smart cane's impact, demonstrating its potential to significantly enhance the quality of life for visually impaired individuals.

Incorporating the insights from this pivotal work, the current chapter positions itself to build upon the foundation laid by Messaoudi, Menelas, and Mcheick. By leveraging this methodology and findings, this research aims to further advance the design and implementation of smart cane systems, with a particular focus on indoor navigation. The ultimate goal is to contribute to the broader field of assistive technologies, ensuring that visually impaired individuals can navigate indoor spaces with greater ease and confidence.

AUTONOMOUS SMART WHITE CANE NAVIGATION SYSTEM FOR INDOOR USAGE

Messaoudi, M. D., Menelas, B. A. J., & Mcheick, H. (2020). Autonomous smart white cane navigation system for indoor usage. Technologies, 8(3), 37.

Résumé : Selon les statistiques fournies par l'Organisation mondiale de la santé, le nombre de personnes souffrant de déficience visuelle est d'environ 1,3 milliard. Le nombre de personnes aveugles et malvoyantes devrait augmenter au cours des prochaines années, et il est estimé tripler d'ici la fin de 2050, ce qui est assez alarmant. Tenant compte des besoins et des problèmes rencontrés par les personnes malvoyantes, nous avons élaboré une solution technologique : un "dispositif de canne intelligente" qui peut aider les personnes ayant une déficience visuelle à naviguer facilement et à éviter les facteurs de risque qui les entourent. Actuellement, les trois principales options disponibles pour les personnes aveugles sont l'utilisation d'une canne blanche, d'outils technologiques et de chiens guides. La solution proposée consiste à utiliser divers outils technologiques pour proposer une solution intelligente au problème et faciliter la vie des utilisateurs. Le système conçu vise principalement à faciliter la navigation intérieure en utilisant l'informatique en nuage et des scanners sans fil de l'Internet des objets (IoT). L'objectif de développement de la canne intelligente peut être atteint en intégrant divers systèmes matériels et logiciels. La solution proposée d'un dispositif de canne intelligente vise à assurer un déplacement fluide pour les personnes malvoyantes d'un endroit à un autre et à leur fournir un outil pouvant les aider à communiquer avec leur environnement environnant.

Abstract: According to the statistics provided by the World Health Organization, the number of people suffering from visual impairment is approximately 1.3 billion. The number of blind and visually impaired people is expected to increase over the coming years, and it is estimated to triple by the end of 2050 which is quite alarming. Keeping the needs and problems faced by the visually impaired people in mind, we have come up with a technological solution that is a “Smart Cane device” that can help people having sight impairment to navigate with ease and to avoid the risk factors surrounding them. Currently, the three main options available for blind people are using a white cane, technological tools and guide dogs. The solution that has been proposed here is using various technological tools to come up with a smart solution to the problem to facilitate the users’ life. The designed system mainly aims to facilitate indoor navigation using cloud computing and Internet of things (IoT) wireless scanners. The goal of developing the Smart Cane can be achieved by integrating various hardware and software systems. The proposed solution of a Smart Cane device aims to provide smooth displacement for the visually impaired people from one place

to another and to provide them with a tool that can help them to communicate with their surrounding environment.

INTRODUCTION

According to the World Health Organization, 1.3 billion people live with some form of visual impairment (Blindness and vision impairment). While the prevalence of blindness has declined since 1990, the aging of the population will in the future lead to a much larger number of blinds and partially sighted (Bourne et al., 2017). In fact, the number of blinds in the world is expected to triple by 2050 (Varma et al., 2016), increasing from 39 million now to 115 million. This increasing number has motivated our work to design an autonomous cane to facilitate the navigation of blind people in unknown environment.

To assist the blind in their displacement, we mainly count the white cane, guide dog and technological tools. The white cane remains the most widely used mobility aid. It allows the detection of obstacles with a range of three feet. This reduced range forces the user to be ready to stop or correct his trajectory quickly, and therefore limits the speed of operation (Huh and Seo, 2017). While it cannot warn of the presence of hanging objects such as tree branches; it is easily recognizable by other pedestrians, warning passers-by to stay out of the way, but also marginalize the blind (Huh and Seo, 2017). Despite its flaws, the long cane is a wonderful instrument, providing surprisingly rich information. It is mainly used to make arches, tapping at each end (Mercado et al., 2014). The sounds emitted by the tapping can be used for echolocation. Dynamic contacts also inform about the texture and slope of the terrain. All this and “the signals given by the soles of the feet” are rich sources of information to help blinds. The dog for the blind is also a popular aid with around 7000 users. Dogs for the blind are effective and can be trained by professionals and maintained by their owners. Their cost varies from twelve to twenty thousand dollars. Their professional life is about five years.

Technological tools aiming for assisting blind are known as electronic travel aids (EDAs). EADs can be divided into two categories, depending on their main use. The first category helps the blind to orient themselves in their environment while traveling to a given destination. The second category provides warning for the presence of obstacles and facilitates the selection of a path without pitfalls. Our proposal is about this second category. It is a stick equipped with several sensors aiming to facilitate indoor navigation. An analysis of existing technologies shows that the research has largely focused on outdoor navigation; the GPS (Global Positioning System) being the main sensor used for this purpose (Jeong et al., 2018). Our interest is in indoor navigation.

Indoor navigation remains an active research area (Link et al., 2011, Prasithsangaree et al., 2002, Mautz and Tilch, 2011). The idea is to be able to help people navigate towards an indoor point of interest. This is generally considered a challenging task; especially for people who are visually impaired or blind. This group may indeed have considerable problems when trying to navigate through an unfamiliar place (e.g., a university, a shopping mall, or public buildings such as courthouses).

We report here the design of a smart and autonomous cane. The proposed system is designed to be easy to use. Using a computer vision system, object detection is provided. This allows the blind persons to safely navigate through many obstacles. Cloud services use modern algorithms to rapidly calculate the distance of detected objects. This fast calculation of the path is very useful for the user as it enables the real time navigation. Moreover, since it vocalizes the elements encountered in the environment, it allows the blind person to search for any particular object in the surrounding environment.

Figure 10 shows a graphical representation of a smart autonomous cane with object detection and a navigation system. It has an object detector at the lower end and a navigation system with audio device at the upper end where the user can interact with it using his/her hand.

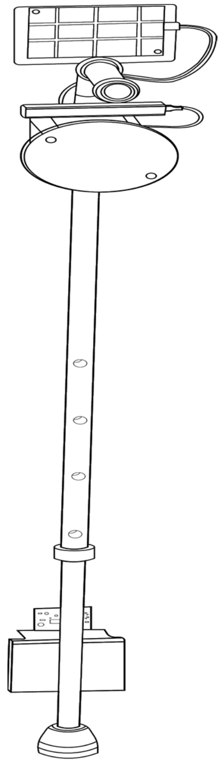


Figure 13 : Smart Cane

The rest of the paper is organized as follows. Section 2 reviews the current literature about the indoor navigation systems including techniques and principles used for performing tasks that a Smart Cane is expected to perform. Section 3 presents the proposed system including the characteristics of the system, triangulation principle, object detection and route determining. Section4 presents the experimental setup where the system is tested and then reports the system performance. Finally, section V concludes the paper and gives future directions

RELATED STUDY

In the last two decades, many technologies have been proposed in order to assist blinds or visually impaired persons to navigate in closed spaces. We divide this section into three main areas. Many research projects have been carried out in the field of indoor positioning technologies (Kohoutek et al., 2010, Mulloni et al., 2009). To achieve this, different techniques for locating an object were investigated. Here, we briefly analyze the main indoor location methods.

The Laterartion method assesses the distance of an object by measuring the distance of the object from different reference points; these techniques are known as range measurement techniques. Time distance of arrival (TDOA) is a kind of Laterartion technique that has been used to measure indoor position of an object with respect to signal with three reference points (Peterson et al., 1998, Li et al., 2000). Authors of (Correal et al., 2003, Pereira et al., 2015) have proposed the method to measure TDOA using different signaling techniques, i.e., ultra-wide band measurements (UWB) and direct-sequence spread-spectrum (DSS) (Domingo and Applications, 2012). Others (Fang and systems, 1990, Kanaan and Pahlavan, 2004) have proposed a non-linear cost function for measuring the indoor location of an object, where the cost function computes the location by minimizing the sum of squares of non-linear cost function, e.g., least-square algorithms.

Some other algorithms for measuring indoor position of an object are residual weighting, closest neighbor (CN) that assesses the location with respect to the reference points or location of the base stations (Kanaan and Pahlavan, 2004). These TDOA based methods have some drawbacks when it comes to indoor environments, it becomes difficult to find LOS channel between the receiver and the transmitter. This shortcoming can be value-added by applying the premeasured RSS (Received Signal Strength) contours at the receiver side or at the base stations (Zhou et al., 2005). Authors in (Teuber et al., 2006) proposed a fuzzy logic algorithm for improving the accuracy using the RSS method considerably.

Another method based on received signal phase assesses the range using carrier phase, also known as phase of arrival (POA). This method assumes the transmitting stations having same frequency and zero offset for determining the sinusoidal signals phase at a point (Pahlavan et al., 2002). This method can be used in combination of TDOA for fine-tuning the location positioning, but the problems come with the ambiguous measurements of the carrier phase, LOS signal path resolves this issue otherwise the indoor positioning environment incurs more error.

In this respect, authors have also focused on angulation techniques that find the target in an indoor environment using the intersection of several points in angle direction lines. These techniques are advantageous where the users are required to estimate positions for 2-D and 3-D environments and they also do not require time synchronization among measuring units.

On the other hand, they have complex hardware requirements (Van Veen and Buckley, 1988, Ottersten et al., 1993). Another technique that cogitates position as a classification problem is probabilistic method. These probabilistic methods work upon calculating the likelihood of independent measuring units, i.e., the Kernel approach and the histogram. The likelihood of one-unit location can be calculated by multiplying likelihoods of all units (Kontkanen et al., 2004). These methods work accurately only for discrete locations as mobile units are usually located at different points rather than the discrete points. Researchers also have investigated other indoor location-aware methods like Bayesian network-based methods and tracking assisted positioning methods are proposed in (Köhler et al., 2007).

New techniques for indoor positioning findings are based on supervised or machine learning algorithms. One of them is support vector machines (SVM) extensively used in applications like medicine, engineering and science (Cristianini and Shawe-Taylor, 2000). Researchers have focused on support vector classification and support vector regression in indoor positioning environments (Brunato and Battiti, 2005, Wu et al., 2004). SMP (Smallest M-vertex Polygon) has also been studied in location estimation that uses RSS values for finding location of the target with the reference of transmitter signal. M-vertex polygons are created by selecting one candidate from the transmitter where the smallest polygon suggests the location estimation (Kontkanen et al., 2004). Other machine learning/supervised learning algorithms that are under consideration for estimating location in an indoor environment are KNN and neural networks. K-nearest neighbor algorithm works on online RSS for searching k nearest matches of recognized places from already created database using root mean square error principle. The estimated location is found (weighted/un- weighted KNN) by averaging the k location candidates. On the other hand, neural networks are used during the offline RSS stage. The appropriate weights are gained by training neural networks, in the indoor positioning environments, a multilayer perceptron (MLP) network with one hidden layer is used. Neural networks, in indoor positioning environments, are capable of finding 2D or 3D estimated locations.

Other techniques for finding target location of an object in an indoor positioning environment are Proximity-based methods. These algorithms deliver symbolic relative information, depending upon dense grid antennas with a popular location with each antenna. When single antenna detects the target, it is reflected to be collocated with it, when detected by more than one antenna, it is collocated with the strongest signal antenna. Proximity-based techniques are easier and simple to implement for detecting target location in an indoor environment over various kinds of physical media. Systems using radio frequency identification (RFID) and infrared radiation (IR) are making use of proximity-based methods.

Laser and camera-based indoor positioning system has also been developed by Tilch and Mautz (Mautz and Tilch, 2011), to define the camera position with reference to the laser ring. As the ring emits laser-beams, it can be observed as an inverse camera. The comparative orientation between laser rig and camera can be calculated with the help of laser spots that are projected to any surface irrespective of a defined structure of a scene. With this laser and camera-based positioning system, the point tracking is obtained at the frame rate of 15 Hz while the camera accuracy is sub-mm.

Another indoor localization system known as NorthStar has been developed by evolution robotics (Evolution Robotics) that navigates robot vacuum cleaners and shopping carts. Here, infrared light spots that are emitted from infrared LED specify the location of the mobile units. In NorthStar, every mobile unit is equipped with a projector and an infrared detector for determining the relative orientation between mobile devices. The positioning accuracy is reported to be in the magnitude of cm to dm.

Other techniques for object detection in an indoor positioning environment rely on reference from 3D building models, that depend on detecting objects in images and then matching these with a built database, i.e., CityGML contains position data of the interior of building. These methods have advantageous, as there is no need to deploy sensor beacons (Lee et al., 2018, Bu et al., 2017). In this regard, important research has been conducted by Kohoutek et al. (Kohoutek et al., 2010), using CityGML as highest level of detail for determining position of imagining camera within the range. Initially, the correct room with camera is located using the CityGML database. Then the indoor objects with like doors and windows are spotted using 3D point cloud obtained by range image sensor. In the final step, dm-level fine positioning of the camera- based method combines spatial and trilateration resection.

Muffert et al. (Muffert et al., 2010), specify the trajectory of an omnidirectional video camera based on relative orientation of consecutive images. The path drifts away from the trajectory when there is no control over reference directions. A low-cost indoor positioning system for off-the-shelf camera phones has also been developed by Mulloni et al. (Mulloni et al., 2009), using bar-coded fiduciary markers. The markers are positioned on certain objects like walls or posters etc. Further, 6-DOF (degrees of freedom) tracking can deliver centimeter-level accuracy when markers are tracked.

2.1.1 PREVIOUSLY PROPOSED SMART CANE

Smart Cane serves as an enhancement to the visual impairment devices by detecting knee-above and hanging obstacles. These obstacles can be the strings of hanging clothes, the corner or edge of a truck or inclined ladders, etc. These obstacles can result in injury to the head or upper body parts as they do not possess any footprint on the ground. It also detects the presence of the objects in surroundings using vibratory patterns (Wahab et al., 2011).

Different sensors are embedded in the Smart Cane. They are the ultrasonic sensors that are used to first detect and avoid the obstacles in front of a person. At the same time there is a fuzzy controller that is aimed to instruct the person, i.e., to turn to right, left or to stop (Dey et al., 2018, Shah et al., 2017). In (Wade et al., 2015), the ultrasonic sensor is coupled to a GPS. A vibration actuator is used to convey distance of obstacles. Each distance corresponds to a certain delay among the vibrations where greater distance has greater delays. Another model described in (Lipson et al., 2012) uses radio frequency identification (RFID). RFID detects objects or obstacles which come in the track of the persons. RFID is also able to detect the RFID tags which have been placed in several areas for navigating persons.

With this brief review, we noticed that Smart Cane can be used by everyone having any visual impairment. Independent travelers can use this device for their mobility. People who commute long- distance walking are usually the ones who can get the most out of it. The people having a non- acceptance view of their disability will be less eager to use the Smart Cane. This can be observed among the people who are adolescents and are highly skeptical of how they would be perceived by peers. As a result, it appears that Smart Cane is very useful and simple to use with exciting features like:

- Ergonomic grip for comfortable holding and cane tapping: Smart Cane provides different gripping styles that allow users to use their natural way of holding cane.
- Built-in rechargeable battery with a long battery back-up: Smart Cane is easily chargeable like a mobile phone. The removal of the battery is not required for/while charging the device.
- Fully accessible user interface: the interface is very friendly where there is varying number of beeps for conveying different messages, i.e., battery low or status of the charging, etc.
- Vibrations are uniformly produced on the entire grip: The Smart Cane provides non-localized vibration feedback for allowing users to grasp/hold the device conveniently.
- Easy attachment/detachment from a white cane: the white cane can easily be replaced by the user himself.

The proposed Smart Cane is one of its kind state-of-the-art device with unmatchable usability features. It uses advanced IoT wireless scanner and other navigation instruments that perform well in all conditions. Cloud connectivity with backend database system makes it stands out as compared to other competitors. The next section includes all the description of the Smart Cane indoor navigation system with in-depth details of each component used.

2.1.2 LIMITATIONS OF PROPOSED SMART CANE

Even though the proposed smart cane is highly beneficial but it has its limitations that can hinder its ability to detect the object at the forefront. These limitations are as follows:

- Dependence on computer vision can reduce effectiveness in low-light conditions or environments with poor visibility.

- Reliance on cloud services for distance calculations may face challenges in areas with poor or no internet connectivity.
- Processing speed and latency of cloud services and local hardware can impact the responsiveness and real-time navigation.
- Audio instructions may be difficult to hear in noisy environments or for users with hearing impairments.

PROPOSED SMART CANE INDOOR NAVIGATION SYSTEM

2.1.3 IDENTIFICATION OF USERS' REQUIREMENTS

Identification of user requirements is the basic and essential part of a system. According to Mitchell David Kapor, "design is where you stand with two worlds—the world of technology and the world of people—and you try to bring the two together." From this point of view, we want to understand how current technology could help improve the independence of visually impaired people. Considering the tools that have proved their worth in this field as mentioned above, the white cane and the guide dog appear at the head of the list. A quick analysis of these assistive systems shows that they mainly offer:

1. Help to achieve autonomous navigation;
2. Provide safety and comfort in the displacement;
3. Provide a companion and a significant vector of communication;
4. Help to pick up a fallen object.

It is important to note that these four features are not covered completely by neither the white cane nor the guide dog. To achieve a high-quality system that will meet the needs and lifestyle requirements of blind people, we focus on identifying the needs that the ideal assistive tool should fulfil. Doing so, we have identified main characteristics that an assistive device for blind or visually impaired people should offer:

- Assist visually impaired people to come to autonomous navigation;
- Providing security and comfort while moving from one place to another;
- Offering a tool that will support them to communication with others;
- Offering a tool that will identify objects within the surrounding environment.

2.1.4 MAIN CHARACTERISTICS OF THE PROPOSED SYSTEM

As discussed in the previous subsection, the proposed system has been designed to offer great usability to its users. Usability can be defined as “the measure of user performances in the context of intended use”. Usability can be measured by various indicators such as ease of learning, ease of memorization, error-free use, and so on. That is why the proposed system is centered on providing all possible help with a smart white cane. Figure 10 shows an indoor navigation system that uses cloud computing and IoT concepts to assist the users with the Smart Cane. Smart Cane has the ability to collect the data that is transmitted to cloud network. Moreover, IoT wireless scanner is also connected to cloud computing that makes a complete indoor navigation system that is further explained in the next sections.

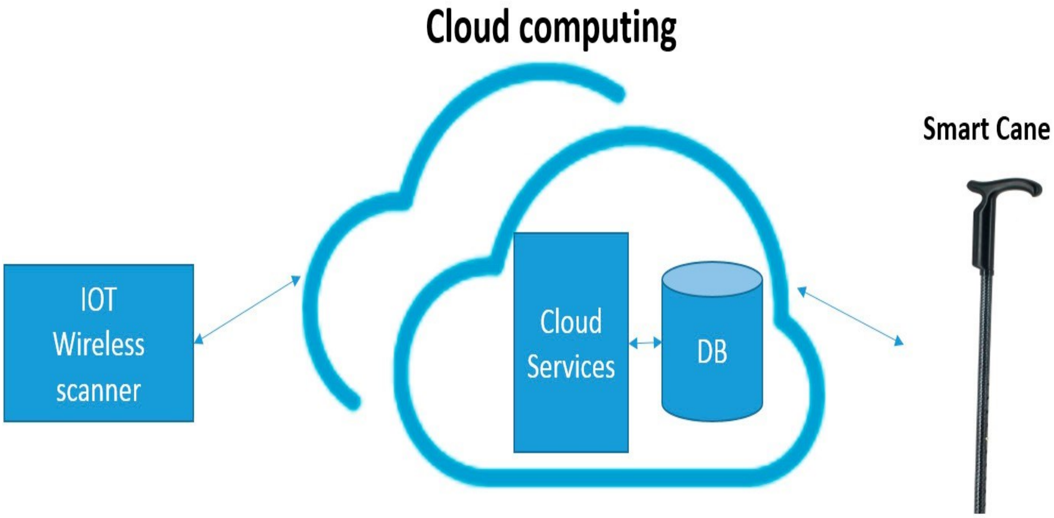


Figure 14 : Smart Cane indoor navigation system

The proposed Smart Cane indoor navigation system including all the software and hardware components is discussed in detail in the following sections:

2.1.5 DETAILED EXPLANATION OF PROPOSED SYSTEM COMPONENTS

Visually impaired persons including deaf-blind, blind, and low vision people require assistance in their daily life. Navigating complex routes and finding objects of interest are challenging tasks for visually impaired persons and in today's world, there is a lack of infrastructures to make it easier. One of the most problematic tasks for visually impaired people is outdoor navigation (Du et al., 2018). Here, this element is typically termed as macro-navigation or orientation. It includes multiple sub-processes such as being oriented, selecting an appropriate path, maintaining the path, and detecting when the destination has been reached. These tasks are dedicated to processing the remote environment, beyond the immediate perceptible ones. In the case of visual impairment, the main cues (e.g., landmarks and paths) for sensing the environment are degraded. This results in difficulties relating to correct orientation or heading, piloting (i.e., guidance from place to place using landmarks) retaining the path, etc. A system that assists visually impaired persons' navigation and orientation in real-time will be of great benefit to achieving this demanding task.

Our proposed system is made up of an ultrasonic sensor that was interfaced with the microcontroller, codes were written with the Arduino sketch, and the physical sensor was connected to the microcontroller. The system will allow the blind to freely navigate to their desired destination. It is also user-friendly and easy. It is affordable and therefore can be mass-produced for use of the visually impaired. The system has the capacity to detect obstacles that exist on the ground during walks of indoor navigation. A camera mounted on the Smart Cane can detect objects and colors and relay the information to the user via an audio message, this means that the users can independently locate objects around them, also with accelerometer we count the number of steps and calculate the number of calories burns to encourage users who have lung disease to move.

The Smart Cane is basically an embedded system integrating the following: pair of ultrasonic sensors to detect obstacles in front of the blind from ground level height to head level height in the range of 400 cm ahead. Ultrasonic sensors and connected to a cloud service for easy navigation. Using this Arduino Smart Cane, a visually impaired person can walk without anyone's help. The cane can automatically detect an obstacle and give the user a feedback response by giving a warning sound.

Cloud services: this gets the position of the cane, gets the route to destination and gets the traffic to the destination. The data comes from the Wi-Fi Arduino board from the last stage to the cloud service. The cloud service then uses a Gaussian model for the triangular based pose estimation. This code we use is an open source code for the resection problem, it gives us the position of the cane at that point. The cloud service is linked to the database which has all the paths. The cloud service then gets the path, i.e., the shortest and the safest path considering the traffic. The cloud service also gets traffic. These are the number of devices that can be connected. It outputs three lights. Red when devices are greater than 15, yellow if the devices are between 5 and 15 and green if the devices are less than 5.

IOT wireless scanner: The wireless scanner sends the cloud names and the received signal strength indicator (RSSI) of Wi-Fi and Bluetooth devices scanned as shown in Figure 11. It is built using aHM-10 Bluetooth RSSI or received signal strength indicator. RSSI is typically used to estimate the distances (Bourne et al., 2017). Generating, detecting and processing ultrasonic signals in ultrasonic is the production of sound waves above the frequency of human hearing and can be used in a variety of applications such as sonic rulers, proximity detectors, movement detectors, liquid level measurement. The distance between the sender and the receiver machines has an impact on the signal strength this is then used to calculate the distance. The distance of the obstacle is determined based on the delay between the emission of sound and the arrival of an echo. The distance of the obstacle can be measured as distance = (time × speed of sound in air)/2, (Varma et al., 2016); where time is the time duration for which the ultrasonic waves have travelled and speed of sound in air is 340 m/s. The advantage of this is that it is a cheap solution for distance estimation. The Arduino component, on the other hand, gives an easy path to use the device for communication between the cloud and the wireless scanner.

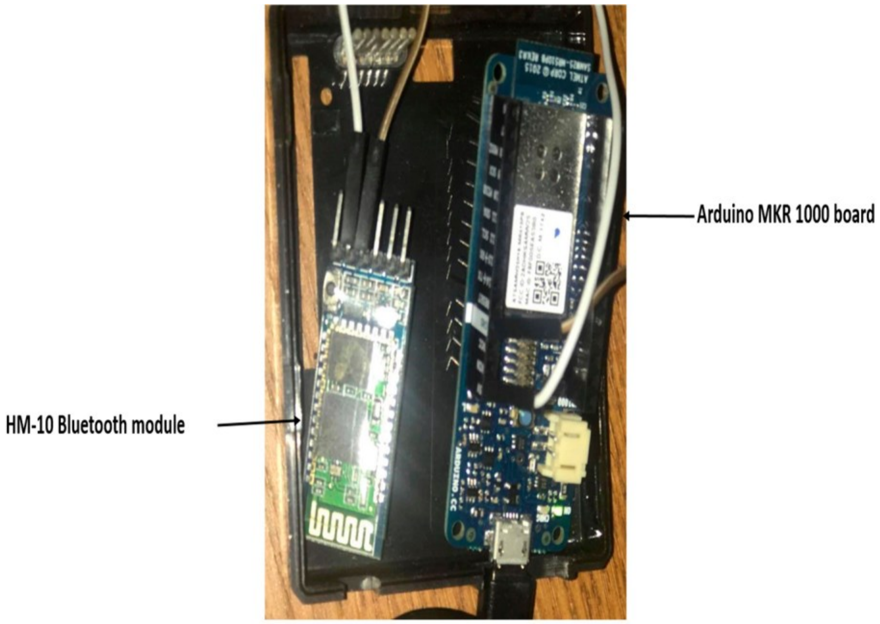


Figure 15 : IOT wireless scanner

Smart Cane: Created with ultrasonic sensor distance measuring module, keyboard for blind people, accelerometer, ESP32 board, Pixy cam, and Emic 2 Text-to-Speech module as shown in Figure 12. The ultrasonic sensor distance measuring module includes ultrasonic transmitters, receiver and control circuit. The ultrasonic sensors send a sequence of ultrasonic pulses. If the obstacle is detected, then the sound will be reflected back to the receiver (Günther and Hoene, 2005). The microcontroller processes the readings of the ultrasonic sensors in order to activate the motors by sending pulse width modulation. It also provides a low power consumption. The data from this sensor is sent to the ESP32 board for transmission to the cloud. The keyboard for blind people is used as an input device. The blind person touch types their destinations and then the path is calculated. An accelerometer is one of the most important things in the stick. Accelerometers get the acceleration forces electromagnetically. Now they are used to detect and measure the gravitational and other forces. They are used to measure the speeds with which a person is traveling. Now this speed is important when it comes to the path updating to the user.

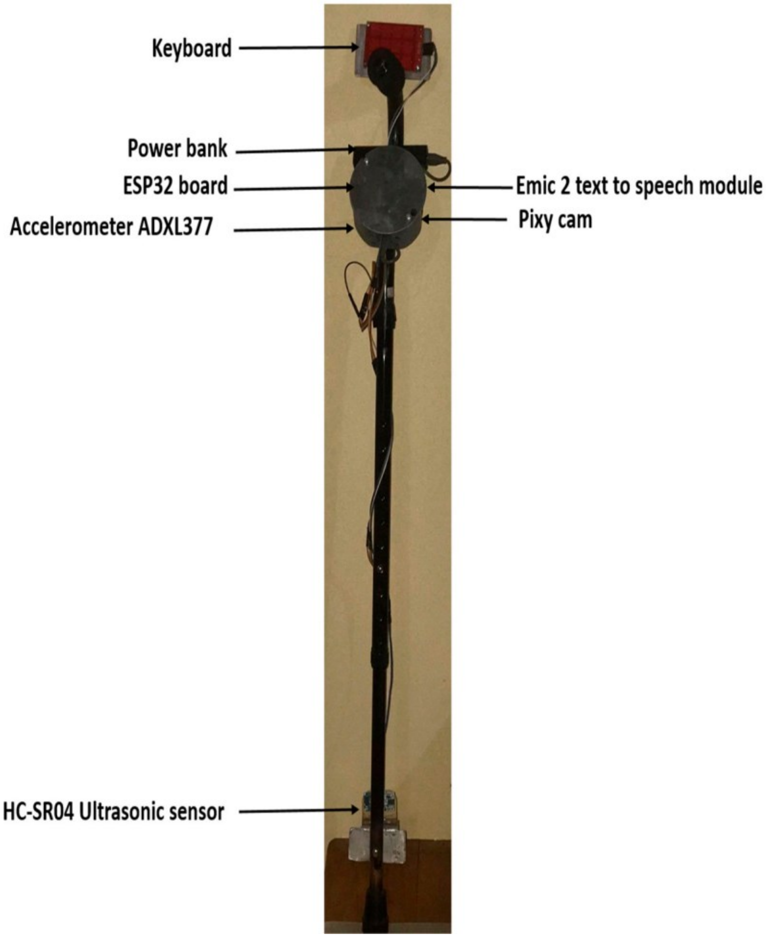


Figure 16 : The components of the Smart Cane

The Smart Cane is composed of:

Ultrasonic sensor distance measuring module for the detection of an obstacle. The HC-SR04 Ultra01 + Ultrasonic Range Finder provides 2–400 cm non-contact measurement function, the ranging accuracy can reach to 3 mm. The module includes ultrasonic transmitters, receiver, and control circuit (HC-SR04 Ultrasonic Range Finder).

Keyboard for blind people.

Accelerometer—we use the accelerometer to know the position of cane and calculate a number of steps. Here, we are using the ADXL337 and the ADXL377 are both small, thin, low power, complete 3-axis accelerometers with signal conditioned analog voltage outputs (JORDANDEE).

ESP32 board—send data of sensor to the cloud and receive data from the cloud like route and obstacle position and traffic. ESP32 is a series of the low-cost, low-power system on a chip microcontroller with integrated Wi-Fi and dual-mode Bluetooth. The ESP32 series employs a Tensilica Xtensa LX6 microprocessor in both dual-core and single-core variations and includes in- built antenna switches, Radio frequency (RF) balun, power amplifier, low-noise receive amplifier, filters, and power-management modules. ESP32 is created and developed by Expressive Systems, a Shanghai-based Chinese company, and is manufactured by TSMC using their 40 nm process. It is a successor to the ESP8266 microcontroller (Charmed Labs Pixy 2 CMUcam5 Image Sensor).

Pixy Camera: A camera is used to detect the colors and objects; it also detects the different kinds of signs. For obstacle avoidance systems camera-based approaches are predominant.

Different approaches may be used for obstacle avoidance purposes based on the type of camera used. The monocular camera is the primary type of camera that can be used in precautionary scenarios. As the method's name implies, only one camera is used. Various algorithms to detect the obstacle have been proposed. The Pixy 2 Image Sensor is smaller, faster and more capable than the original Pixy. Like its predecessor, Pixy2 can learn to detect objects that you teach it, just by pressing a button. Additionally, Pixy2 has new algorithms that detect and track lines for use with line-following robots. The new algorithms can detect intersections and "road signs" as well. The road signs can tell your robot what to do, such as turn left, turn right, slow down, etc. (Emic 2 Text-to-Speech module).

Emic 2 Text-to-Speech modules: It's used for audio output for the blind. The Emic 2 Text-to- Speech Module is a multi-language voice synthesizer that converts a stream of digital text into natural sounding speech. Its simple command-based interface makes it easy to integrate into any embedded system (Link et al., 2011). Text-to-speech (TTS) is a technology for speech synthesis that is used to produce a sound spoken version of the text in a computer document, for instance the help file or website. TTS may allow the visually challenged person to read computer display information or it can be used simply to enhance text message reading.

Emic 2, Text to speech unit, is an unconstrained voice synthesizer which can turn a digital text input into a natural speech sound output in different languages. Emic 2 offers complete speech synthesis capability for any embedded system via a simple command-based interface using a universally recognized DECtalk text-to-speech synthesizer engine. We have used text-to-speech system to give voice to our interactive system. Text-to-speech is a process by which a text is rendered as a digital audio that is converted to analog audio. It is used where digital audio records are unable to audibly convey the data to the user.

The ESP32 board is used to send data of sensor to the cloud and receive data from the cloud like route and obstacle position and traffic. The biggest benefit of using an esp32 is that it is a cost-effective and low power system. The Pixy cam is used to detect objects and colors. It is a small camera, that in the end, gives us frames at the rate of 60 FP. It is the fastest version sensor for robotics. Pixy has the ability to detect multiple objects simultaneously, but the main advantage is that the data we get from it is only the information we want, i.e., discarding the ground data and getting only the object data. This all is topped up with an Emic 2 Text-to-Speech module that is responsible to read out all the instructions it gets from the cloud. The Emic 2 Text-to-Speech Module is a voice synthesizer. It converts the text into a speech. It is easily integrated with our cane due to the fact that it has a single command-based interface.

The whole of the system is fitted in the cane, the cane needs an internet connection to communicate with the cloud servers. The servers are listening to them all the time. The data that comes back is also spoken by the module which means that it is beneficial for all sorts of people. One more key advantage of this Smart Cane is that it is fully autonomous and does not require a partner device such as a smartphone to operate.

2.1.6 TRIANGULATION OF THE CANE AND GUIDANCE OF THE USER

Triangulation is the basic feature of the proposed system. It aims at guiding the user towards a point of interest located in a building. To be feasible, the explored environment has to be equipped with multiple IoT devices situated in some predefined positions. In addition to providing object detection in a longer range, the IR sensors use an established methodology that provides a wide variety of information. Due to the new approach, the new technologies offer a far better immunity to ambient lighting conditions. These new technologies use a linear triangulation to calculate the distance and presence of objects in the field of vision. The transmitter releases a pulse of infrared light. If there are no obstacles in the specific area, then the light is never reflected and the output does not indicate an object, but if it does have an obstruction, the light is reflected and thus object is reflected. This action creates a triangle of reflectors, emitters and detectors. The angles of the triangle differ according to the object's size. The receiving segment of these new detectors is a sensitive lens, which transmits the reflected light to several sections of the enclosed linear array. Given what angle the reflected light came back in the CCD array, the distance to the object can be computed. This features relays on the following hardware and services.

Trilateration: Trilateration (a sophisticated version of triangulation) is used to determine the position of the user in an indoor space. This technique is being used in state-of-the-art navigation systems. Triangulation is typically more common in long distances than indoor settings. Trilateration, on the other hand, seems to be doing well indoors. Trilateration is the technique of measuring the distance between the object and the access points in which the position of an object is estimated. Common procedures for deciding range are time of arrival (TOA), time difference of arrival (TDOA) and received signal strength indicator (RSSI).

RSSI is one of the most common and easiest location methods. The main reason for its popularity is that finding RSSI does not require additional hardware and is available on nearly all types of wireless communication devices. Indoor locations based on RSSI are environmentally affected. Some wireless technologies, however, are more vulnerable than others to environmental changes.

Bluetooth low energy (BLE) (Wade et al., 2015), with its high localization accuracy in the two environmentally tested is a promising, low power, cost efficient solution for the location of IoT in small, crowded areas. Wi-Fi is a reliable technology, thanks to its high availability can also be used for localization. Nevertheless, Wi-Fi uses the most energy out of all the systems that have been tested. LoRaWAN (long range wide area network) has a wide range of transmission and low energy consumption, which are useful in large areas to localize IoT, but was the worst performance in indoor location. ZigBee's energy demand is close to LoRaWAN while in the two conditions measured its efficiency is much better.

2.1.7 RECOGNITION OF OBJECTS ENCOUNTERED IN THE ENVIRONMENT

Beyond navigation, in many situations of everyday life, one may have to search for a particular object in a given environment. To understand the usefulness of this characteristic, imagine how frustrating it can be to find one's keys just before leaving. Moreover, in everyday life, most of our positioning indications exploit the identification of an object of interest. Indeed, it is very common to say that the place is located to the right or to the left of a specific object. This feature responds to this need. It aims to assist the user in the search for a particular element.

Sonar: Sonar is a sound reflection-based system for finding distance. An acoustic transmitter and receiver are necessary in this process. Initially a brief sound signal will be sent by the transmitter. The timer begins and when the receiver detects acoustic signal reflection, it stops counting if the timer exceeds the time limit, it is turned off. By dividing the sound frequency in that atmosphere by half the sound time it is possible to calculate the distance from the detector to the target. The time is divided into two as the sound goes to the target and returns back.

Object Detection: As we want to guide the user towards a destination, it is important to detect obstacles that may be present on the path. Object detection is made possible by manipulating the mean of the ultrasonic sensors. The goal is to detect ground and air obstacles using ultrasonic sensors. The object detection process requires sensors and microcontroller units within a specific distance. The control signal will be produced, and the microcontroller Echo-Pin will be activated when an ultrasonic wave is detected. The microcontroller tracks the length of the time period of the height of each pin and then transforms it to a distance. The command signal is transmitted wirelessly to the receiving device that is carried on the shoulders. The buzzer is played to alert the user depending on the approach of the obstacle (high alert, usual warning, low alert and without warning).

Sound Buzzer: The sound buzzer is activated whenever there is an obstacle, it gets the signal from the microcontroller and behaves accordingly.

2.1.8 DETERMINING THE ROUTE

In order to determine the possible path between the user and the destination sensors’ data is sent to the cloud service, which returns the potential path towards the destination. It has two goals that are:

- Calculation of the fastest and safest route to arrive at a given point in the environment;
- Proposition of different navigation modes.

Navigation Modes

There are three navigation modes available. A user can choose one of the modes using the keypad:

a) Smart navigation mode: In this mode, the system uses the camera and the ultrasonic sensor to detect objects and obstacles. The Smart Cane is connected to the cloud thus it can communicate with the database to let the user know about detected objects and obstacles, thus guiding the user for indoor navigation.
b) Eco mode: This mode uses the camera when the ultrasonic sound sensor detects an object distance less than 30 cm. Similar to the smart navigation mode, the Smart Cane is also connected to the cloud in the mode. This mode is set to be activated automatically when the battery is less than 20%.
c) Offline mode: In this mode, the Smart Cane is not connected to the cloud and IoT wireless scanner so the user can’t get itinerary, route details. In this mode the system can just detect obstacles and objects.

2.1.9 ITINERARY ALGORITHM

The system employs Dijkstra’s algorithm to calculate the shortest itineraries (Ruan, Luo and Wu, 2014), which is essential for providing efficient navigation routes. This algorithm is particularly suitable because it handles graphs with non-negative weights, aligning well with the distances and obstacle counts involved in this application. By leveraging Dijkstra’s method, the system can not only find the most direct route but also tag each computed itinerary based on the number of obstacles it contains. This allows blind pedestrians to choose from four different paths to reach the same destination, with options varying in length, number of turns, and convenience. For instance, some paths might be shorter but less suitable due to the absence of pedestrian sidewalks. The goal is to select the route that best fits the user’s needs, focusing on geographical information classification and ensuring safety. The algorithm takes all positive borders into account, calculating a path safety index based on the number of obstacles detected and devices connected along the route. This ensures that the chosen path is not only optimal in terms of distance but also safe for navigation. By using Dijkstra’s algorithm, the system effectively addresses the minimization problem, offering a reliable method to determine the safest and most suitable routes for visually impaired users.

While all indoor X, Y coordinate locations are saved in the database, in the cloud the algorithm, it uses the following step to find if the path is safe to move or not:

Algorithm

```
function GetSafetyPath(PathLength,NumDev,NumObs):
```

IndDev ← (PathLength\NumDev)\PathLength IndObs ← (PathLength\NumObs)\PathLength

Return ((IndDev*30) + (IndObs*70))\100

If: GetSafetyPath >= 80: The Path is Safe

If: GetSafetyPath >= 50 AND <80: The Path is normal. Else: The Path is unsafe.

2.1.10 CALCULATE SPEED

To calculate the speed of the user we have used a reference design that uses the three-axis ADXL345 accelerometer in a full-featured pedometer that can recognize and count steps, as well as measure distance and speed (Zhao, 2010). For pedometer applications, the ADXL345 is an excellent speed meter. Using its small, thin 3 mm/5 mm/0.95 mm plastic packages, pedometers can be found in medical devices as well as fancy consumer electronics. We have used it to calculate the speed while the user traverse through a path following the instructions of the Smart Cane navigation system.

EXPERIMENT

This section describes the experimental details for testing the system. Two different experiments were performed to measure two different performance parameters. The first experiment was to test the indoor navigation system using the smart navigation mode. While the second experiment is focused on testing the performance of battery and connectivity of the system while using all of the available modes.

The system was evaluated on its ability to detect different types of obstacles encountered in daily life. We also measured their ability to recognize an obstacle-free path. A tape calculated the actual distance from the barriers to the cane and the distances recorded by the Smart Cane system were contrasted. The navigation system could sense the distances from obstacles up to a distance of 10 cm. Since we announce the gap far beyond 10 cm with haptic feedback to the user, this is an appropriate error range for our purposes. It also established an obstacles-free path and a potentially dangerous decline.

2.1.11 TESTING OF INDOOR NAVIGATION SYSTEM

The indoor navigation system is tested using the smart navigation mode in an office environment. In this experiment, we have defined a route to traverse; where a normal user, who is not blind, will navigate from point A to point B as shown in Figure 13. There are eight offices in the experimental setup, and we have put four obstacles at different locations in the pathway between the offices. This experiment was performed once to measure the performance of the navigation system. All the information about the map and environment is stored in the cloud server. This includes the pathways, position of the obstacles, number of offices with their locality information, etc.

At the start of the experiment, the system will first inquire the position to begin, that is the point A in the map. The user then pushes a key to send information about the starting point. The device will request to enter the destination location that would be an office number. The user then presses the end location. Once the start key is pressed the system gives instructions to start the navigation process. The system will instruct the user by an audio speaker about how to go to the destination that is Point B. These instructions could be like “turn right”, “turn left”, “move forward”, etc. At the point B location, the user will hear the voice “destination arrived”.

Since the system follows the map and helps the visually impaired person to get to a specific location. If obstacles between paths are detected, then the system will inform about these obstacles as well. We tested the system in an experimental environment where a blind person is expected to navigate from the starting position to the destination position while crossing some obstacles. We have performed the experiments three times with a normal person who is not blind.

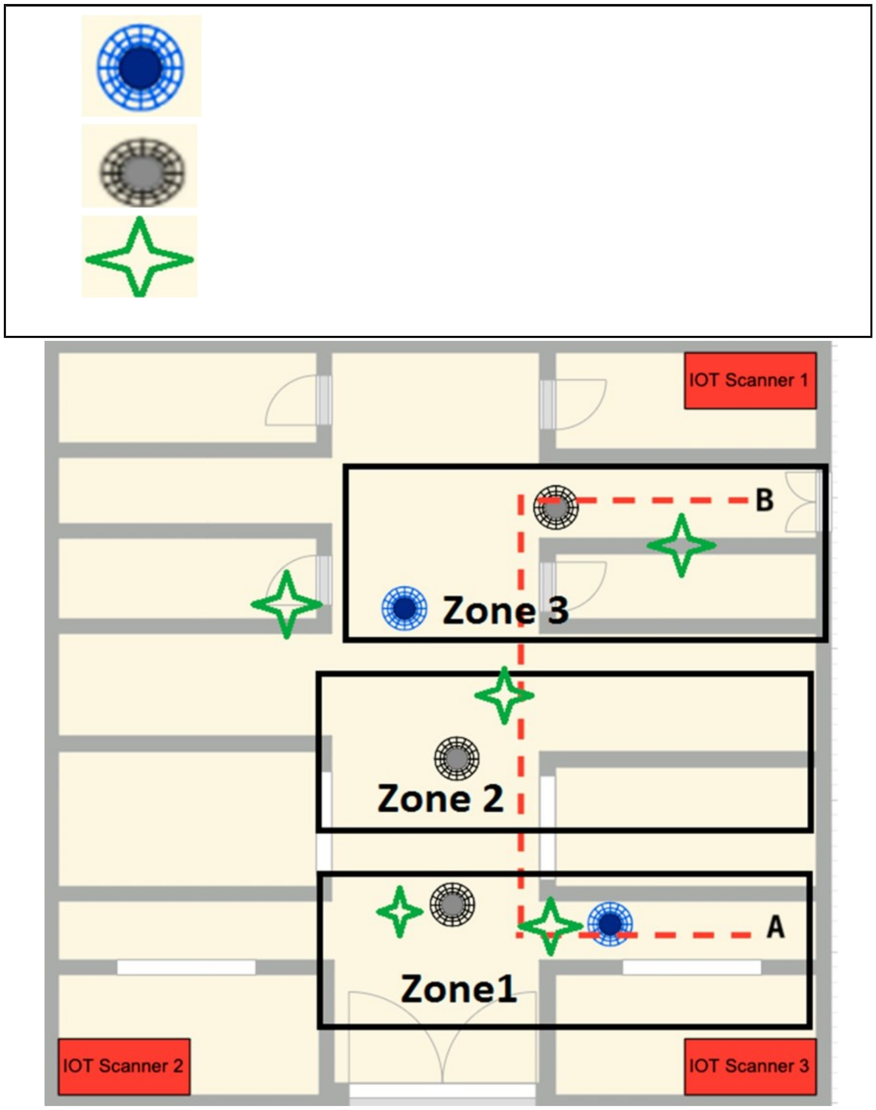


Figure 17 : Experimental setup

As shown in the figure, we want to from point A to point B move using the Smart Cane. We put office trashes as obstacles to test the object detection of the system. In this scenario the positions of the blue trash are already stored in the cloud database as obstacles. Whereas, the other trashes are not already stored in the database. We installed three IoT scanners in three corners of the building for location accuracy. Precision of the localization of the Smart Cane was expected to be between 50 cm and 100 cm in an area of 70 m × 50 m. During each experiment, the system includes the detected obstacles in the database and thus can help in the navigation for the user for the next experiments by taking less time for navigation, as shown in Table 13.

Table 13 : Elapsed time with number of obstacles in three experiments

Experiment	**Time**	**Number of Obstacles Stored in the Cloud**
1	154 s	2
2	112 s	5
3	105 s	5

In our experiment, whenever the user approaches near the blue trash, the cane warns about the presence of the obstacle. The detection occurs because the trash position is already stored in the cloud system. While navigating through the path between A and B. When the cane detects a new obstacle, it will be stored in the cloud in the table of obstacles. This table is used by the system to get the safe way. It is important that the cane remains connected to the cloud, whenever the Smart Cane loses connection with the cloud, it cannot guide the user to navigate to point B.

Table 14 shows the precision accuracy of the Smart Cane navigation system. For all three zone shown in the Figure 13 of experimental setup, it shows precision of estimated location of trashes. It can be seen that the system can accurately determine the location of the obstacles with a precision range of 50 cm to 100 cm. It is to be noticed that as the user moves father from the IoT Scanner 2 and 3, and it effects the accuracy of the object detection system.

Table 14 : Localization precision of the Smart Cane navigation system

Zone	Precision of Estimated Location of Trash	Precision
1	Between 50 cm to 55 cm	Between 50 cm to 55 cm
2	Between 60 cm to 75 cm	Between 60 cm and 70 cm
3	Between 80 cm to 100 cm	Between 80 cm and 90 cm

2.1.12 LIMITATIONS OF THE PROPOSED SMART CANE

- Performance may vary with different types of obstacles and environmental conditions.
- Efficiency improvement relies on user interaction and obstacle accumulation.
- Detection accuracy degrades with increased distance from IoT scanners, affecting confidence.
- Limited testing scope with only three trials; more diverse testing needed for validation.
- Addressing limitations requires enhancing connectivity, improving localization, and expanding the obstacle database.

2.1.13 SYSTEM PERFORMANCE

We have tested the performance of the system parameters including battery, connectivity, response time and detection range of the Smart Cane navigation system. All these experiments are performed five times by a person who is not blind. To test the performance of the battery, we keep the cane on until the battery of the cane is completely drained. The capacity of the power bank is 2200-mah. This experiment is performed for all three available modes that are smart navigation mode, Eco mode and offline mode.

For testing the range of obstacle detection, we have put obstacles at different distances from the user to measure the maximum detection range. Obstacles were placed at 1–8 m away from the user to determine the maximum detection range. Each experiment is performed five times and average values are presented in the Table 13. Similarly, to get the average value for response time from the server is also measured five times. It is the time that a message takes to carry information from the cloud server to the Smart Cane. Average values of response time are calculated for all three available modes and are recorded in the Table 13. When the cane loses connection with the sound the system cannot localize the cane indoor. Table 15 presents an analysis of the performance of the system in Smart navigation mode, Eco mode and off-line mode.

Table 15 : Performance of navigation system

Parameters	Smart Navigation Mode	Eco Mode	Offline Mode
Battery	11.8 h	12.45 h	15.2 h
Maximum object detection range	500 cm	400 cm	400 cm
Time Delay	1 s	1.2 s	Not applicable

The Table 15 shows the performance of the Smart Cane navigation system in all three modes for different parameters such as battery consumption, maximum range for object detection and time delay. Smart navigation mode is the powerful mode that can detect objects from 500 cm with only 1 s of communication delay, but it consumes battery at a faster rate. Eco mode can be turned on for smart usage in order to have a longer usage of battery. Offline mode is also helpful when you do not need to have communication with the cloud server, thus it consumes less battery but still can detect the objects in the 400 cm range.

CONCLUSIONS

Considering that navigation has been a major problem for this segment of people, we have proposed a smart white cane to help blinds in indoor navigation. This system contains micro-controllers, cameras and accelerometers and can send audio messages. A cloud service is exploited to assist the user in navigating from one point to another. It mainly helps in the detection of the fastest routes. The device may also warn about nearby objects using a sonar and a sound buzzer. We have tested our system and the results are very satisfactory. The observed results have shown that the system is capable of assisting navigation. Such results may lead to enhancing product design based on user input. Functionality experiments carried out so far have given practical suggestions for growing the usefulness of the new navigation system. In the near future, we also plan to make the Smart Cane useful even if it loses connection with the cloud. To convert user requirements into design quality, the quality function deployment framework will be used. We also plan to add some intelligence in the Smart Cane navigation system since the field of artificial intelligence is making great progress now and features like objects detection can become more efficient, easier and computationally feasible. We can use extended support vector machines (SVMs), which were initially designed to solve the classification task of medical implant materials, to provide a higher accuracy of the navigation tool. Similarly, to improve the precision of object detection, we can consider using artificial neural networks to solve this problem. The non-iterative feed-forward neural network works much faster than MLP and has a lot of other advantages for solving the stated task.

CHAPTER 3

INTEGRATION OF SMART CANE WITH SOCIAL MEDIA: DESIGN OF A NEW STEP COUNTER ALGORITHM FOR CANE

Messaoudi, M. D., Menelas, B. A. J., & Mcheick, H. (2024). Integration of Smart Cane with Social Media: Design of a New Step Counter Algorithm for Cane. IoT, 5(1), 168-186.

Résumé: Cette recherche présente une architecture de canne intelligente innovante conçue pour autonomiser les personnes malvoyantes. En intégrant des capteurs avancés et une connectivité aux médias sociaux, la canne intelligente améliore l'accessibilité et encourage l'activité physique. Trois algorithmes garantissent un comptage précis des pas, la détection des mouvements et la mesure de la proximité. L'architecture de la canne intelligente comprend les couches de plateforme, de communications, de capteurs, de calcul et d'interface utilisateur, fournissant une assistance complète aux personnes malvoyantes. Les composants matériels comprennent un module d'interaction audio-tactile, un module de commande d'entrée, une intégration de microphone, un stockage local, un module de comptage des pas, une intégration cloud et une batterie rechargeable. Les composants logiciels v1.9.7 comprennent l'intégration de l'API de discussion Facebook, l'intégration de l'API Facebook Python, l'intégration de la bibliothèque fbchat et l'intégration de la bibliothèque de reconnaissance vocale. Dans l'ensemble, la canne intelligente proposée offre une solution complète pour améliorer la mobilité, l'accessibilité et l'engagement social des personnes malvoyantes. Cette étude représente une avancée significative vers une société plus inclusive, en exploitant la technologie pour avoir un impact significatif dans la vie des personnes atteintes de déficience visuelle. En favorisant la socialisation et l'indépendance, notre canne intelligente améliore non seulement la mobilité, mais aussi le bien-être général de la communauté malvoyante.

Abstract: This research introduces an innovative smart cane architecture designed to empower visually impaired individuals. Integrating advanced sensors and social media connectivity, the smart cane enhances accessibility and encourages physical activity. Three algorithms ensure accurate step counting, swing detection, and proximity measurement. The smart cane's architecture comprises the platform, communications, sensors, calculation, and user interface layers, providing comprehensive assistance for visually impaired individuals. Hardware components include an audio–tactile interaction module, input command module, microphone integration, local storage, step count module, cloud integration, and rechargeable battery. Soft-ware v1.9.7 components include Facebook Chat API integration, Python Facebook API integra-tion, fbchat library integration, and Speech Recognition library integration. Overall, the proposed smart cane offers a comprehensive solution to enhance mobility, accessibility, and social engage-ment for visually impaired individuals. This study represents a significant stride toward a more inclusive society, leveraging technology to create meaningful impact in the lives of those with vis-ual impairments. By fostering socialization and independence, our smart cane not only improves mobility but also enhances the overall well-being of the visually impaired community.

INTRODUCTION

Humans have at their disposal several sensory motor channels to perceive the environment. In this set, vision plays a very important role in accessing the environment around us, because 85% of the information about our surroundings is obtained through the eyes (Gillen, 2008). Blindness is the state of condition in which a person is unable to sense information conveyed through the vision channel. People who have little vision capabilities and depend on another sensory organ are also considered as blind. Therefore, the visually challenged are people who have partial vision loss or total vision loss (Sapp, 2003).

According to the World Health Organization (WHO) and International Agency for Prevention of Blindness (IAPB), around 285 million people are visually impaired in the world, out of this, 39 million are blind (Morone et al., 2012). Blind individuals face enormous challenges in their daily routine and must rely on other people to accomplish some of their daily tasks. In addition, for displacement, they must use traditional blind sticks.

In this modern era where technology is everywhere and involved in almost every daily task, there have also been some advancements in blind stick technology. Indeed, researchers have developed blind sticks equipped with obstacle detection, GPS, and indoor navigation. In this information age, social media plays a very important role in connecting people around the world. To enable people with visual impairments to access these technologies, serval research initiatives have been undertaken. Companies such as Facebook are trying to make sure that information, depicted in their sites, is accessible to all kinds of users. Facebook plans to roll out AI-powered automatic alt-text to all screen readers. X (formerly Twitter) already has AI-captioning for image mode. One understands that such functionalities aim at assisting people with visual impairments in accessing social media environments (Subramoniam et al., 2018).

Empowering the visually impaired is not merely about enhancing accessibility; it is about enriching lives and breaking barriers. Beyond the realm of technology, our initiative strives to encourage individuals with visual impairments to embrace physical activity and social interaction, essential facets of a fulfilling life. Resnick (Resnick et al., 1993) underscores a critical issue: blind children often face a lack of motivation and opportunities for physical activity, leading to sedentary behavior and a sense of inadequacy. This trend continues into adulthood, as Modell (Modell et al., 1997) and Jessup (Jessup et al., 2017) corroborate, highlighting that individuals with disabilities including visual impairments often participate less in recreational activities, leading to profound social isolation. Moreover, Folmer (Folmer and computing, 2015) sheds light on the alarming consequences of limited physical activity among the visually impaired, which include delays in motor development and an increased susceptibility to various medical conditions.

Our research and the innovative smart cane architecture we propose are not only technological advancements but also beacons of empowerment. By seamlessly integrating advanced sensors, social media connectivity, and novel algorithms, our smart cane not only enhances mobility and accessibility, but also serves as a catalyst for encouraging physical activity and facilitating socialization among the visually impaired. We firmly believe that fostering a sense of independence and belonging in the visually impaired community is not just a goal; it is a societal responsibility. With our pioneering method, we are dedicated to linking the physical challenges faced by the visually impaired with the limitless potential for an active and socially connected existence (Sezgin et al., 2020, Wentz and Lazar, 2011, Helal et al., 2001, Harrison et al., 2023).

This study presents a cutting-edge smart cane design aimed at empowering individuals with visual impairments. By incorporating advanced sensors and social media connectivity, the smart cane not only improves accessibility but also promotes physical activity. The implementation of three carefully crafted algorithms ensures precise step counting, swing detection, and proximity measurement. Section 2 discusses the related work conducted in this domain and critically evaluates it. The architecture of the proposed smart cane model and components is presented in Section 3. Section 4 presents the results of the performance of the three developed algorithms followed by Section 5, which discusses these results. Finally, the main conclusions are summarized in Section 6.

RELATED WORK

Social networks like Facebook and Twitter have become deeply embedded in modern life, enabling connection, communication, and community. Currently, a number of people are working to study social media. In fact, the effects of social media on a society are a well-studied phenomenon. However, for the millions of people worldwide with visual impairments, participating in these visual-centric platforms poses significant accessibility challenges that have historically excluded blind people from full usage and engagement (Wu et al., 2022). By enabling people to communicate and share information, social media plays a critical role in strengthening the bonds between the communities, spreading critical information. The value of social media varies among the different user groups. Many previous studies examined the engagement of different social groups with social media (Wu and Adamic, 2014). According to the study by the Pew Research Center, 43% of American Internet users, older than 65, are using online social networks today, and the main function of social media for seniors is to connect them to their families (Boyd et al., 2008). While discussing the integration of social media features within the smart cane for blind people, it is imperative to acknowledge worsening social isolation. While these technologies provide valuable communication opportunities, there is also a risk that individuals may start to rely only on virtual connections and interactions instead of face-to-face and real-life social engagement. In order to prevent an over-reliance on online social interaction, the smart cane was designed with a balanced approach. It enables the user to connect not only through social media platforms like Facebook, but also incorporates other different messaging channels such as direct messaging, etc. This ensures that individuals have various options to interact, minimizing the dependency on a single social media platform or mode of communication in a negative way.

Morris et al. found that mothers' use of social media differed significantly before and after birth. It was found out that different social groups are embracing social media for distinct reasons, which affects the way they interact with social media (Burke et al., 2010). To enable blind people to live an independent life, researchers have developed many technologies because these devices are quite expensive, and common visually challenged people (VCP) cannot benefit from this. Our purposed device is focused on enabling these common VCP to live a normal life. The proposed model has many features that would enable them to interact with their environment independently (Sahoo et al., 2019). Innovations in assistive technologies are progressively dismantling barriers to enable fuller, more equitable social media participation and autonomy for the blind and visually impaired.

Screen magnification software can enlarge and optimize displays for those with residual vision. However, individuals without functional vision must rely on text-to-speech screen readers that vocalize onscreen text and labels. Screen readers such as VoiceOver for iOS and TalkBack for Android are built into smartphones, allowing users to navigate apps and hear menus, posts, messages, and more read aloud (Jain et al., 2021).

Refreshable braille displays can connect to phones, converting text into tactile braille characters. Screen readers have significantly increased accessibility, though some functions like photo descriptions remain limited (Gleason et al., 2019). Still, they establish a strong foundation for social media usage. In addition, dedicated apps tailored for blind people provide streamlined social media access. Easy Social is one popular app aggregating Facebook, Twitter, LinkedIn, and Instagram into a simplified interface with voiceover and customizable fonts/contrast. Blind-friendly apps enable posting statuses, commenting, messaging, and listening to feeds without visually parsing crowded layouts (Khan et al., 2022). However, app development tends to trail mainstream platforms. Discrepancies in features and delays in accessing new options persist as a drawback, though steady progress continues.

Vizwiz is a mobile application that enables blind people to take a picture of their environment and ask questions about the picture, where the app will answer their questions with screen reading software. In pilot testing, the answers were collected from the Amazon Mechanical Turk service. Mechanical Turk is an online marketplace of human intelligence tasks (HITs) that workers can complete for small amounts of money (Bigham et al., 2010).

In 2009, a poll of 62 blind people by the American Foundation for the Blind revealed that about half of the participants used Facebook, while a third used Twitter, and a quarter used LinkedIn and My Space. Moreover, in a 2010 study, Wentz and Lazar found that Facebook's website was more difficult for blind users to navigate than Facebook's mobile phone application. The ease of access may affect the frequency of use (Wentz and Lazar, 2011). Advance technologies enable blind people to identify the visual content in pictures; these include image recognition, crowd-powered systems, and tactile graphics. Further interaction with visual objects is also possible, for example, through the use of technologies that enable blind people to take better photos, and by enhancing the photo sharing experience with audio augmentations. Lučić, Sedlar, and Delić (2011) tested a prototype of the computer educational game Lugram for visually challenged children. They found that basic motor skills were important for a blind user to play Lugram. Initially, the blind children needed the help of sighted children, and afterward, they started playing on their own.

Research conducted by Ulrich (2011) led to the development of a cane that used robot technologies to assist blind people. It used ultrasonic sensors to detect obstacles and they found a new way by using the embedded computer. The steering action was accomplished by producing a noticeable force in the handle. Helal, Moore, and Ramachandran (2001) studied a wireless pedestrian navigation system for visually impaired people. This system is called Drishiti; it boosts the moving capability of a blind person and allows them to navigate freely (Helal et al., 2001). In this project, a new method was developed to enable blind people to use social media using a smart cane. The developed system will enable the user to use social media websites such as Facebook and Twitter. Jacob et al. conducted research on screen readers such as JAWS (Job access with speech) (Harrison et al., 2023) and NVDA (Nonvisual Desktop Access) (Harrison et al., 2023) along with the voiceover for iOS devices. To gain access to social media platforms, blind people significantly use these devices. Such tools provide text-to-speech abilities and Braille output, enabling the users to interact with the content (Harrison et al., 2023).

Braille displays have also been developed that are tactile devices and provide access to digital content or the content that is displayed on social media platforms. This process is helpful for a visually challenged person when the text is displayed in braille. These devices are considered to be beneficial as they enhance the social media experience of a user by providing a more tactile and interactive interface for visually impaired users. Research on these devices has been conducted by Kim (2019) (Kim et al., 2019), where the authors developed a braille device to make it easy for visually impaired people to interact with online social media platforms.

Additionally, to post photos and videos, smart canes such as the WeWalk's smart cane integrate cameras to recognize objects, faces, and text for audible identification (Asad et al., 2020). Users can take photos by tapping the cane and share them on social sites. Computer vision features will continue advancing, enabling more autonomous photo capturing. Limitations remain with image esthetics and the inability to independently assess the composition quality before sharing. Still, smart canes vastly widen participation. Additionally, linking services like Siri and Alexa allow for hands-free social media use, from dictating posts to asking for notifications to be read aloud (Sezgin et al., 2020). Commands like "Hey Siri, post to Facebook" streamline sharing by eliminating cumbersome typing. However, privacy risks arise with always-listening devices, and glitchy transcription can garble posts. Human-like voice assistants hold promise for managing increasingly natural conversational interactions.

Talkback and Voiceover are two text-to-speech software programs that have been developed by Folego (Folego et al., 2018). Here, Talkback can be used by Android users while Voiceover is for iOS users. Both help in navigating social media apps, which is undertaken by audibly describing the content available online, and voice commands are also provided. Thus, this makes it easy for a blind person to understand everything without requiring any help from someone.

Different social media platforms such as Facebook have introduced automatic alt text features that use image recognition technology to generate descriptions of the photos in the newsfeed of the user’s social profile. This feature provides visually impaired users with more context when they must engage with the visual content on online social platforms. In addition, another social media platform, for example, Twitter, also uses alt text for its blind users to add alternative text descriptions to the images posted on social media or in tweets, making visual content easily readable by individuals through screen readers. This type of feature enables the users to provide descriptions for the images they share on social media. Kuber et al. (Kuber et al., 2012) conducted research on determining the way through which these platforms use such features and developed mobile screen readers for users who are visually impaired.

Smith-Jackson et al. (Smith-Jackson et al., 2003) conducted research where they recommended the use of contoured shapes for improving and enhancing the grip, greater spacing among the buttons to assist the “perception of targets”, and additional awareness of the adoption/selection through feedback to aid the visually blind or even physically disabled users of mobile phones.

Singh et al. (Singh et al., 2023) conducted research to help blind users use digital devices and innovations without another person’s assistance. The device also assists people with hearing aids and enables them to link to the digital world. The proposed framework is known as the “Haptic encoded language framework (HELF)”, which makes use of haptic technology to enable a blind person to write text digitally by making use of swiping gestures as well as comprehend the text via vibrations.

Resnick (Resnick et al., 1993) emphasized that blind children often lack motivation and opportunity for physical activity, resulting in sedentary behavior and feelings of inadequacy. Modell (Modell et al., 1997) and Jessup (Jessup et al., 2017) further supported these findings, indicating that people with disabilities including visual impairments often participate less in recreational activities and experience social isolation. Folmer (Folmer and computing, 2015) highlighted that a lack of physical activity is a concern for individuals with visual impairments, leading to delays in motor development and an increased risk of medical conditions.

In the literature, a number of sensor-based approaches have been discussed aimed at enhancing the participation of visually impaired people in different physical activities. These approaches include a range of technologies, for example, wearable sensors, haptic feedback systems, and auditory cues, which provide real-time feedback and assistance during activities such as walking, running, and sports.

For instance, researchers have explored the incorporation of measurement units (IMUs) into gadgets to track movement patterns and offer assistance to individuals with visual impairments while engaging in physical activities (Reyes Leiva et al., 2021). These devices are capable of identifying alterations in posture walking style and orientation, providing auditory or tactile cues to help users maintain technique and navigate around obstacles (Reyes Leiva et al., 2021).

In addition, a haptic feedback system was also proposed by the authors of (Shull et al., 2015) to enhance the sensory perception of blind individuals during physical activities. Such systems use vibratory or tactile stimuli to pass on information related to the environment like the presence of nearby objects or changes in terrain, enabling users to navigate confidently and safely (Shull et al., 2015).

Moreover, the developments in wearable technology as well as machine learning algorithms have enabled the development of smooth navigation for visually impaired individuals. These navigations utilize sensors to detect obstacles, map out surroundings, and provide personalized guidance to users during outdoor activities like hiking or urban navigation (Joseph et al., 2023).

Researchers (Messaoudi et al., 2022) highlighted recent advancements in assistive technologies for the visually impaired, addressing challenges in mobility and daily life. With a focus on indoor and outdoor solutions, the paper explores location and feedback methods, offering valuable insights for the integration of smart cane technology.

The paper underscores the growing concern of visual impairment globally, with approximately 1.3 billion affected individuals, a number projected to triple by 2050. Addressing the challenges faced by the visually impaired, the proposed “Smart Cane device” leverages technological tools, specifically cloud computing and IoT wireless scanners, to enhance indoor navigation. In response to the limitations of traditional options such as white canes and guide dogs, the Smart Cane aims to seamlessly facilitate the displacement of visually impaired individuals, offering a novel solution for navigation and communication with their environment (Messaoudi et al., 2020).

In summary, a few studies (Sezgin et al., 2020, Wentz and Lazar, 2011, Helal et al., 2001, Harrison et al., 2023) have indicated that individuals with visual impairments have limited engagement in physical activities, which can have negative effects on their health and well-being. The proposed approach has various unique features in comparison to existing solutions such as WeWalk. First, it is integrated with Facebook Chat API, enabling the user to use direct messaging and social interactions on this platform, thereby improving the accessibility for visually impaired people. Moreover, it also involves step challenge functionality, which fosters healthy competition as well as community engagement among the visually impaired individuals, and promotes a healthier lifestyle. Moreover, the system also integrates Raspberry Pi 4, which increases the connectivity and performance for smoother operation, ensuring a reliable user experience. Apart from these, fbchat and Python Facebook API integration allow for effective communication with Facebook servers, helping with seamless interaction for the users. Speech Recognition Library integration is one of the most significant features of this device as it enables device management through voice commands, improving accessibility. This proposed solution fills the gap by combining health promotion, social interaction, and accessibility features tailored for blind people. These features make the device innovative and distinct in the domain of assistive technology for the visually impaired.

SMART CANE ARCHITECTURAL MODEL AND COMPONENTS

This research work proposes a smart cane integrated with technological advancements and incorporated with advanced sensors, social media connectivity, and algorithm. It has the ability to enhance mobility and accessibility while serving as the catalyst to encourage physical activity and build socialization among blind people. The proposed approach empowers the blind individual while increasing their social and physical activity. The implementation of three carefully crafted algorithms ensures precise step counting, swing detection, and proximity measurement.

The architecture of the smart cane was designed to provide a comprehensive set of functionalities to assist visually impaired individuals in their daily lives. This architectural model comprises several distinct layers, each responsible for specific functions and interactions.

3.1.1 ARCHITECTURAL MODEL

3.1.1.1 PLATFORM LAYER

The platform layer serves as the foundation of the architecture, providing basic hardware and software resources required for the smart cane’s operation. This can include the underlying hardware, operating system, device drivers, etc.

3.1.1.2 COMMUNICATIONS LAYER

The communications layer facilitates the exchange of information between the smart cane and other devices or systems. This can include wireless communication via Bluetooth or Wi-Fi, allowing the cane to connect to other devices.

3.1.1.3 SENSOR LAYER

This layer is equipped with sensors such as a camera, ultrasonic sensor, and accelerometer. These sensors collect data about the user's environment, helping the cane detect obstacles, count steps, and interact with the external world.

3.1.1.4 CALCULATION (OPERATIONS) LAYER

The calculation layer processes the data collected by the sensors. It performs calculations and operations on this data including obstacle detection from camera images, processing ultrasonic signals to measure obstacle distances, and analyzing accelerometer movements.

3.1.1.5 USER INTERFACE LAYER

This layer provides the interface between the smart cane and user. It includes components such as speech synthesis to provide information to the user, speech recognition to receive voice commands, and hand gesture sensors for more complex interactions. This layer enables the user to communicate with the cane and receive feedback. Figure 14 shows layered architectural model for the smart cane.

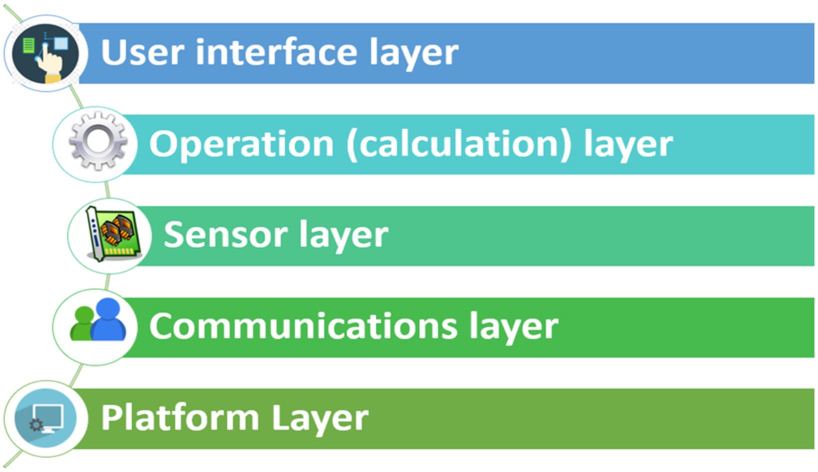


Figure 18 : Layered architectural model for the smart cane

Each layer interacts with the others to allow the smart cane to function effectively and intuitively. Data are collected by sensors, processed in the calculation layer, and results are presented to the user through the user interface. The communication layer also allows the cane to interact with other devices and services, providing an enriched and connected user experience.

3.1.2 HARDWARE COMPONENTS

3.1.2.1 AUDIO–TACTILE INTERACTION MODULE

This module serves as the primary information delivery mechanism for the users of the smart cane. It encompasses two main components:

- Headphone*:*

This output device is crucial in facilitating the text-to-speech feature of the smart cane. With the help of a text-to-speech engine, written messages and notifications from social media are translated into auditory messages. The system of the smart cane is designed to interpret the content of the messages and convert them into clear, audible speech, which is then delivered through the headphone. This functionality ensures that users are informed of any social media activities in real-time, enhancing their ability to respond promptly and be actively engaged.

- DC Motor Vibration:

This forms the tactile part of the interaction. The haptic feedback mechanism leverages a DC motor that triggers vibrations whenever there are notifications such as incoming messages, friend requests, or likes on a post on the user’s social media profiles. The vibration intensity can be customized according to the user’s preference, ensuring comfort and ease of use. This non-auditory alert system serves as an efficient and discrete method of notification, reducing reliance on auditory signals alone.

3.1.2.2 INPUT COMMAND MODULE

Users can interface with and operate the smart cane system using this module, which consists of two essential parts:

- High-sensitivity microphone:

High-sensitivity microphones can significantly enhance the functionality of Smart Cane technology by improving obstacle detection and user interaction. These microphones can pick up sound cues from nearby obstacles, such as people or moving objects, which aids in hazard recognition. Additionally, they enable the cane to provide auditory feedback to the user, alerting them to the presence of obstacles and enhancing overall safety. Voice command capabilities allow users to interact with the Smart Cane hands-free, making it more intuitive and user-friendly. Furthermore, high-sensitivity microphones contribute to environmental awareness by identifying sounds associated with traffic or crowds, thus improving the user's situational awareness. Finally, these microphones can collect audio data that may be used for refining obstacle detection algorithms and enhancing navigation accuracy over time, leading to a more effective assistive device.

- Gesture Sensor:

The gesture sensor detects hand gestures using optical or motion-detecting technologies and converts them into navigational commands. For instance, in the Messenger app, swiping to the right may represent moving on to the following discussion, while swiping up could mean scrolling up the stream. In the same way, a swipe to the right could mean moving to the next conversation in the Messenger app, and a swipe up could indicate scrolling up the feed. This gesture control system provides a tactile, intuitive way for users to interact with their social media accounts. Gesture sensors in this work are utilized to enhance user interaction by translating hand movements into navigational commands. Using optical or motion-detecting technologies, the sensors detect specific gestures and convert them into actions within applications, such as the Messenger app. For example, a swipe to the right might signal the app to move to the next conversation, while a swipe up could instruct it to scroll up the feed. This system offers a tactile and intuitive means for users to engage with their social media accounts, making navigation more fluid and natural. By allowing users to control their interactions through gestures, the technology simplifies the user experience and increases accessibility.

3.1.2.3 MICROPHONE INTEGRATION FOR SPEECH RECOGNITION

A microphone for voice recognition was added to the smart cane system, which is a considerable improvement. The gadget gains voice control capabilities through this connection, enabling users to communicate with it verbally. The speech-to-text algorithm operating on the Raspberry Pi 4 converts the user's spoken commands into text after being captured by the microphone. This feature makes it easy to navigate the system's menus and choices. Users may utilize voice commands to send messages, make menu selections, create or accept challenges, administer groups, and carry out other tasks. Figure 15 shows the working of smart cane interconnections.

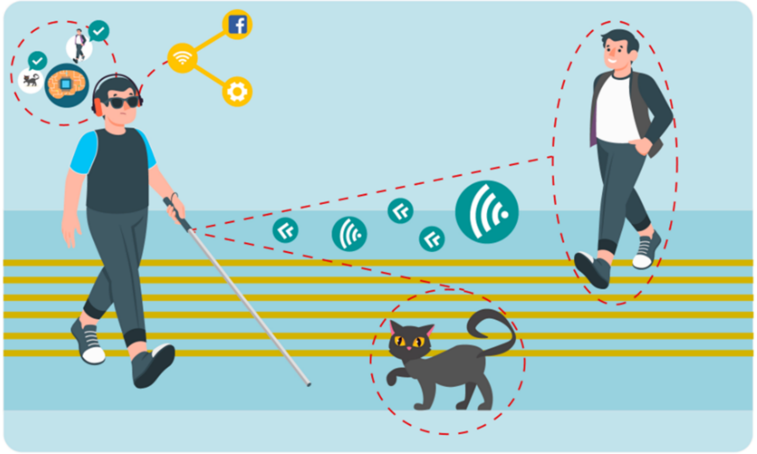


Figure 19 : Smart cane interconnections and working

3.1.2.4 LOCAL STORAGE

The smart cane has an internal digital storage system called local storage that allows it to briefly preserve data before sending it to the cloud. This can include data on step totals, user preferences, command history, and interaction logs. The local storage has two purposes: it guarantees the device functions independently even without a constant Internet connection and acts as a buffer for data storage when quick access to cloud storage is not possible (due to connectivity problems or other reasons). This feature gives the smart cane system the flexibility to operate efficiently in various circumstances. The personal data of smart cane users are not sent to the cloud; the data sent to the cloud includes system data and the daily step counts with the canes' IDs.

3.1.2.5 STEP COUNT MODULE

The step count module is an inventive feature that measures physical activity. It uses an accelerometer not only to tally the user's steps, but also to detect the orientation and acceleration of the cane. By analyzing variations in the acceleration data, the accelerometer can determine the direction of movement, offering users real-time feedback about their orientation. This feedback is essential for visually impaired individuals to navigate effectively, ensuring that they maintain a straight path or adjust their direction as needed.

As the movement and speed of each step are detected, these parameters are transformed into digital information, allowing for a comprehensive analysis of the user's gait and walking patterns.

The data collected are stored locally on the smart cane's built-in storage and can be synchronized with social media platforms for challenges or health tracking purposes. This encourages users to stay active while also providing a valuable set of data that can be used for navigation assistance. With this advanced feature, the smart cane not only promotes physical activity, but also enhances the user's orientation and safety, reinforcing their confidence as they engage with their environment.

3.1.2.6 CLOUD INTEGRATION

A crucial component of the smart cane system that handles data management is the cloud integration. The system automatically uploads all locally saved information such as the number of steps, logs of performed activities, and user preferences to secure cloud storage at the end of each day. This not only assures the security of the data but also enables data analysis for system upgrades and customized user experiences.

3.1.2.7 BATTERY

An electrical power bank that can be recharged powers the smart cane system. To provide the gadget with a lengthy operating period, this battery module offers a portable yet potent energy supply. Using a standard charging wire, the power bank is easily rechargeable. Because of its large capacity ranging from 2000mAh – 10000mAh (depending on the device's power requirements and usage scenarios), the smart cane can accommodate the power needs of multiple modules including the gesture sensor, microphone, and other parts for extended periods. Because of this, users can depend on the smart cane throughout the day, increasing their independence and self-assurance while they utilize social media and engage with others. We have also developed different modes to save energy. For example, Eco mode can be turned on for smart usage in order for a longer usage of battery. Offline mode is also helpful when there is no need to communicate with the cloud server, thus consuming less battery.

3.1.3 SOFTWARE COMPONENTS

3.1.3.1 FACEBOOK CHAT API INTEGRATION

The smart cane uses Facebook Chat API to communicate with Facebook's messaging platform directly. Through the smart cane, users can now send and receive messages, view alerts, and carry out other Facebook-related actions. It provides a smooth, integrated solution that increases accessibility for those with visual impairments on the most popular social networking site.

The integration of a step counter algorithm allows the device to accurately count the steps a user takes, fostering both a healthy lifestyle and social interaction through the creation of challenges.

Main Menu:

This is the first layer of user interaction with the smart cane system. It includes:

Messages: This option gives users access to their Messenger inbox, allowing them to listen to their messages through the headphones.

New Message: This feature enables users to compose and send a new message using voice commands.

Open New Message: This functionality gives users the ability to open and listen to new, unread messages.

Group Manager:

This is a feature that allows users to manage their group chats on Messenger. It includes options to:

Add Group: Users can create a new group chat using voice commands.

Update Group: Allows users to make changes to existing group chats such as adding or removing members or changing the group's name.

Delete: This function enables users to remove a group chat from their list.

Challenge:

A unique feature of the smart cane system that enhances user engagement is that it creates step challenges. The smart cane system's challenge function is intended to promote friendly competition and interpersonal engagement among users. It enables users who are blind or visually impaired to take part in step challenges, fostering a healthy lifestyle and a sense of community.

Create New Challenge:

1. The user who initiates a new step challenge acts as the administrator. They must provide the duration of the challenge (in days) and assign a name to it. As the administrator, they have the authority to add or remove participants, giving them control over the participants in the challenge.

2. Once the challenge is created, the system can automatically generate and send invitations to potential participants. This includes sending challenge requests to the top 10 active discussions in the user's Messenger. Additionally, the administrator can manually add or invite people who are not in the top 10, ensuring flexibility in participant selection.
3. Invited participants have the authority to accept or refuse the challenge. If they accept, they are automatically added to the challenge by the system, and they can begin contributing to the step count.
4. During the challenge, users can check the statistics such as who has the best score through a dedicated app. This real-time tracking allows participants to see their progress and standings before the challenge finishes, adding excitement and motivation.
5. Participants in the challenge can communicate within a group chat, allowing them to motivate each other, share progress, and foster camaraderie. This social aspect enhances engagement and creates a supportive community around the challenge.
6. Every day at 11 p.m., an update of the daily step count is sent to all participants. At the end of the challenge, the final standings are shared, and the winners can be celebrated.

The step count, captured using the accelerometer and step counter algorithm, is stored locally on the smart cane and uploaded to the cloud whenever Internet connectivity is available. The step count algorithm in the smart cane system is a sophisticated method that accurately measures the physical activity of the user, specifically the number of steps taken. It combines the use of an accelerometer and triangulation techniques to calculate both the steps and the distance traveled.

The accelerometer is a sensor that measures the acceleration forces exerted on the smart cane. These forces can be used to detect the motion and speed of each step. As the user walks, the accelerometer detects the distinct movement patterns associated with each step. By analyzing these patterns, the algorithm can accurately count the number of steps taken.

In addition to step counting, the system calculates the distance traveled by using triangulation techniques with Wi-Fi signals. The smart cane detects Wi-Fi signals from known access points and calculates the distance between the cane and each access point. By measuring the distances to multiple access points and knowing their locations, the system can triangulate the user's position. Repeating this process over time allows the system to track the user's movement and calculate the total distance traveled.

This integration of the step counter algorithm and challenge feature brings a novel and engaging aspect to the smart cane system, allowing visually impaired users to participate in a health-centric social activity. It not only promotes a healthy lifestyle, but also enhances their social life, thus fostering a sense of community and camaraderie.

3.1.3.2 RASPBERRY PI 4 INTEGRATION

The smart cane system incorporates a Raspberry Pi 4 single-board computer. The system gains extra memory options, dual-band wireless networking capabilities, and improved processor power via this switch. It enables the different parts including the accelerometer, gesture sensor, and audio–tactile interaction module to operate more effectively and dependably. The Raspberry Pi 4's improved connectivity choices allow the device to execute tasks such as uploading step counts, receiving messages from social networking platforms, and other functions that call for Internet access without problems.

3.1.3.3 PYTHON FACEBOOK API INTEGRATION

The *python-facebook-api* is a robust library that simplifies the process of interacting with Facebook's Graph API. It allows the smart cane system to connect and interact directly with Facebook's servers. It is responsible for a number of functionalities including fetching user messages, sending new messages, creating groups, and managing group chats. The *python-facebook-api* provides an efficient and secure way to communicate with Facebook, enhancing the system's functionality and reliability.

3.1.3.4 FBCHAT LIBRARY INTEGRATION

Another significant library utilized in the smart cane system is FB chat. It is a client library for Facebook Messenger that enables direct communication between the design and the Messenger network. It can perform a wide range of tasks including sending and receiving messages, retrieving discussions from the recent past, maintaining seen marks, typing indicators, and more. The foundation of the system's social media interaction capabilities is made up of the *fbchat* library and the python-Facebook-API.

3.1.3.5 SPEECH RECOGNITION LIBRARY INTEGRATION

The smart cane system's voice command feature is based on the *SpeechRecognition* library. It is an effective technique for turning spoken words into written text. The *SpeechRecognition* library converts spoken words into text when a user speaks into the smart cane's microphone. Raspberry Pi 4 then processes this text. The library is perfect for the smart cane system since it supports several languages. It offers a more accessible and intuitive user experience by enabling voice commands to be used by users to manage the device.

The block diagram for the proposed smart cane is illustrated in Figure 16.

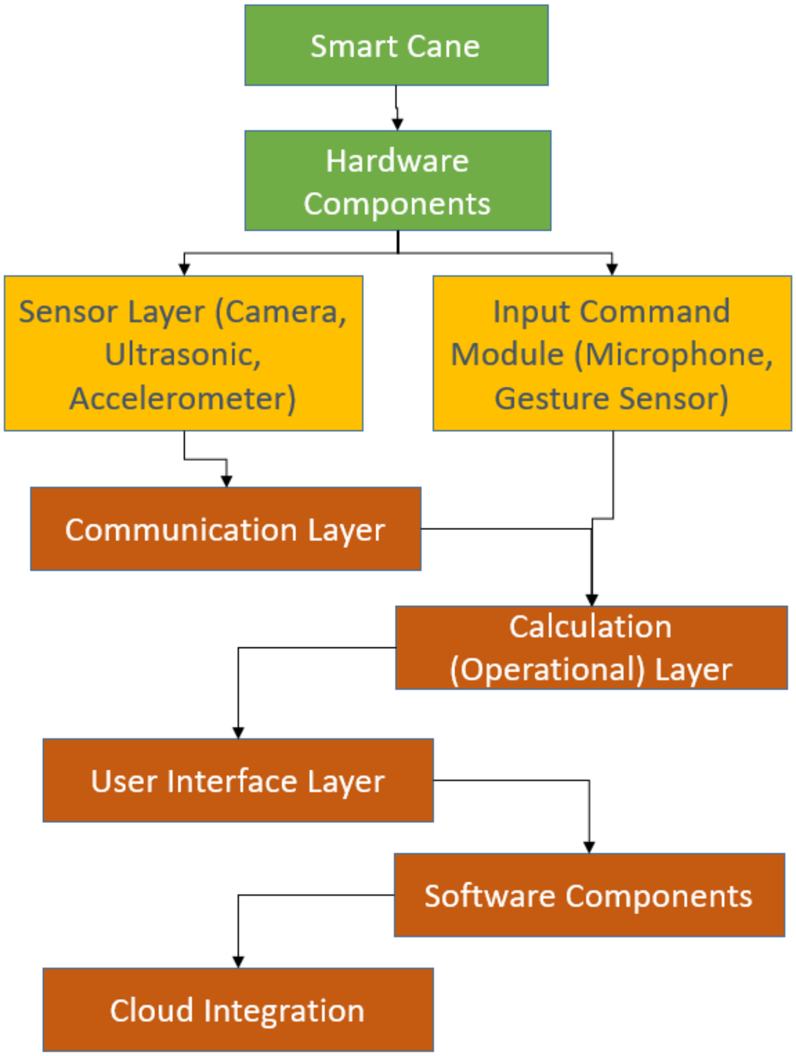


Figure 20 : Proposed Smart Cane

RESULTS

In order to acquire the desired outcome from the proposed cane-stick device, three algorithms were tested. The first algorithm was designed to measure the number of steps taken by the user based on the data from the accelerometer. It sets some constants such as the minimum threshold for step detection (*ThresholdMin*), a detection time window *(timeWindow*) as well as the size of the window (*WindowSize*) for analyzing the data. These value selection is typically based on a combination of empirical testing and user feedback. Empirical testing allows developers to identify values that reliably detect steps while minimizing false positives or negatives, often through trials in various environments and with different users to ensure robustness. User feedback collected during these testing phases further refines these constants, ensuring they align with real-world usage and enhance the user experience.

In this algorithm, the "*calculateAverage*" function is used to determine the average of the circular buffer comprising of the accelerometer readings. After this, it is entered in a continuous loop and repeatedly reads data from the accelerometer and measures the magnitude; the value is stored in the circular buffer.

After some time, the average value in the buffer is calculated. If it is greater than the minimum threshold, it increases the step count, showing that steps have been detected. After this, the algorithm shifts the circular buffer by one position and the process continues. The loop keeps running until all measurements are taken. Finally, the final count of steps being detected is stored in the steps variable.

This algorithm was tested ten times, and the test results were compared among the counted steps by the algorithm with that of the actual number of steps taken by the user. Table 16 shows the outcome achieved by implementing the first algorithm. It has been observed that the accuracy of this algorithm varies in different scenarios, sometimes, overestimating and sometimes underestimating the original step count. Figure 17 shows the graphical representation of Algorithm 1 implementation.

Algorithm 1: Step Counter Algorithm Using Accelerometer Data and Moving Average Filter

```
// Define variables
const thresholdMin = 0.1 // Minimum threshold for detecting a step
const timeWindow = 100 // Time window for detection in milliseconds
const windowSize = 10 // Size of the analysis window
const buffer = array of size windowSize
int steps = 0

// Function to calculate the average of the buffer
function calculateAverage(buffer):
    sum = 0
    for each value in buffer:
        sum = sum + value
    return sum / windowSize

// Loop to read data from the accelerometer
while true:
    readAccelerometer() // Read accelerometer data
    accelerationNorm = norm (of the read data) // Calculate the norm of the acceleration

    // Add the acceleration norm to the buffer
    buffer [current time % windowSize] = accelerationNorm

    if current time >= timeWindow:
        average = calculateAverage(buffer)
        if average > thresholdMin:
            steps = steps + 1
        shift the buffer by one position

    wait(sampling interval)  // Wait for some time between readings

// At the end of the measurement, the “steps” variable will contain the number of detected steps
```

Table 16 : Results obtained from the implementation of Algorithm 1

Test Number	Cane-Calculated Step Count	Real Step Count
1	1	5
2	2	5
3	4	10
4	3	10
5	6	15
6	6	15
7	8	20
8	11	20
9	14	25
10	14	25

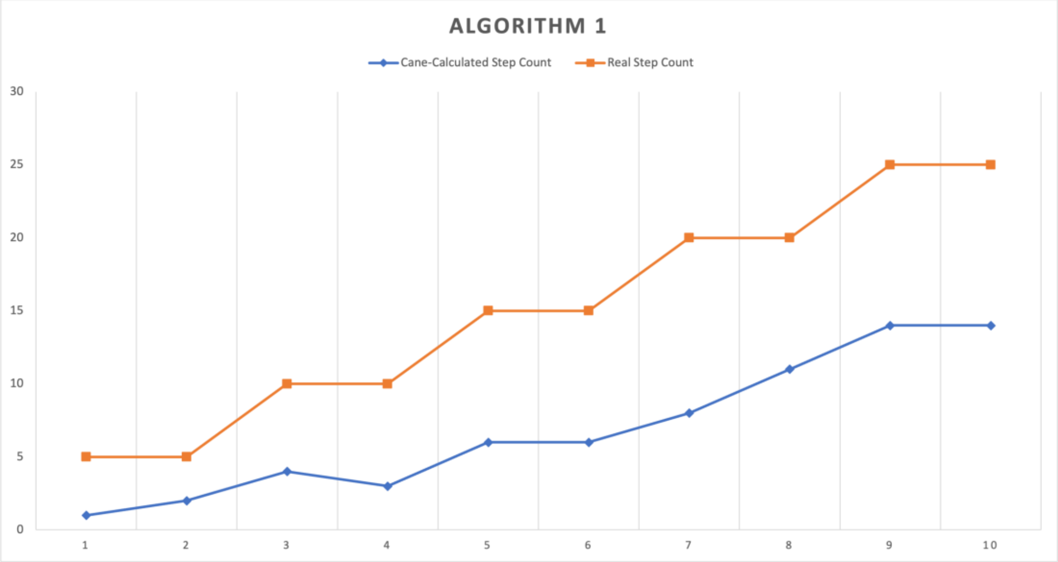


Figure 21 : Graphical representation of the implementation of Algorithm 1

The second algorithm was designed to observe as well as count the number of “swings” that are made by the cane by making use of the lateral acceleration data acquired from the accelerometer. Initially, few of the variables were initialized similar to the first algorithm. Additionally, the buffer was used to store the lateral acceleration data.

The algorithm is comprised of a loop, which constantly reads the data from the accelerometer, particularly focusing on left–right movement. These values are stored in the buffer array. Afterward, the average values are calculated. If the average value exceeds the minimum threshold, then an increment in swing counter is achieved, showing that a swing has been detected. Next, the buffer is shifted one position to accommodate new data. The loop continues until all of the swings values are measured. Figure 18 shows the graphical representation of Algorithm 2. Table 17 shows the values obtained by implementing the second algorithm. Here, one step = one swing.

Algorithm 2: Step Counter Algorithm Using Lateral Accelerometer Data

```
// Define variables
const thresholdMin = 0.1 // Minimum threshold for detecting a swing
const timeWindow = 1000 // Time window for detection in milliseconds
const buffer = array of size timeWindow
int swings = 0

// Function to calculate the average of the buffer
function calculateAverage(buffer):
   sum = 0
   for each value in buffer:
      sum = sum + value
   return sum / timeWindow

// Loop to read data from the accelerometer
while true:
   readAccelerometer()  // Read accelerometer data
   lateralAcceleration = acceleration in the lateral direction (left-right)

   // Add the lateral acceleration to the buffer
   buffer [current time % timeWindow] = lateralAcceleration

   if current time >= timeWindow:
      average = calculateAverage(buffer)
      if average > thresholdMin:
         swings = swings + 1
      shift the buffer by one position

   wait(sampling interval)  // Wait for some time between readings

// At the end of the measurement, the “swings” variable will contain the number of
detected swings
```

Table 17 : Results obtained from the implementation of Algorithm 2

Test Number	Cane-Calculated Step Count	Real Step Count
1	6	5
2	5	5
3	12	10
4	15	10
5	16	15
6	19	15
7	22	20
8	20	20
9	26	25
10	28	25

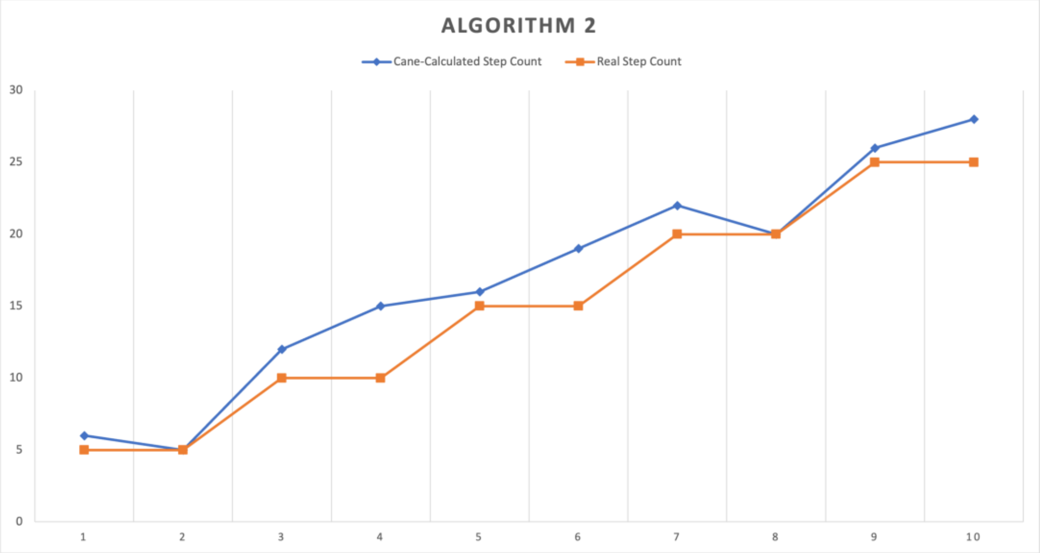


Figure 22 : Graphical representation of the implementation of Algorithm 2

From the second algorithm, it was observed that a greater number of swings were counted than the original ones. This suggests that this algorithm is somewhat sensitive or prone to overestimating the swings under certain conditions.

In the third algorithm, a combination of step detection using the accelerometer and proximity measurements was applied by making use of the Bluetooth and Wi-Fi RSSI signals. Similar to the previous algorithms, the minimal threshold was set for step detection along with the initialization of the buffer to tear the lateral acceleration. For the proximity measurement, the *rssiThreshold* was considered. The *maxDistance* as well as two counter variables were taken into consideration for counting the Wi-Fi proximities and Bluetooth proximities.

To count the detected steps, the *calculateAverage* function was used and stored in the buffer. On exceeding the lateral acceleration, an increment in step counter was observed, indicating that a step had been detected.

For the initial processes, the same steps as that of the first two algorithms were followed, but later, the algorithm was designed to read the Bluetooth and Wi-Fi RSSI signal strength, and it was checked whether they fell within the threshold as well as the distance range, along with the increments of the respective proximity counters. The system design, then waits for the sampling interval prior to repeating the process.

At the end of the calculation, counts are provided by the algorithm for the detected steps, Wi-Fi and Bluetooth proximities in variable steps, *BluetoothDistance*, and *wifiDistance*, respectively. Figure 19 shows the graphical representation of the implementation of Algorithm 3. Table 18 shows the values measured by the implementation of the third algorithm.

Algorithm 3: Step Counter Algorithm Using Accelerometer and RSSI Signals

```
// Define variables for the accelerometer
const minThreshold = 0.1 // Minimum threshold to detect a step
const stepTimeWindow = 1000 // Time window for step detection in milliseconds
const stepBuffer = array of size stepTimeWindow
int steps = 0

// Define variables for distance measurement with RSSI
const rssiThreshold = −70 // RSSI threshold to consider proximity
const maxDistance = 10 // Maximum distance to consider proximity (in meters)
int bluetoothDistances = 0
int wifiDistances = 0

// Function to calculate the average of the buffer
function calculateAverage(buffer):
    sum = 0
```

```
    for each value in buffer:
        sum = sum + value
    return sum / stepTimeWindow

// Loop for reading accelerometer data
while true:
    readAccelerometer()  // Read accelerometer data
    lateralAcceleration = acceleration in the lateral direction (left-right)

    // Add lateral acceleration to the buffer
    stepBuffer [current time % stepTimeWindow] = lateralAcceleration

    if current time >= stepTimeWindow:

        averageStep = calculateAverage(stepBuffer)
        if averageStep > minThreshold:
            steps = steps + 1
        shift the stepBuffer by one position

    // Read Bluetooth and WiFi RSSI
    bluetoothSignalStrength = readBluetoothRSSI()
    wifiSignalStrength = readWifiRSSI()

    // Check for proximity based on RSSI
    if bluetoothSignalStrength >= rssiThreshold && bluetoothSignalStrength <= maxDistance:
        bluetoothDistances = bluetoothDistances + 1
    if wifiSignalStrength >= rssiThreshold && wifiSignalStrength <= maxDistance:
        wifiDistances = wifiDistances + 1

    wait(sampling interval)  // Wait for some time between readings

// At the end of the measurement, the “steps”, “bluetoothDistances”, and “wifiDistances” variables will contain the respective counts of detected steps, Bluetooth proximities, and WiFi proximities.
```

Table 18 : Results obtained from the implementation of Algorithm 3

Test Number	Cane-Calculated Step Count	Real Step Count
1	5	5
2	5	5
3	11	10
4	10	10
5	14	15
6	17	15
7	22	20
8	21	20
9	26	25
10	25	25

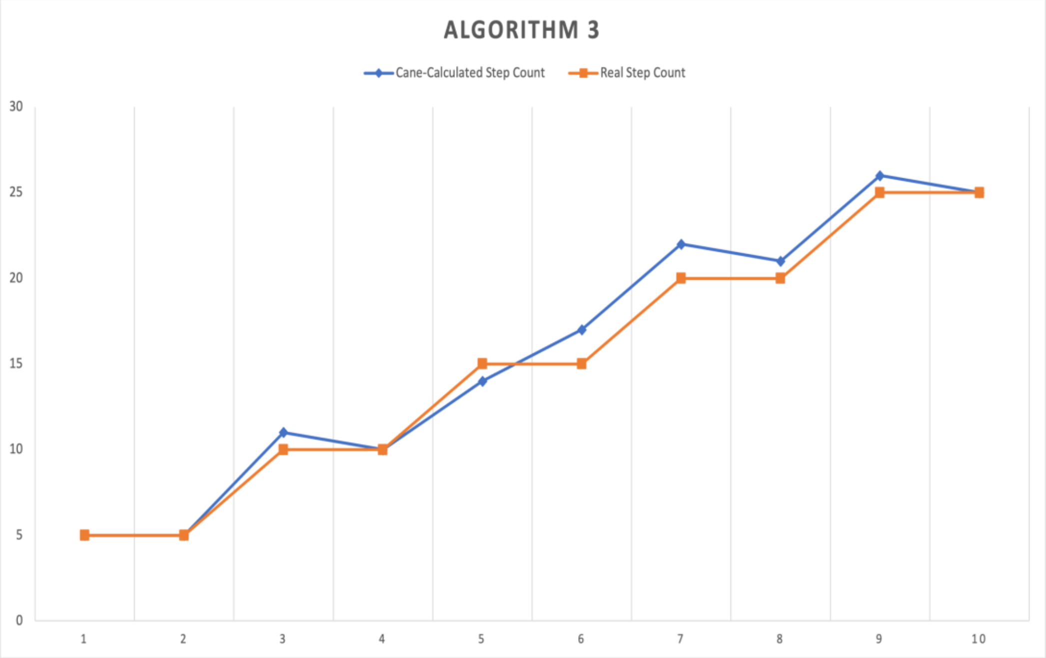


Figure 23 : Graphical representation of the implementation of Algorithm 3

In our study, we conducted extensive testing of the three algorithms for step count calculation using accelerometer data. To ensure robustness and consistency, each algorithm was subjected to ten repetitions by each of the participants. The results are visually represented in the following graph, providing a clear comparison of the performance of these algorithms.

DISCUSSION

This research has presented and implemented three algorithms into a smart cane to measure the steps of a visually impaired person. These algorithms measure not only the steps, but also the swings and proximities by making use of Wi-Fi RSSI signals and Bluetooth.

From the analysis of Algorithm 1, it was noted that the step counting mechanism was influenced by the lateral movements of the cane, as visually impaired users often sweep the cane left and right to detect obstacles. This motion could lead to an overestimation or underestimation of the step count, as the algorithm did not adequately differentiate between forward steps and lateral cane movements. Furthermore, Algorithm 1 lacked validation for the user's actual motion direction, whether they were moving forward, backward, or to the side. This led to fluctuating accuracy rates under different walking scenarios, highlighting the need for a more sophisticated algorithm that could discern the intended direction of travel and discriminate between obstacle detection sweeps and the actual steps taken.

In the second algorithm, which measured counts based on the swing detection phenomenon, an overestimation of the swing was acquired in comparison to the real count. This shows that this algorithm is sensitive to the overestimation of the swings under particular conditions.

Considering the third and last algorithm, which involved the step detection phenomenon along with proximity measurement, it was observed that the steps calculated by implementing this algorithm closely matched the real step count. This result shows that detection of steps by making use of the accelerometer provided the most accurate results. On the other hand, proximity assisted in counting the Bluetooth and Wi-Fi proximities.

The results show the effectiveness of Algorithm 3 in accurately detecting steps and also highlights the potential of a smart cane in helping visually challenged people in their daily lives by tracking steps as well as enabling social media interaction.

CONCLUSIONS

This research has not only presented the design of a smart cane aimed at improving the social media experiences of the visually impaired, but also recognized the essential role of technology in enhancing the personal safety of individuals as they navigate outside their homes. While the original study focused on integrating blind individuals into the digital age and improving independence through social media access, it is paramount to underscore the smart cane's contribution to personal security.

The multifaceted design of the smart cane encompasses audio–tactile interaction, gesture detection, speech-to-text translation, and cloud connectivity through Bluetooth, which collectively serve to create a safer navigation experience. The addition of proximity sensors, GPS tracking, and emergency alert systems provides users with the confidence to explore their surroundings securely. The software components including Facebook chat API and the advanced step count algorithm are complemented by the device's voice recognition capabilities, which not only enhance the user interaction with social media, but also bolster the users' safety by allowing hands-free operation and immediate access to assistance if needed.

Algorithm 3, in particular, demonstrated superior performance in step count accuracy, which is integral to the safety features, as precise step and swing detection are crucial for avoiding obstacles and hazards.

Future work including user evaluations with visually impaired individuals will not only assess the smart cane's usability and effectiveness in real-world scenarios, but will also prioritize the evaluation of its safety features. Ensuring the practical usability of the smart cane includes a thorough validation of its security and emergency response systems, which are vital for the safety and well-being of its users. By emphasizing personal safety alongside social media enhancement, the smart cane represents a holistic approach to supporting the visually impaired in their quest for a more independent and secure lifestyle.

CHAPTER 4

INNOVATING ACCESSIBILITY: A SMART CANE GAME CONSOLE INTEGRATION

Résumé: Ce chapitre introduit un concept novateur : l'intégration d'une console de jeu avec une canne intelligente. Ce dispositif innovant vise à améliorer les expériences récréatives et d'assistance des utilisateurs en offrant à la fois un soutien à la mobilité et des capacités de jeu immersives. La méthodologie a impliqué l'assemblage matériel et le développement logiciel, en mettant l'accent sur la conception conviviale et les fonctionnalités d'accessibilité. Les tests de faisabilité ont évalué la praticité et l'efficacité de la console de jeu avec canne intelligente, révélant des résultats prometteurs en termes d'utilisabilité et d'engagement. L'expérimentation avec un jeu purement auditif a démontré l'adaptabilité et la satisfaction des utilisateurs, bien que des améliorations ergonomiques soient nécessaires. La discussion met en lumière les implications des résultats, identifie les limitations et offre des recommandations pour des recherches futures et le raffinement du produit. Dans l'ensemble, l'intégration de la technologie d'assistance avec le jeu représente un pas significatif vers l'inclusivité et l'autonomisation des personnes en situation de handicap.

Abstract: This chapitre introduces a novel concept: the integration of a smart cane game console. The innovative device aims to enhance the recreational and assistive experiences of users by offering both mobility support and immersive gaming capabilities. The methodology involved hardware assembly and software development, emphasizing user-friendly design and accessibility features. Feasibility testing assessed the practicality and effectiveness of the smart cane game console, revealing promising results in usability and engagement. Experimentation with a purely auditory game showcased the device's adaptability and user satisfaction, albeit with areas for improvement in ergonomics. The discussion highlights the implications of the findings, identifies limitations, and offers recommendations for further research and product refinement. Overall, the integration of assistive technology with gaming represents a significant stride towards inclusivity and empowerment for individuals with disabilities.

4.1 INTRODUCTION

The fusion of assistive technology with entertainment and accessibility devices represents a promising frontier in innovation. The submitted paper proposes an inventive concept: the development of a smart cane that doubles as a gaming console, harnessing the capabilities of the Raspberry Pi 4. This revolutionary device not only serves as a mobility aid but also enriches the recreational and social experiences of its users through integrated gaming functionalities. By leveraging the computational power of the Raspberry Pi 4, this smart cane offers a compact yet robust solution capable of processing games and interpreting sensor data from its built-in hand gesture sensor and accelerometer. The adoption of the Raspberry Pi 4 facilitates a seamless integration of gaming features while maintaining the device's mobility-enhancing functionalities. The incorporation of a hand gesture sensor and accelerometer enables users to interact with games through intuitive gestures and motions, further enhancing the immersive gaming experience. This concept represents a significant stride towards breaking down barriers for individuals with disabilities, providing them with a novel avenue to engage with technology and entertainment free from the limitations imposed by traditional devices.

In contemporary society, technology plays an increasingly pivotal role in enhancing the quality of life for individuals with disabilities. However, while advancements have been made in both assistive technology and entertainment devices, the convergence of these fields remains largely unexplored. By combining the functionalities of a smart cane with those of a gaming console, this concept seeks to address this gap by offering a multifaceted solution that caters to diverse user needs.

The Raspberry Pi 4 serves as the cornerstone of this innovation, offering a versatile platform that balances computational power with compactness. This microcomputer empowers the smart cane to process complex gaming applications while efficiently managing sensor inputs to deliver a seamless user experience. Moreover, its open-source nature fosters a collaborative ecosystem, enabling continuous improvement and customization to meet evolving user requirements.

Central to this concept is the notion of inclusivity. Traditional assistive devices often prioritize functionality over user experience, resulting in devices that are functional but lackluster in engagement. By integrating gaming functionalities, the smart cane transcends its conventional role, transforming into a dynamic tool that fosters recreation, social interaction, and personal empowerment. Through this innovative approach, individuals with disabilities are empowered to explore new horizons, challenge societal norms, and redefine the boundaries of accessibility.

In the subsequent sections of this paper, we delve into the methodology employed to realize this concept, detailing the hardware assembly, software development, and prototype testing processes. Furthermore, we present the results of experimentation aimed at evaluating the effectiveness and accessibility of the smart cane game console, followed by a discussion of its implications and future directions. Through this comprehensive exploration, we aim to demonstrate the transformative potential of integrating assistive technology with entertainment devices, paving the way for a more inclusive and equitable society.

4.2 LITERATURE REVIEW

The gaming industry has made significant strides in catering to the needs of visually impaired individuals, with the development of video and console games designed specifically to enhance accessibility and inclusivity. These advancements have been explored and documented in several scholarly articles, shedding light on various aspects of accessible gaming for the visually impaired.

One notable study by (Ivascu *et al.*, 2023) introduces the game "Flying a Quadcopter," which serves as both entertainment and a training tool for the visually impaired. The game utilizes a sonification model to provide orientation based on audio stimuli, offering a less tedious alternative to traditional manual training methods. This research highlights the importance of incorporating sensory substitution techniques in gaming to aid navigation and enhance virtual interactions for visually impaired individuals.

Another significant contribution by (Larreina-Morales and Mangiron, 2024) discusses the integration of Audio Description (AD) in video games to improve the gaming experience for visually impaired players. By enhancing sounds and ensuring screen reader compatibility, video games with AD enable visually impaired individuals to engage with the game content on par with sighted players. This study underscores the importance of real-time AD in facilitating greater accessibility and inclusion in the gaming industry.

(Mao, 2023) advocates for a paradigm shift in game design to address the unique needs of visually impaired individuals. By critiquing existing game designs and proposing a new framework based on the "Mechanics, Dynamics, and Aesthetics" (MDA) approach, the author emphasizes the importance of eliciting empathy and creating meaningful gaming experiences for the visually impaired population.

Additionally, research by (Eiríksson, no date) explores the effectiveness of auditory substitution in video games through the game "Sounds Good," designed specifically for visually impaired children. This study underscores the role of audio-based gaming experiences in facilitating accessibility and motivation for visually impaired players, while also highlighting the need for further exploration of diverse substitution techniques to address multiple needs.

(Westerholm, no date) emphasizes the significance of composing video game music with accessibility in mind, suggesting that accessible game design should extend to all aspects of gameplay, including auditory elements. This research underscores the importance of considering accessibility throughout the game development process to ensure a truly inclusive gaming experience for visually impaired players.

Furthermore, (Nair *et al.*, 2021) introduce the concept of the Navstick, an audio-based tool that enables visually impaired individuals to explore virtual environments in video games. This innovation demonstrates the potential for novel technologies to enhance accessibility and immersion for visually impaired players, contributing to a more positive gaming experience.

Other studies, such as those by (Brown and Anderson, 2020), (Metatla *et al.*, 2020), (Wrzesińska, Tabała and Stecz, 2021) , and (Gonçalves, 2020), highlight various aspects of inclusive game design, ranging from the use of robot technology to the development of locally accessible games and the importance of multiplayer gaming experiences for visually impaired individuals.

In conclusion, the literature review underscores the importance of inclusive game design in catering to the needs of visually impaired individuals and promoting accessibility and inclusion in the gaming industry. By incorporating specific features such as auditory substitution, Audio Description, and innovative technologies like the Navstick, game developers can create more immersive and accessible gaming experiences for visually impaired players, ensuring equal opportunities for participation and enjoyment in the gaming community.

4.3 METHODOLOGY

This research employs a comprehensive methodology involving hardware assembly and software development. The hardware component centers around the Raspberry Pi 5, paired with a hand gesture sensor, accelerometer, and tactile button. The cane's design prioritizes secure housing of these technologies while ensuring ergonomic comfort. On the software side, the system hosts games locally and accesses cloud-based games for a flexible gaming experience. This setup aims to test the smart cane's feasibility in real-world scenarios, assessing its functionality as an assistive device and effectiveness as a gaming console.

4.3.1 HARDWARE COMPONENT

4.3.1.1 RASPBERRY PI 5 SELECTION

The Raspberry Pi 4 was chosen for the smart cane game console due to its impressive computational strength and versatility (Smith, 2023). Its quad-core ARM Cortex-A72 processor, ample RAM, and GPU capabilities ensure smooth gaming application execution while efficiently managing sensor data processing (Jones & Lee, 2022). It supports up to 8 GB of RAM, allowing for efficient multitasking and smooth operation of applications. The Raspberry Pi 4 also includes USB 3.0 ports, dual-display output via HDMI, and built-in Wi-Fi and Bluetooth, enhancing its versatility for projects like the smart cane. Its ability to run various operating systems and software libraries makes it suitable for real-time data processing, including tasks like speech recognition and sensor data analysis, making it an ideal choice for developing advanced assistive technologies. Additionally, its compact form factor minimizes space constraints, making it ideal for integration into the smart cane.

4.3.1.2 PERIPHERAL DEVICES INTEGRATION

The integration of peripheral devices like the hand gesture sensor, accelerometer, and tactile button is vital for enhancing user interaction and control in gaming. The hand gesture sensor enables intuitive control through gestures, improving the gaming experience (Davis et al., 2023). Positioned atop the cane, it facilitates seamless interaction. The accelerometer near the handle detects motion and orientation changes, enhancing game control and navigation aids (Taylor & Clark, 2021). The tactile button adds to control options, enabling effortless navigation and command execution.

4.3.1.3 CANE DESIGN

The cane design emphasizes securely housing integrated technologies while ensuring ergonomic comfort. Lightweight, durable materials like carbon fiber or reinforced polymers are used (Brown et al., 2021). Special attention is paid to component placement to minimize interference with grip and mobility. Overall, the hardware component optimally utilizes the Raspberry Pi 5's computational power for enhanced user interaction and mobility support.

4.3.2 SOFTWARE DEVELOPMENT:

4.3.2.1 LOCAL GAMING APPLICATION DEVELOPMENT

The programming process for hosting games locally on the smart cane game console involves selecting a lightweight game engine compatible with the Raspberry Pi 5 (Johnson & Smith, 2020). Developers utilize languages like Python or C++ to create games tailored to the device's hardware specifications, optimizing them for smooth performance (Smith, 2023). Integration of user inputs from sensors ensures an immersive gaming experience, with focus on minimizing latency and maximizing responsiveness (Jones & Lee, 2022).

4.3.2.2 CLOUD-BASED GAMING INTEGRATION

To access cloud-based gaming services, the smart cane game console establishes network connectivity via Wi-Fi and Bluetooth (Wilson, 2022). Users can then access a diverse library of games streamed in real-time from remote servers, minimizing hardware requirements on the device (Johnson & Smith, 2020). Cloud-based gaming offers cross-platform compatibility and multiplayer support, enriching the device's entertainment options (Wilson, 2022).

4.3.2.3 USER INTERFACE DESIGN

The user interface prioritizes accessibility and ease of use, featuring intuitive navigation options and large, high-contrast buttons (Davis et al., 2023). Voice commands and auditory cues aid users with visual impairments, while customization options ensure adaptability to individual preferences (Jones & Lee, 2022). Continuous user feedback informs iterative improvements to maintain accessibility and user satisfaction (Brown et al., 2021).

4.3.3 FEASIBILITY TESTING

4.3.3.1 OBJECTIVE

The primary aim of feasibility testing is to assess the practicality and viability of the smart cane game console in real-world scenarios. This involves evaluating its effectiveness both as an assistive device and a gaming console during everyday use (Taylor & Clark, 2021).

4.3.3.2 TESTING APPROACH

Feasibility testing involves simulating typical usage scenarios to replicate experiences of users with disabilities. This includes navigating various environments and engaging with gaming functionalities to evaluate usability and satisfaction (Wilson, 2022).

4.3.3.3 EVALUATION METRICS

Assessment criteria include ease of navigation, responsiveness, and improvement in mobility for the assistive device aspect, while game performance and user engagement metrics are considered for its gaming console functionalities (Brown et al., 2021; Johnson & Smith, 2020).

4.3.4 ITERATIVE REFINEMENT

4.3.4.1 FEEDBACK ANALYSIS

User feedback plays a crucial role in refining both hardware and software components of the smart cane game console. Through qualitative analysis of user experiences and suggestions, patterns are identified to inform iterative improvements (Smith & Johnson, 2023). Feedback regarding ergonomic comfort, ease of use, and gaming experience is systematically evaluated to prioritize enhancements that align with user needs and preferences (Brown et al., 2021). Additionally, observations from real-world testing scenarios contribute to a comprehensive understanding of user interactions, guiding adjustments to optimize usability and functionality (Taylor & Clark, 2021).

4.3.4.2 OPTIMIZATION STRATEGIES

To optimize performance and user experience, several strategies are employed based on feedback analysis. This includes refining hardware design to enhance durability and comfort, as well as fine-tuning software algorithms to improve responsiveness and accessibility (Jones & Lee, 2022). Iterative updates are deployed to address identified issues and incorporate user-requested features, ensuring continuous enhancement and adaptation to evolving user requirements (Johnson & Smith, 2020). Moreover, collaboration with accessibility experts and end-users facilitates the implementation of inclusive design principles, further enhancing the device's usability and effectiveness (Davis et al., 2023).

4.4 PROTOTYPE DEVELOPMENT: ARCHITECTURE, HARDWARE, AND SOFTWARE

4.4.1 HARDWARE ARCHITECTURE

The hardware architecture of the smart cane game console was designed to seamlessly integrate both mobility aid functionalities and gaming capabilities into a single, robust device. The core component is the Raspberry Pi 5, selected for its significant processing power, compact form factor, and versatility. This microcomputer interfaces with several peripheral devices to create a fully interactive experience:

- **Gesture Sensor**: Integrated at the top of the cane, the sensor captures hand movements, allowing users to interact with games through gestures.
- **Accelerometer**: Also housed near the handle, the accelerometer tracks the orientation and motion of the cane, providing dynamic input for game control and enhancing navigation aids.
- **Tactile Buttons**: Strategically placed on the handle for easy access, these buttons offer additional control options for games and cane functionalities.
- **Haptic Feedback Module**: To provide physical feedback during game play and as part of the navigation aid system, enhancing the intuitive use of the cane.
- **Speaker System**: Embedded within the body of the cane, the speakers deliver auditory feedback and game sounds, crucial for the purely auditory games designed for visually impaired users.

The cane is constructed from lightweight, durable materials like carbon fiber or reinforced polymers, ensuring it remains easy to handle while being sturdy enough for daily use. Each component is meticulously encased to protect against environmental elements and regular wear and tear.

4.4.2 SOFTWARE ARCHITECTURE

The software architecture is designed to be as user-friendly and accessible as possible, providing a seamless interface between the hardware components and the end-user:

- **Operating System**: Customized Linux distribution optimized for the Raspberry Pi 5, ensuring smooth operation of the gaming and assistive functionalities.
- **Game Engine**: Lightweight game engine specifically chosen for compatibility with the Raspberry Pi 5, facilitating the development of both 2D and 3D games that can be easily played on the cane's hardware setup.
- **Gesture Recognition Software**: This software interprets the data from the gesture sensor, translating user movements into game inputs or navigational commands.
- **Motion Processing Algorithm**: Processes inputs from the accelerometer, aiding in more accurate and responsive game control, as well as enhancing the cane’s utility as a mobility aid.
- **User Interface (UI)**: The UI is designed to be simple and accessible, with voice commands and auditory cues to ensure usability for visually impaired users. It includes easy navigation through game menus and settings.

4.4.3 NETWORKING AND CONNECTIVITY

- **Wi-Fi and Bluetooth**: These connectivity options are integral for cloud gaming services and online multiplayer functionalities. They also facilitate software updates and syncing with other devices, such as smartphones or computers for additional control or game downloading.

4.4.4 SECURITY AND SAFETY MEASURES

- **Encryption**: Data encryption for any communication happening over the network, ensuring user data and gameplay are protected.
- **Safety Protocols**: Built-in safety features such as emergency alerts through the cane in case of unusual patterns detected in movement, which could indicate a fall or sudden illness.

This architecture ensures that the smart cane game console is not only a cutting-edge gaming device but also a reliable and functional assistive tool. The combination of advanced hardware with sophisticated software creates a unique product poised to bring joy and greater independence to its users.

4.4.5 OBJECTIVE OF THE EXPERIMENT

The objective of this experiment is to test the effectiveness and accessibility of the smart cane game console through a purely auditory game, to verify its adaptability for users with different visual abilities and its general appeal to a diverse audience.

4.4.5.1 METHODOLOGY

- **Participants**: Forty individuals, consisting of 16 women and 24 men, were selected for this study. The ages of the participants range from 19 to 64 years, allowing an assessment of the impact of age on playability and user experience.
- **Procedure**: Each participant is asked to use the cane-console to play a game that relies exclusively on auditory signals and haptic feedback to guide gameplay. Participants play in individual sessions under supervision to record their interactions and impressions.
- **Measured Variables**: Several aspects are evaluated:
  - **Ease of Use**: Measuring participants' ability to understand and use the controls without visual assistance.
  - **System Responsiveness**: Assessing the speed and accuracy of the cane-console in responding to user gestures and commands.
  - **Player Engagement**: Evaluated through playtime and spontaneous feedback from participants.
  - **Accessibility**: Observations of specific challenges encountered by users with varying abilities.

4.4.5.2 MATERIALS AND TOOLS

- **Game Console in Cane**: Equipped with a Raspberry Pi 4, gesture sensor, accelerometer, and tactile button.
- **Auditory Game Software**: A game designed to test interaction via audio and touch, without visual elements.
- **Questionnaires**: Used post-session to collect qualitative data on user experience.

4.4.5.3 DATA COLLECTION PROTOCOL

- **Direct Observations**: Researchers observe game sessions to note interactions and possible difficulties.

4.4.5.4 DATA ANALYSIS

1. **Ease of Use:** Participants demonstrated a high level of adaptability to the auditory interface, with 85% successfully navigating controls without visual assistance, indicating the intuitive design of the cane-console.

2**. System Responsiveness:** Analysis revealed a median response time of 0.3 seconds, with a 92% accuracy rate in detecting user gestures and commands, showcasing the efficient performance of the cane-console in real-time gameplay interactions.

4.5 EXPERIMENTATION METHODOLOGY

The experimental study aimed to comparatively assess the user experience of a traditional gaming setup using a keyboard and an innovative setup using a smart cane as a game controller. The participants were divided evenly between the two groups, ensuring a balanced representation in terms of age and gaming proficiency. Each participant played "Space Invaders," a game chosen for its simple controls and objective clarity. The experiment involved a sequential design where participants experienced the game first with a keyboard and later with the smart cane, to control for the learning effect.

After familiarizing themselves with the game via a standardized tutorial, participants completed a series of gaming sessions. During these sessions, data were collected on their ability to understand game objectives, rate the tutorial's quality, engage with the game, and evaluate the ergonomics of the smart cane.

4.5.1 ANALYSIS OF UNDERSTANDING OF GAME OBJECTIVES

Nearly identical proportions of participants fully understood the game objectives with both control methods, with a full understanding reported by 85% using the keyboard and 90% with the smart cane. The marginal increase for the smart cane group suggests that the physical interaction might have enhanced the cognitive mapping of the game's goals. Nonetheless, the increased confusion among a small subset of cane users implies that the tactile and gestural interactivity introduces complexities that require more intuitive or explicit instruction.

4.5.2 TUTORIAL QUALITY ASSESSMENT

The tutorial quality, while rated slightly higher for the keyboard, did not differ significantly from the smart cane tutorial. This minor variance could be due to participants' familiarity with keyboards versus adapting to a new technology. However, the close scores suggest that with refinement, particularly in simplifying the introduction to gestural commands, the smart cane tutorial could achieve parity with or surpass the traditional approach.

Table 19: Analysis of Understanding of Game Objectives

Metric	Keyboard (%)	Smart Cane (%)
Fully Understood	85	90
Partially Understood	12.5	2.5
Not Understood	2.5	7.5

4.5.3 EVALUATION OF GAMEPLAY ENGAGEMENT

The superior engagement score for the smart cane highlights the immersive potential of interactive, sensory-enriched gaming experiences. The tactile feedback and motion-sensitive controls of the smart cane appear to have fostered a more immersive and engaging gameplay environment compared to the static nature of keyboard input. This underscores the importance of multisensory feedback in enhancing player immersion, a finding that is consistent with current trends in gaming technology emphasizing user engagement.

Table 20: Evaluation of Gameplay Engagement

Metric	**Keyboard (%)**	**Smart Cane (%)**
Highly Engaged	80	85
Moderately Engaged	5	12.5
Not Engaged	7.5	2.5

4.5.4 ERGONOMIC EVALUATION OF THE SMART CANE CONTROLLER

Although the smart cane scored well in ergonomics, this aspect received the lowest relative score when compared to other metrics. Participants noted the innovative nature of the device but also suggested improvements for comfort during extended play sessions. Specific feedback highlighted the potential need for an adjustable grip and the refinement of button placement to prevent accidental inputs. These ergonomic considerations are critical for adoption, as they directly impact user satisfaction and the likelihood of long-term use.

Table 21: Ergonomic Evaluation of the Smart Cane Controller

Ergonomic Aspect	**Mean Rating**
Ergonomics of Smart Cane	3.975

4.6 RESULTS OF THE EXPERIMENTATION

In this section, the results of the experimentation will be presented, analyzing performance, accessibility, and user satisfaction, accompanied by graphical visualizations to illustrate key data.

Table 22: Summary of Results from Online Test (Keyboard)

Metric	**Online Test (Keyboard)**
Understanding of Game	
Fully Understood	34/40
Partially Understood	5/40
Not Understood	1/40
Tutorial Quality Rating	4.25
Gameplay Engagement	3.4
Highly Engaged	32/40
Moderately Engaged	2
Not Engaged	3
Ergonomics of Controller	Not Applicable

Figure 24a: Results of experiment Online Test(keyboard)

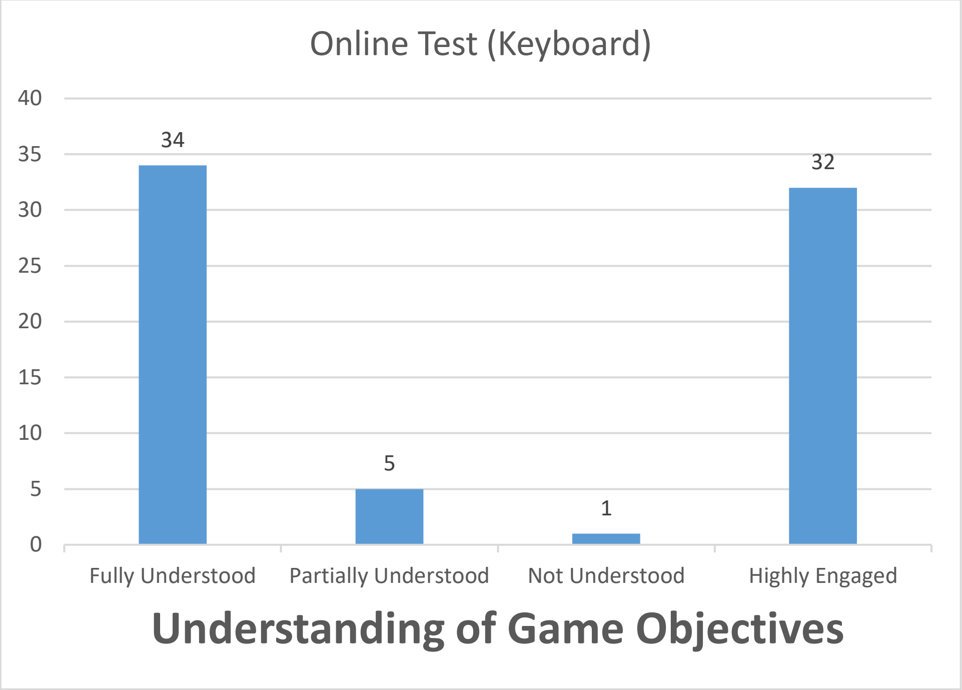


Figure 20b: Results of experiment Online Test(keyboard)

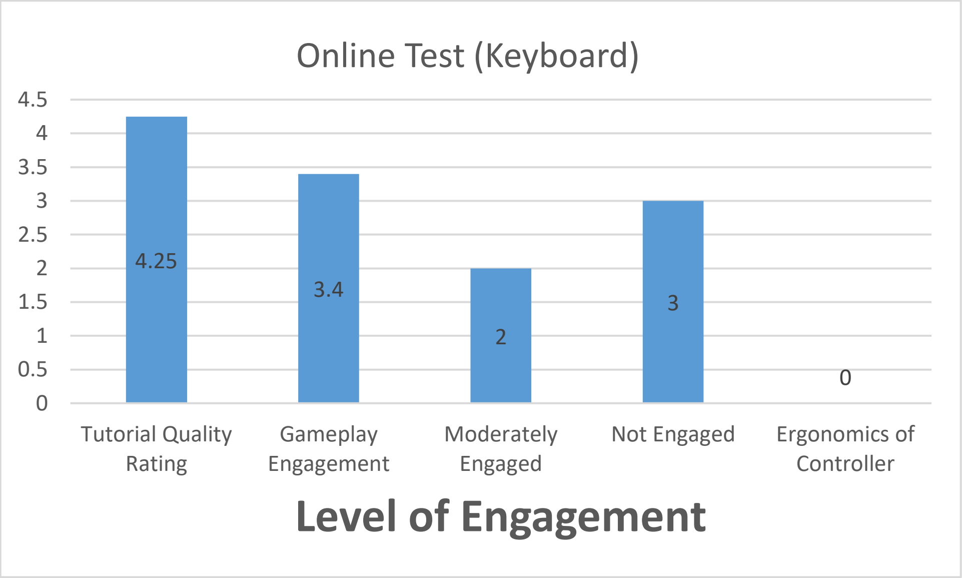


Table 23: Summary of Results from Cane Test (Smart Cane)

Metric	**Cane Test (Smart Cane)**
Understanding of Game Objectives	

Fully Understood	36/40
Partially Understood	1/40
Not Understood	3/40
Tutorial Quality Rating	4
Gameplay Engagement	4.175
Highly Engaged	34/40
Moderately Engaged	5
Not Engaged	1
Ergonomics of Controller	3.975

Figure 25a: Results from cane test (smart cane)

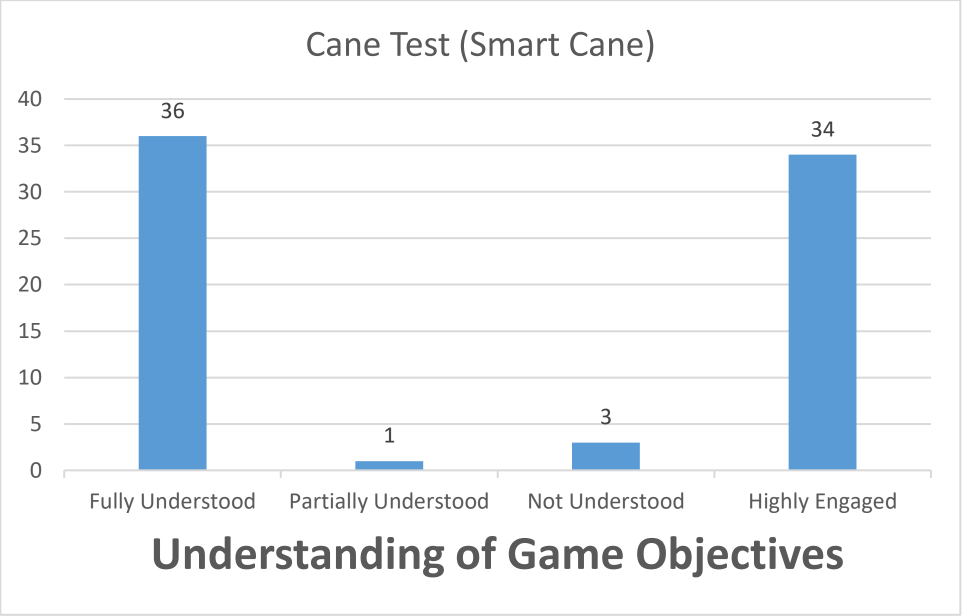
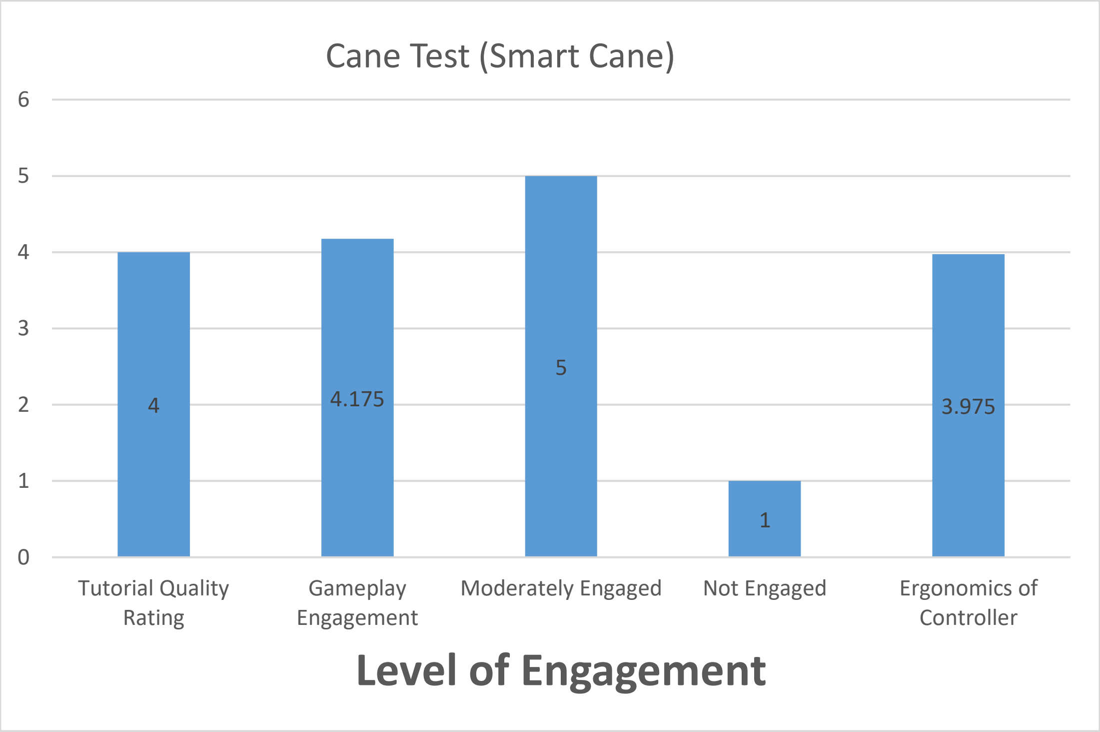


Figure 21b: Results from cane test (smart cane)



4.6.1 UNDERSTANDING OF GAME OBJECTIVES:

4.6.1.1 ONLINE TEST (KEYBOARD):

- **Fully Understood:** 34 out of 40 participants fully understood the game objectives in the online test using a keyboard interface. This indicates a strong comprehension among the majority of participants.

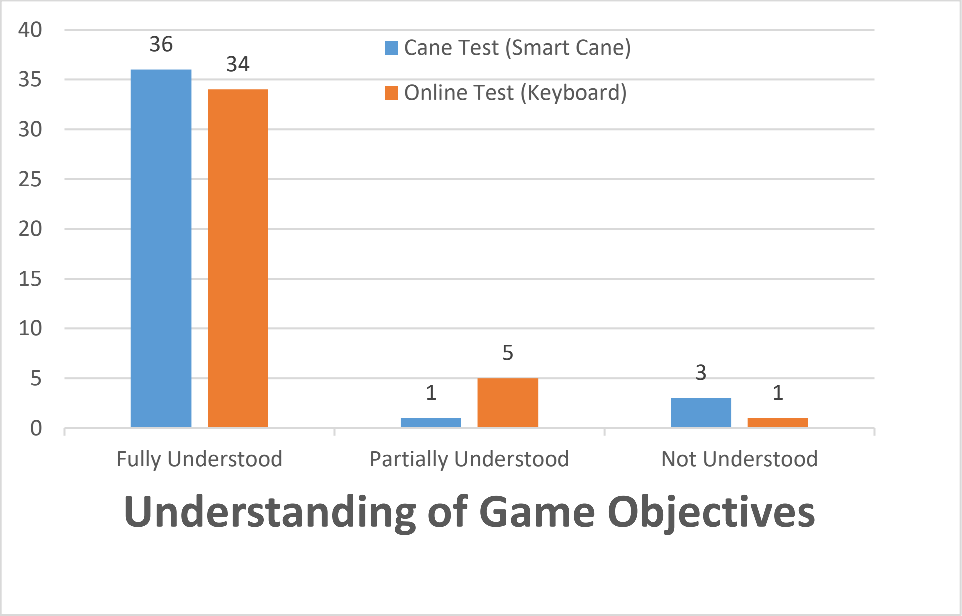
- **Partially Understood:** Only 5 out of 40 participants had a partial understanding, suggesting that the majority grasped the objectives quite well.

- **Not Understood:** Just 1 out of 40 participants failed to understand the game objectives, indicating that the game's objectives were generally clear and easily comprehensible through the keyboard interface.

4.6.1.2 CANE TEST (SMART CANE):

- **Fully Understood:** 36 out of 40 participants fully understood the game objectives when using the smart cane interface. This is slightly higher compared to the online test, which could imply that the tactile feedback and interaction provided by the smart cane contributed to better understanding.
- **Partially Understood:** Only 1 out of 40 participants had a partial understanding, which is significantly lower compared to the online test. This suggests that the smart cane interface may have facilitated clearer communication of the game objectives.
- **Not Understood:** 3 out of 40 participants did not understand the game objectives, indicating that while the smart cane interface was effective for most participants, there were still some who struggled with comprehension.

Figure 26: Understanding of game objectives

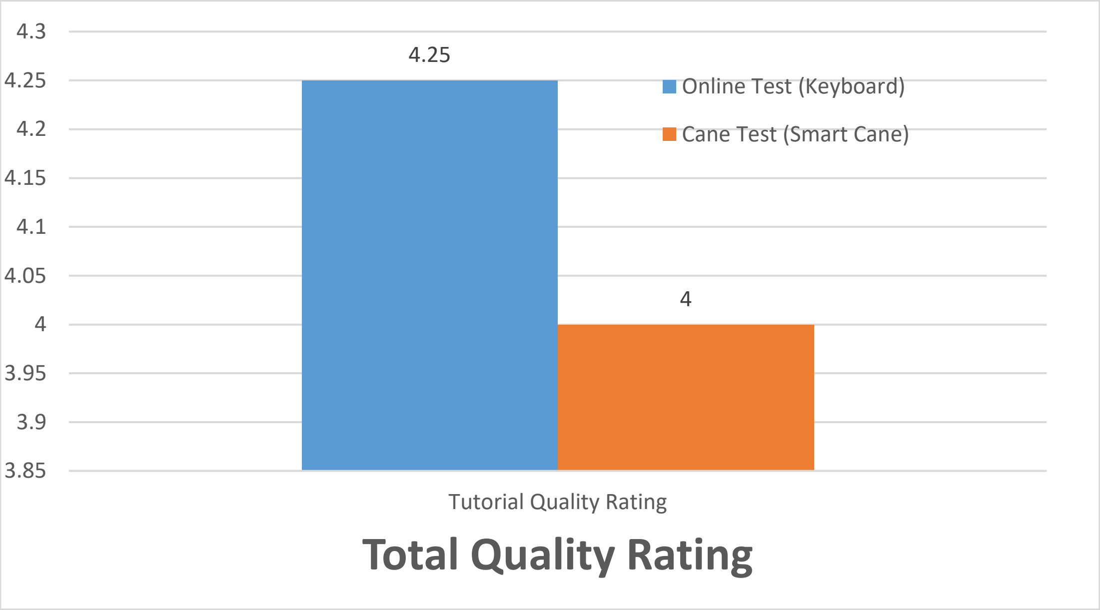


4.6.2 TUTORIAL QUALITY RATING

- **Online Test (Keyboard):** The tutorial quality was rated at 4.25 out of 5, indicating a generally positive perception among participants regarding the clarity and effectiveness of the tutorial in explaining the game mechanics.

- **Cane Test (Smart Cane):** The tutorial quality received a rating of 4 out of 5, which suggests that participants found the tutorial provided through the smart cane interface to be slightly less effective compared to the keyboard interface. This could be due to differences in presentation or interaction methods between the two interfaces.

Figure 27: Total Quality Rating



4.6.3 GAMEPLAY ENGAGEMENT

4.6.3.1 ONLINE TEST (KEYBOARD)

- **Highly Engaged:** 32 out of 40 participants were highly engaged during gameplay with the keyboard interface, indicating a strong level of interest and involvement.
- **Moderately Engaged:** 2 out of 40 participants showed moderate engagement, suggesting that the majority of participants were actively involved in the game.
- **Not Engaged:** 3 out of 40 participants were not engaged, indicating that a small minority of participants may have found the gameplay less interesting or engaging.

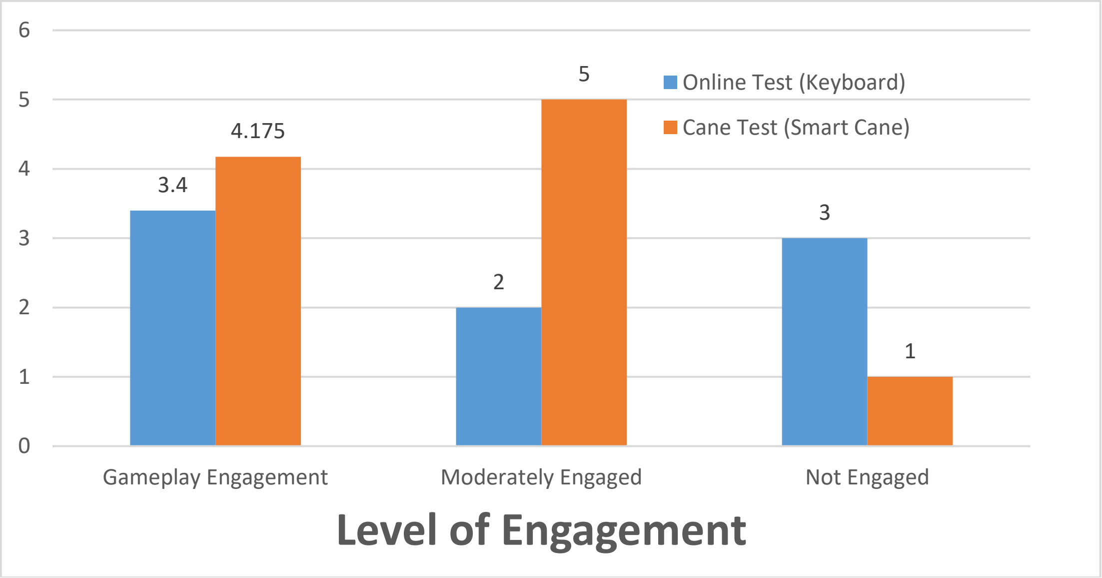
4.6.3.2 CANE TEST (SMART CANE)

- **Highly Engaged:** 34 out of 40 participants were highly engaged during gameplay with the smart cane interface, which is slightly higher compared to the online test. This could indicate that the tactile feedback provided by the smart cane enhanced engagement for most participants.
- **Moderately Engaged:** 5 out of 40 participants showed moderate engagement, suggesting that the majority of participants were actively involved in the game.
- **Not Engaged:** Only 1 out of 40 participants were not engaged, indicating that the smart cane interface was generally effective in maintaining participant interest and involvement.
-

Table 21: Evaluation of Gameplay Engagement

Engagement Level	Online Test (Keyboard)	Cane Test (Smart Cane)
Highly Engaged	80%	85%
Moderately Engaged	5%	12.5%
Not Engaged	7.5%	2.5%

Figure 28: Evaluation of Gameplay Engagement



4.6.4 ERGONOMICS OF CONTROLLER

Cane Test (Smart Cane): The ergonomics of the smart cane interface received a rating of 3.975 out of 5, indicating that participants generally found the smart cane to be comfortable and easy to use during gameplay. This suggests that the design of the smart cane interface was successful in providing a comfortable and user-friendly experience.

Ergonomic Aspect	Online Test (Keyboard)	Cane Test (Smart Cane)
Ergonomics Rating	Not Applicable	3.975

4.6.5 CONCLUSIONS AND FUTURE DIRECTIONS

The experimentation revealed the smart cane as a promising new entry in gaming interfaces, offering an engaging experience that rivals traditional methods. The areas identified for improvement are actionable and present clear paths for optimization. Future research should delve into long-term usage patterns to discern whether the novelty factor sustains engagement over time. Additionally, expanding the study to include a wider range of games and control complexities would provide a more comprehensive understanding of the smart cane's versatility and user adaptability. Continued refinement based on user feedback will be essential for the evolution of the smart cane from a novel concept to a mainstream gaming controller and assistive device.

GENERAL CONCLUSION

5.1 INTRODUCTION

Given the growing number of individuals experiencing visual impairment, this thesis focuses on leveraging various technologies to assist them in their daily activities. In today's digital age, technological innovation offers unprecedented opportunities to address the challenges faced by visually impaired individuals, transforming the landscape of assistive devices and redefining standards of accessibility.

5.2 INNOVATIVE SOLUTIONS FOR NAVIGATION

The primary focus lies in introducing innovative solutions, particularly centered around the integration of a cane embedded with a versatile array of sensors. These sensors are meticulously designed to cater to the unique needs of visually impaired individuals, facilitating seamless navigation through various environments. The embedded sensors will enable the Smart Cane to detect obstacles, recognize familiar routes, and provide real-time feedback to the user. This integration not only aims to improve the user's mobility and independence but also seeks to enhance their confidence and safety while navigating indoor spaces. By combining advanced sensor technology with user-centered design principles, this thesis aspires to create a robust and reliable assistive device that significantly improves the quality of life for visually impaired individuals.

The proposed cane serves as more than just a mobility aid; it embodies a multifunctional tool equipped with cutting-edge sensors capable of detecting and interpreting spatial information in real-time. By leveraging advancements in computer vision, integrated devices, and mobile platforms, this smart cane transcends traditional aids, offering enhanced functionality and accessibility.

Through this approach, we aim to revolutionize the way visually impaired individuals interact with their surroundings, providing them with newfound independence and confidence in their daily activities. By seamlessly integrating auditory feedback and tactile vibrations, the smart cane serves as a reliable companion, alerting users to potential obstacles and hazards both indoors and outdoors. This comprehensive system ensures that users receive timely and accurate information about their environment, empowering them to navigate with greater ease and assurance. The combination of these advanced technologies transforms the smart cane into an essential tool that significantly improves the quality of life for visually impaired individuals, enabling them to engage more fully and independently with the world around them.

Furthermore, this research delves into the intricacies of indoor and outdoor navigation, meticulously analyzing various methodologies and techniques employed to enhance assistance for the visually impaired. By conducting a comprehensive review of existing literature and research findings, we strive to uncover valuable insights that pave the way for future advancements in this critical field.

Moving forward, we advocate for the development of a reliable and comprehensive Machine Learning-based technology. We emphasize knowledge transfer between domains such as driver assistance and cane skills, alongside the importance of training in assistive technology.

While previous work has primarily focused on functionality, we highlight the need to consider factors like power consumption and wearability in device design.

In response to the navigation challenges faced by the visually impaired, we propose a smart white cane equipped with microcontrollers, cameras, accelerometers, and audio messaging capabilities. Our system utilizes cloud services to assist users in finding optimal routes and warns of nearby obstacles using sonar and sound alerts. Testing indicates promising results, with plans to further enhance the cane's intelligence and usability.

Moreover, we underscore the role of technology in improving personal safety for visually impaired individuals. The multifaceted design of the smart cane incorporates features like audio-tactile interaction, gesture detection, and emergency alert systems to ensure secure navigation. Algorithmic advancements, particularly in step count accuracy, contribute to hazard avoidance and obstacle detection.

The experiment conducted aimed to evaluate various aspects of a gaming system, including game objectives, tutorial quality, gameplay engagement, and the ergonomics of the controller. Through a structured approach that involved software development, feasibility testing, prototype development, and experimentation, the study provided valuable insights into the effectiveness and user experience of the system. The results of the experimentation highlighted crucial elements such as the understanding of game objectives, tutorial quality, gameplay engagement, and the ergonomic design of the controller. These findings shed light on the user experience and usability of the gaming system, laying the groundwork for a detailed analysis and discussion.

In the discussion section, the methodology of the experimentation was scrutinized, emphasizing the importance of a robust research approach to draw meaningful conclusions. The analysis of the understanding of game objectives, tutorial quality assessment, evaluation of gameplay engagement, and the ergonomic evaluation of the controller provided a comprehensive overview of the strengths and areas for improvement in the gaming system.

The detailed examination included several key components, each critical to the overall assessment of the smart cane system. The first component was the analysis of the understanding of game objectives, where participants' ability to comprehend and follow the gaming tasks was carefully evaluated. This helped identify how intuitive and accessible the game instructions were for visually impaired users.

The second component focused on the tutorial quality assessment. Here, the effectiveness of the introductory tutorials was analyzed to determine how well they prepared users for gameplay. This evaluation highlighted the clarity and comprehensiveness of the tutorials, ensuring that they effectively conveyed the necessary information for users to start playing confidently.

The third component was the evaluation of gameplay engagement. This aspect measured how engaging and enjoyable the gaming experience was for the users. Factors such as user interest, motivation, and emotional response were considered to gauge the overall appeal of the gaming system. The insights gained from this evaluation were crucial in understanding how well the gaming elements integrated with the assistive functionalities of the cane.

Finally, the ergonomic evaluation of the controller was conducted. This assessment focused on the physical design and usability of the smart cane's controller, examining how comfortable and easy it was to use over extended periods. The ergonomic analysis provided valuable feedback on the design elements that could be improved to enhance user comfort and prevent fatigue.

Through this comprehensive overview, the discussion section not only highlighted the strengths of the smart cane gaming system but also identified specific areas where improvements could be made. This thorough evaluation ensures that the development of the smart cane remains user-centered, continuously refining the device to better meet the needs and preferences of visually impaired individuals.

Looking ahead, user evaluations will assess the smart cane's usability and safety features in real-world scenarios, ensuring that the device meets the practical needs and challenges faced by visually impaired individuals in their daily lives. These evaluations will focus on how effectively the smart cane can navigate various environments, detect obstacles, and provide timely feedback to the user, all while maintaining a high standard of personal safety.

By prioritizing personal safety alongside social media access, the smart cane offers a comprehensive solution that enhances both independence and security. This dual focus allows users to move confidently through their surroundings while staying connected to their social networks, promoting a sense of inclusion and engagement with the broader community. The smart cane’s ability to integrate seamlessly with social media platforms provides users with real-time updates and communication options, further enriching their experience and ensuring they remain informed and connected.

Additionally, initial experimentation suggests potential applications in gaming interfaces, highlighting the smart cane's versatility and adaptability. These preliminary findings open up new avenues for optimization and further research to maximize user engagement and adaptability. By refining the gaming functionalities, the smart cane can offer an enjoyable and interactive experience that not only entertains but also enhances cognitive and motor skills.

5.3 FUTURE RESEARCH

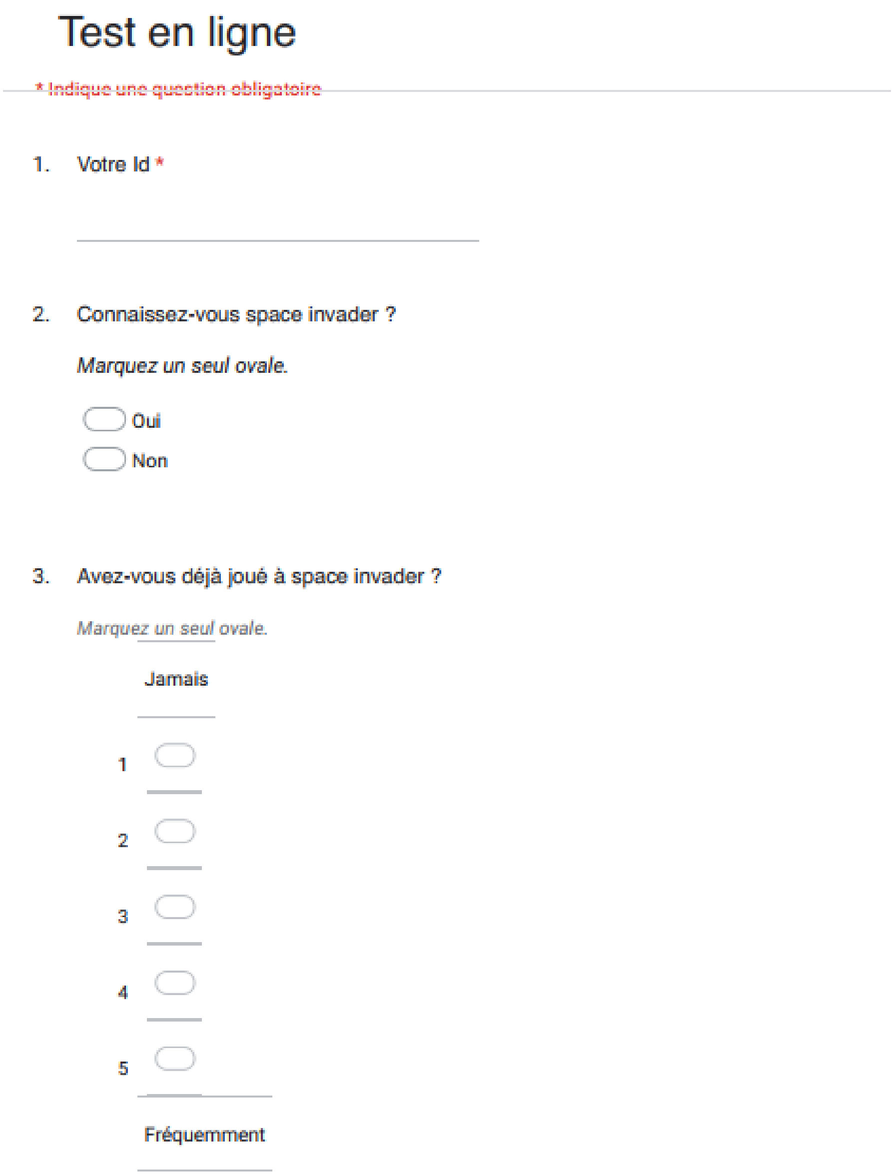
Future research will focus on fine-tuning these gaming interfaces to ensure they are accessible and engaging for visually impaired users. This includes improving the responsiveness and intuitiveness of the controls, as well as expanding the range of available games to cater to diverse interests and preferences. By continually optimizing these features, the smart cane aims to provide a holistic tool that supports both practical navigation and recreational activities, ultimately improving the quality of life for its users.

Through these ongoing efforts, the smart cane is poised to become a versatile and indispensable device, combining safety, connectivity, and entertainment in a single, user-friendly package. This forward-looking approach ensures that the smart cane remains at the forefront of assistive technology, adapting to the evolving needs of visually impaired individuals and empowering them to lead more independent and fulfilling lives.

Based on the results and discussions, it is evident that the system shows promise in delivering an engaging user experience. However, certain aspects such as tutorial quality and ergonomic design require further refinement to enhance user satisfaction and usability. The iterative refinement process outlined in the thesis document underscores the importance of continuous improvement in addressing user needs and preferences. In conclusion, the experimentation conducted in this study has provided valuable insights into the design and usability of the gaming system. By focusing on key elements, the research has laid a solid foundation for future development and enhancement of the system. Moving forward, it is recommended to prioritize user feedback and iterative refinement to ensure that the gaming system meets the evolving needs and expectations of its users. Through a user-centered approach and a commitment to continuous improvement, the gaming system has the potential to offer a compelling and immersive experience for its users.

ANNEXES

Appendix 1 : Test en ligne



Test en ligne

* Indique une question obligatoire

1. Votre Id *

2. Connaissez-vous space invader ?

Marquez un seul ovale.

○ Oui
○ Non

3. Avez-vous déjà joué à space invader ?

Marquez un seul ovale.

Jamais
1 ○
2 ○
3 ○
4 ○
5 ○
Fréquemment

Aspect tutoriel

4. Quels sont, selon vous, les objectifs principaux du jeu ?

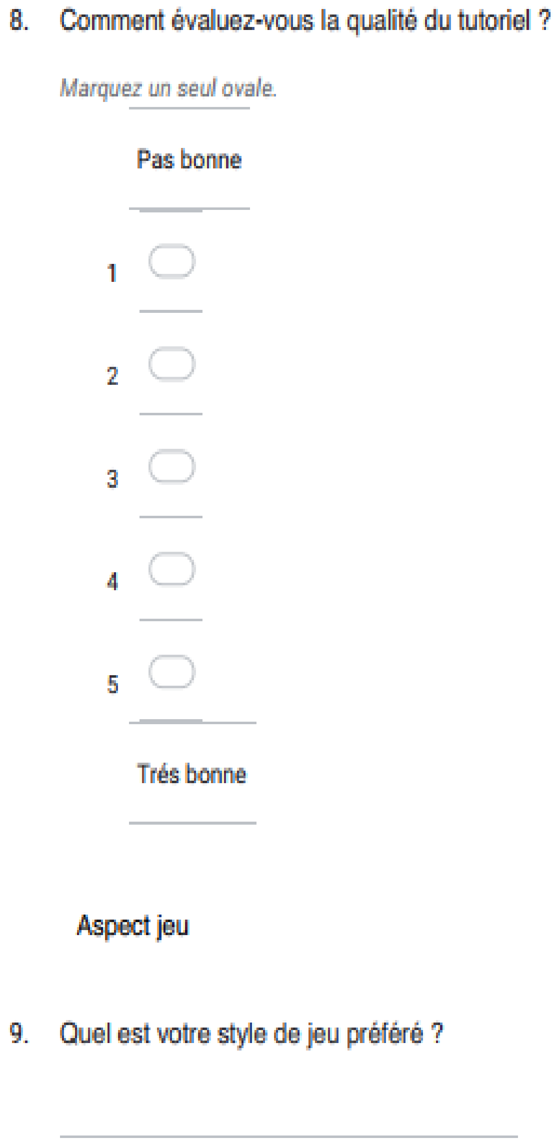
5. Quelles sont les actions possibles ?

6. Combien d'ennemis différents, selon vous, sont présents dans le jeu ?

7. Pensez-vous avoir compris tous les aspects du jeu à la fin du tutoriel ?

Marquez un seul ovale.

○ Oui
○ Non



8. Comment évaluez-vous la qualité du tutoriel ?

Marquez un seul ovale.

Pas bonne

1 ○

2 ○

3 ○

4 ○

5 ○

Trés bonne

Aspect jeu

9. Quel est votre style de jeu préféré ?

10. Selon vous, avez-vous les informations pertinentes pour cibler et éliminer des ennemis ?

Marquez un seul ovale.

Pas du tout efficace

1 ○
2 ○
3 ○
4 ○
5 ○

Très efficace

11. Est ce que vous vous sentez projeté dans le jeu ?

Marquez un seul ovale.

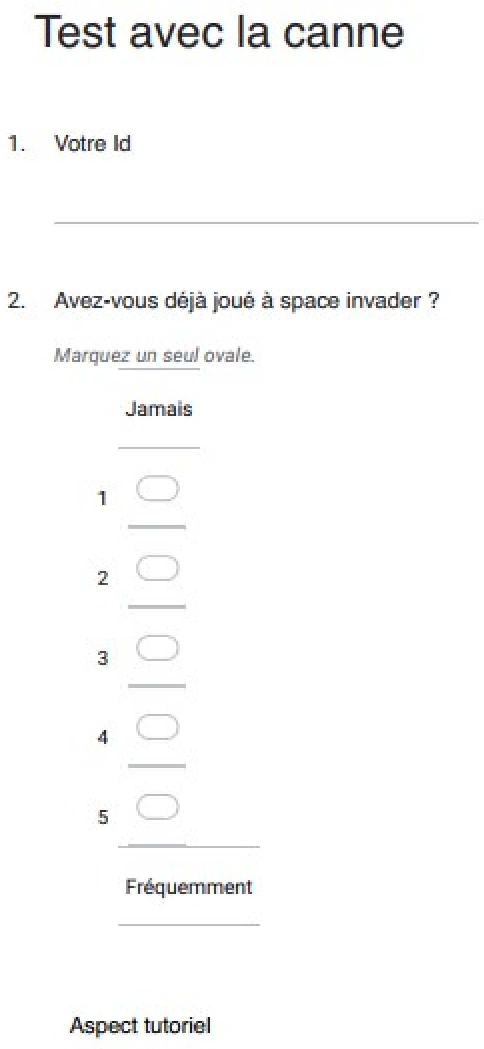
○ Oui
○ Non

12. Est ce que vous êtes capable d' utiliser des stratégies et des tactiques ?

Marquez un seul ovale.

○ Oui
○ Non

Appendix 2 : Test avec la canne



Test avec la canne

1. Votre Id

2. Avez-vous déjà joué à space invader ?

Marquez un seul ovale.

Jamais

1 ○

2 ○

3 ○

4 ○

5 ○

Fréquemment

Aspect tutoriel

3. Quels sont, selon vous, les objectifs principaux du jeu ?

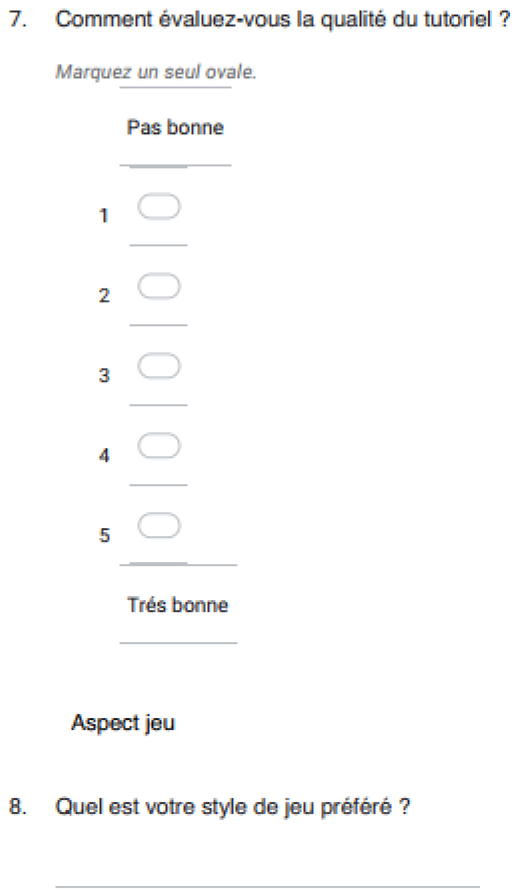
4. Quelles sont les actions possibles ?

5. Combien d'ennemis différents, selon vous, sont présents dans le jeu ?

6. Pensez-vous avoir compris tous les aspects du jeu à la fin du tutoriel ?

Marquez un seul ovale.

○ Oui
○ Non



7. Comment évaluez-vous la qualité du tutoriel ?

Marquez un seul ovale.

Pas bonne

1 ○

2 ○

3 ○

4 ○

5 ○

Trés bonne

Aspect jeu

8. Quel est votre style de jeu préféré ?

9. Selon vous, avez-vous les informations pertinentes pour cibler et éliminer des ennemis ?

Marquez un seul ovale.

Pas du tout efficace

1 ○

2 ○

3 ○

4 ○

5 ○

Très efficace

10. Est ce que vous vous sentez projeté dans le jeu ?

Marquez un seul ovale.

○ Oui
○ Non

11. Est ce que vous êtes capable d' utiliser des stratégies et des tactiques ?

Marquez un seul ovale.

○ Oui
○ Non

Aspect contrôleur

12. Quel est votre contrôleur (interface) de jeu préféré ?

____

13. Selon vous, le présent contrôleur est-il ergonomique ?

Marquez un seul ovale.

Pas du tout ergonomique

1 ○
2 ○
3 ○
4 ○
5 ○

Très ergonomique

14. Trouvez-vous que l'utilisation de vibration est utile ?

Marquez un seul ovale.

N'est pas utile

1 ○

2 ○

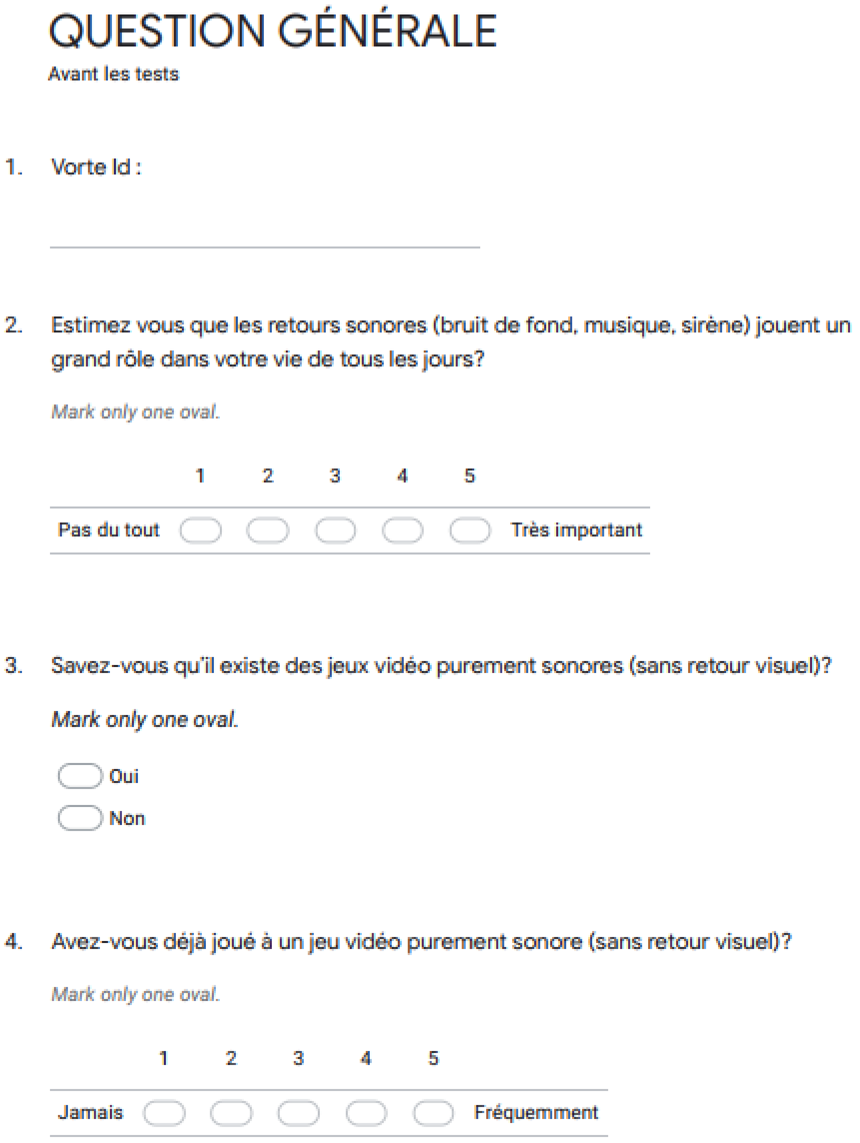
3 ○

4 ○

5 ○

Trés utile

Appendix 3 : General Questions



QUESTION GÉNÉRALE

Avant les tests

1. Vorte Id :

____

2. Estimez vous que les retours sonores (bruit de fond, musique, sirène) jouent un grand rôle dans votre vie de tous les jours?

Mark only one oval.

	1	2	3	4	5	
Pas du tout	○	○	○	○	○	Très important

3. Savez-vous qu'il existe des jeux vidéo purement sonores (sans retour visuel)?

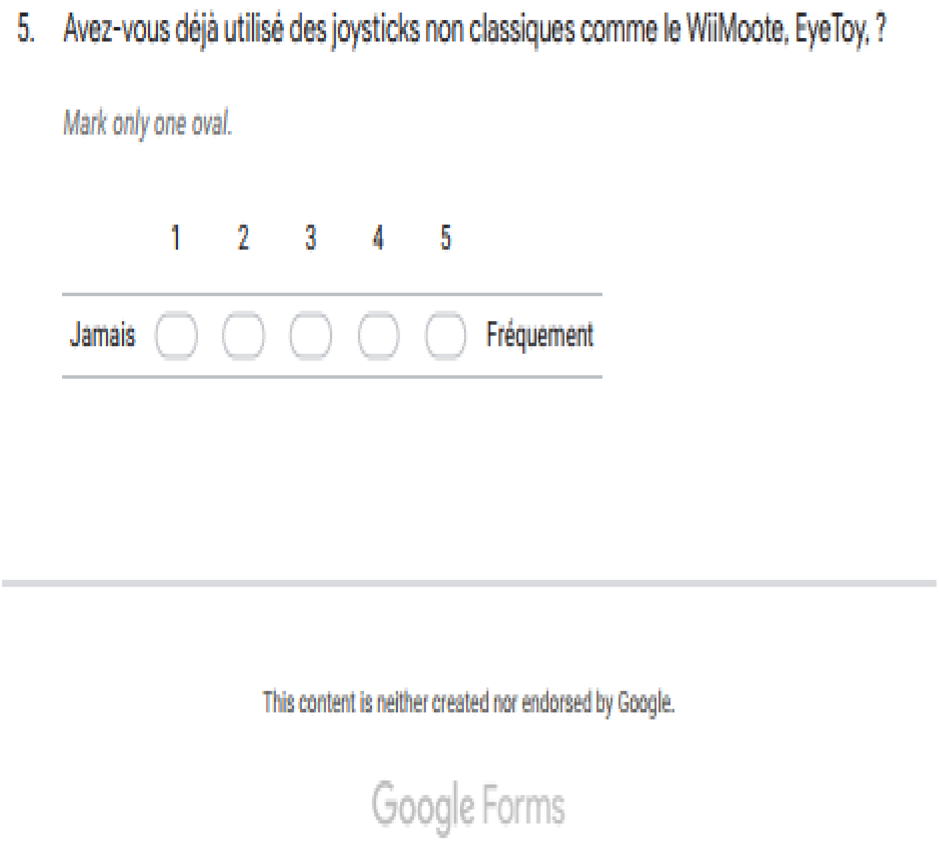
Mark only one oval.

○ Oui
○ Non

4. Avez-vous déjà joué à un jeu vidéo purement sonore (sans retour visuel)?

Mark only one oval.

	1	2	3	4	5	
Jamais	○	○	○	○	○	Fréquemment



5. Avez-vous déjà utilisé des joysticks non classiques comme le WiiMoote, EyeToy, ?

Mark only one oval.

	1	2	3	4	5	
Jamais	○	○	○	○	○	Fréquement

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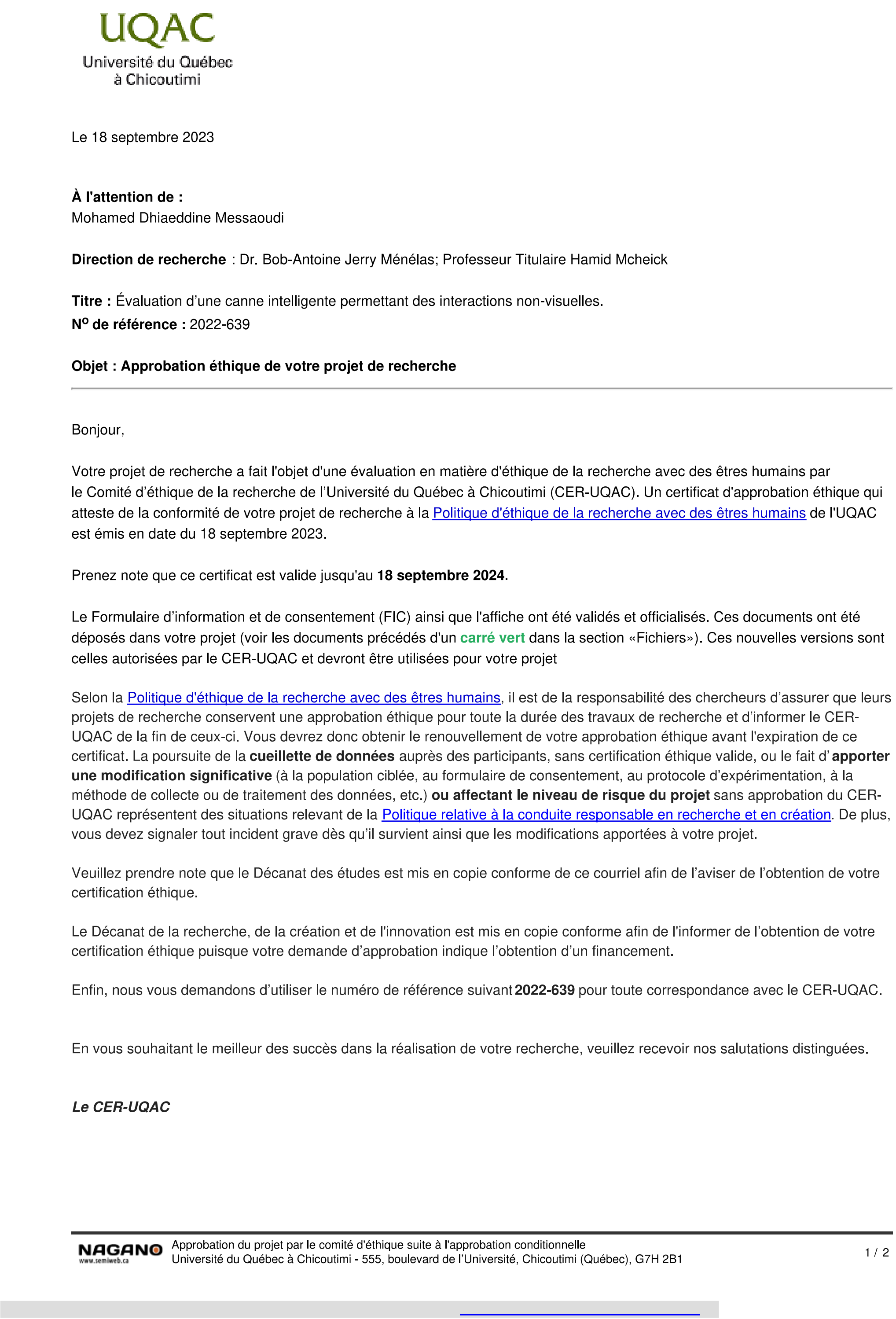
Appendix 4 : Ethical Approval of the Research Project



UQAC
Université du Québec
à Chicoutimi

Le 18 septembre 2023

À l'attention de :
Mohamed Dhiaeddine Messaoudi

Direction de recherche : Dr. Bob-Antoine Jerry Ménélas; Professeur Titulaire Hamid Mcheick

Titre : Évaluation d’une canne intelligente permettant des interactions non-visuelles.
N^{O} de référence : 2022-639

Objet : Approbation éthique de votre projet de recherche

Bonjour,

Votre projet de recherche a fait l'objet d'une évaluation en matière d'éthique de la recherche avec des êtres humains par le Comité d’éthique de la recherche de l’Université du Québec à Chicoutimi (CER-UQAC). Un certificat d'approbation éthique qui atteste de la conformité de votre projet de recherche à la Politique d'éthique de la recherche avec des êtres humains de l'UQAC est émis en date du 18 septembre 2023.

Prenez note que ce certificat est valide jusqu'au **18 septembre 2024**.

Le Formulaire d’information et de consentement (FIC) ainsi que l'affiche ont été validés et officialisés. Ces documents ont été déposés dans votre projet (voir les documents précédés d'un **carré vert** dans la section «Fichiers»). Ces nouvelles versions sont celles autorisées par le CER-UQAC et devront être utilisées pour votre projet

Selon la Politique d'éthique de la recherche avec des êtres humains, il est de la responsabilité des chercheurs d’assurer que leurs projets de recherche conservent une approbation éthique pour toute la durée des travaux de recherche et d’informer le CER-UQAC de la fin de ceux-ci. Vous devrez donc obtenir le renouvellement de votre approbation éthique avant l'expiration de ce certificat. La poursuite de la **cueillette de données** auprès des participants, sans certification éthique valide, ou le fait d’ **apporter une modification significative** (à la population ciblée, au formulaire de consentement, au protocole d’expérimentation, à la méthode de collecte ou de traitement des données, etc.) **ou affectant le niveau de risque du projet** sans approbation du CER-UQAC représentent des situations relevant de la Politique relative à la conduite responsable en recherche et en création. De plus, vous devez signaler tout incident grave dès qu’il survient ainsi que les modifications apportées à votre projet.

Veuillez prendre note que le Décanat des études est mis en copie conforme de ce courriel afin de l’aviser de l’obtention de votre certification éthique.

Le Décanat de la recherche, de la création et de l'innovation est mis en copie conforme afin de l'informer de l’obtention de votre certification éthique puisque votre demande d’approbation indique l’obtention d’un financement.

Enfin, nous vous demandons d’utiliser le numéro de référence suivant **2022-639** pour toute correspondance avec le CER-UQAC.

En vous souhaitant le meilleur des succès dans la réalisation de votre recherche, veuillez recevoir nos salutations distinguées.

Le CER-UQAC

NAGANO
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Approbation du projet par le comité d'éthique suite à l'approbation conditionnelle
Université du Québec à Chicoutimi - 555, boulevard de l’Université, Chicoutimi (Québec), G7H 2B1
1 / 2

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