Educational Administration: Theory and Practice
2024, 30(5), 8087-8102
ISSN: 2148-2403
https://kuey.net/

Research Article

An Enchanced Audio-Based Smart Cane For Visually Impaired People

Jeremy Baldonado[1*], Karren C. Faelangca MIT[2]

[1*]Researcher, Information Technology Education, Ramon Magsaysay Memorial Colleges-Marbel Inc., Koronadal, South Cotabato, Philippines, baldonadoj2@gmail.com,
[2]ITE Program Director, Ramon Magsaysay Memor, ial Colleges-Marbel Inc., Koronadal, South Cotabato, Philippines, karencamarinz@gmail.com

Citation : Jeremy Baldonado, Karren C. Faelangca MIT, (2024), An Enchanced Audio-Based Smart Cane For Visually Impaired People, *Educational Administration: Theory and Practice*, *30*(5), 8087-8102
Doi: 10.53555/kuey.v30i5.4305

ARTICLE INFO

ABSTRACT

This research paper presents the development and evaluation of an Enhanced Audio-Based Smart Cane aimed at improving the mobility and independence of visually impaired individuals. The system integrates object detection, distance measurement, and audio feedback functionalities to enhance situational awareness and navigation. Rigorous testing and evaluation reveal exceptional performance in object detection, with minimal errors observed. However, inconsistencies in distance measurement and occasional audio feedback issues suggest areas for improvement. User engagement testing demonstrates positive feedback on system usability and effectiveness. Recommendations for enhancement include the integration of LiDAR technology for precise distance measurement, upgrading the processing unit for improved performance, and implementing Bluetooth connectivity for enhanced user comfort. Overall, the Enhanced Audio-Based Smart Cane shows promise in addressing the needs of visually impaired individuals, with continuous refinement and advancements aimed at optimizing its functionality and user experience.

Keywords: *Visually Impaired, Smart Cane, Object Detection, Audio Feedback, Distance Measurement, Accessibility, Assistive Technology, Machine Learning, Mobility aid.*

INTRODUCTION

Background of the Study

The global prevalence of vision impairment, affecting an estimated 2.2 billion individuals, highlights the urgent need for comprehensive and accessible eye care (World Health Organization: WHO, 2023). Astonishingly, nearly half of this demographic—approximately 1 billion people—endure conditions that are either preventable or remain unaddressed. Causes of distance vision impairment or blindness include cataracts, refractive error, age-related macular degeneration, glaucoma, diabetic retinopathy, and presbyopia, impacting a significant 826 million individuals.

Regional disparities compound the issue, with low- and middle-income regions experiencing a fourfold higher prevalence of distance vision impairment compared to high- income regions. Unaddressed near vision impairment is particularly acute in western, eastern, and central sub- Saharan Africa, where rates surpass 80%, while high- income regions report significantly lower rates, falling below 10%. (World Health Organization: WHO, 2023).

As the global population continues to grow and age, the risk of vision impairment escalates, posing a substantial challenge to public health. The WHO projects a surge in the prevalence of vision impairment, demanding urgent attention and effective strategies to mitigate its impact. This thesis aims to explore the multifaceted aspects of vision impairment, investigating potential interventions, policy implications, and strategies to enhance global eye care.

The overarching goal is to contribute to a world where preventable vision loss becomes a rarity (World Health Organization: WHO, 2023).

In addressing the challenges faced by visually impaired individuals, traditional navigation aids such as white canes, guide dogs, and assistance from trained guides or volunteers have long been employed (Lin et al., 2017).

Research indicates that those who become blind in early life often develop efficient acoustic skills, including echolocation, for navigation (Kuriakose et al., 2020).
Wayfinding and navigation for visually impaired individuals heavily rely on landmarks, clues, and the utilization of auditory or olfactory senses. Tactile paving, particularly near public transport stations, offers a supportive infrastructure for navigation, enhancing safety for pedestrians requiring assistance (Acoustical Society of America, 2017). Orientation and Mobility (O&M) skills further empower visually impaired individuals to navigate unfamiliar environments safely (Acoustical Society of America, 2017). Orientation involves understanding one's current location and destination, while mobility pertains to the capability to navigate safely and efficiently between places (Bhowmick & Hazarika, 2017).
In the era of technological advancements, assistive technologies have become integral to the daily lives of people with disabilities. These technologies, encompassing devices, services, and environmental modifications, aim to overcome various barriers to independence and promote active, productive, and equal participation in society (Bhowmick & Hazarika, 2017). Research indicates the increasing significance of assistive technologies in navigation, with examples such as Wayfindr8 and Envision marking notable progress (Kuriakose et al., 2020).
This thesis proposes an enhanced audio-based smart cane utilizing a combination of object detection API, Google Text-to-Speech, and ultrasonic sensors. The system aims to facilitate easier and more independentnavigation for visually impaired individuals by detecting obstacles and providing audio feedback. Through practicality and affordability, this project seeks to contribute to ongoing efforts to enhance accessibility for visually impaired individuals, fostering independence and social inclusion.
Use the enter key to start a new paragraph. The appropriate spacing and indent are automatically applied.

A. Objectives of the Study

Generally, this study aims to create, design, and develop the study entitled "An Enhanced Audio-Based Smart Cane for Visually Impaired People". This system would provide a safer and more independent mobility experience for individuals who are blind or visually impaired. This can be achieved through the following specific objectives: Specific Objectives

Specifically, this study aims to:

- Develop and implement an efficient object detection system as the foundational element of the enhanced smart cane, prioritizing its role in identifying and notifying users about obstacles in their environment.
- Integrate a distance measurement component into the enhanced smart cane system to provide reliable information about the proximity of detected obstacles, enhancing user navigation and safety.
- Implement a user-friendly audio feedback system, strategically communicating the object name and distance of obstacles detected by the smart cane to enhance user understanding and situational awareness.

B. Significance of the Study

The beneficiaries of the enhanced audio-based smart cane project for visually impaired individuals would primarily be individuals who are blind or visually impaired. The smart cane would provide them with a safer and more independent mobility experience, allowing them to navigate their environment with greater confidence and ease.
In addition to the visually impaired individuals themselves, other potential beneficiaries of this project might include:

Caregivers, family members, or friends who provide support to visually impaired individuals, may feel more at ease knowing that their loved ones have an enhanced navigation tool to help them avoid obstacles and navigate their surroundings.
Service providers who work with visually impaired individuals, such as orientation and mobility specialists, rehabilitation professionals, or assistive technology specialists, may be able to incorporate the enhanced audio- based smart cane into their training or rehabilitation programs.
The broader community, which benefits when visually impaired individuals can participate more fully in society and engage in activities such as employment, education, and socialization. The enhanced audio-based smart cane has the potential to improve the overall quality of life for visually impaired individuals and promote greater inclusion in the community.
To the researcher. The system will help the researcher to develop their skills and practical experience that surely usable for them in the future.
To the future researcher. This study would probably help them to analyze another problem and to become the foundation for their references.

C. Scope and Limitation

This study focuses on the development and evaluation of an Enhanced Audio-Based Smart Cane aimed at improving navigation for visually impaired individuals. It incorporates object detection using an integrated camera, with a minimum accuracy threshold of 60% for reliability. Additionally, ultrasonic sensors are optimized for precise distance measurement in various environmental conditions. Clear and contextually relevant audio feedback based on detected obstacles is generated using Google Text-to- Speech for natural output. Real-time user support is emphasized to enhance situational awareness, ensuring cost-effectiveness and potential scalability. The study contributes to accessibility efforts by promoting independence and social inclusion among visually impaired individuals.

Limitation of the Project

A significant limitation of the Enhanced Audio-Based Smart Cane is its reliance on a pre-trained object detection model. While effective for common urban and indoor obstacles, it may struggle with specialized or uncommon objects not in the original training dataset. The system's effectiveness depends on the diversity of the dataset, potentially limiting its performance with novel or unexpected obstacles. Ongoing model refinement, updates, and potential retraining with diverse datasets are necessary to improve adaptability. Balancing practicality with adaptability remains a challenge in optimizing the capabilities of the Enhanced Audio-Based Smart Cane.

I. THEORETICAL FRAMEWORK

A. *Review of Related Literature*

Smart Cane

The Smart Cane represents a significant advancement in electronic travel devices, specifically designed to enhance navigation for visually impaired individuals. Acting as an improved iteration of the traditional white cane, this electronic counterpart addresses limitations by incorporating advanced features for obstacle detection. Employing ultrasonic sensors, the Smart Cane detects obstacles, including those hanging and at knee level, providing users with comprehensive awareness of their surroundings. Users can set locations using voice commands, and the device offers GPS guidance to assist in reaching destinations. A microcontroller serves as the control system, facilitating efficient processing and coordination of the Smart Cane's functionalities. Additionally, the device includes a GPS with a memory card for storing various locations, making it versatile for multiple destinations. Powered by rechargeable batteries, the Smart Cane can be conveniently recharged through USB or an AC adaptor. However, it is noted that the GPS signal accuracy is limited to a 5-meter radius, rendering it suitable for outdoor navigation rather than indoor use. The Smart Cane also features a camera at its head, utilizing an algorithm to detect obstacles ahead and providing an additional layer of environmental awareness. Proper training for visually impaired users is emphasized as a prerequisite to effectively utilize the Smart Cane in public spaces. The paper proposes a tailored design to meet the unique needs of visually impaired individuals, aiming to facilitate seamless navigation in various public environments (Sharma et al., 2017).

Tensorflow Object Detection

"In recent years, there has been notable advancement in deep neural network architectures. Currently, Keras and TensorFlow stand out as prominent players, featuring diverse pre-trained models within their libraries, including VGG16, VGG19, ResNet50, Inception V3, Xception, and MobileNet. Classical convolutional networks such as VGG and AlexNet from 2012 adhere to a conventional pattern, while MobileNet offers a simplified architecture designed for optimal performance in mobile applications. ResNet, Inception, and Xception have emerged as pivotal benchmarks in the realm of artificial vision and learning, renowned for their versatile deep architectures (Sundar, et al., 2018)."

Numerous factors contribute to the revolutionary progress in deep learning. Key among these factors is the accessibility of extensive and high-quality datasets, and the utilization of parallel computing, particularly through Graphics Processing Units (GPUs), facilitating efficient activation for backpropagation. The integration of new architectures and regularization techniques is noteworthy, enabling the training of more expansive networks with a reduced risk of overshooting. Additionally, the availability of robust optimizers and the support of thriving communities on software platforms like TensorFlow, Theano, Keras, CNTK, PyTorch, Chainer, and Mxnet have collectively streamlined problem-solving processes. Presently, the Python programming language holds significant prominence in the field of Machine Learning, particularly due to its robust support for deep learning frameworks (Sanchez et al., 2020).

Within this context, TensorFlow stands out as an open- source software library for machine learning, offering the flexibility to deploy computing on both CPU and GPU. Developed by Google, it utilizes data flow graphs. PyTorch, supported by Facebook, employs the Python language. Theano, a Python library, facilitates mathematical expressions involving tensors. CNTK, developed by Microsoft, is an open set of tools for deep learning. Keras, a high-level neural network library created by Francis Chollet, a member of Google's Brain team, allows users to choose whether the built models will be executed in Theano, TensorFlow, or CNTK. Keras and TensorFlow offer three different model construction approaches: using a sequential model, a functional API, and pre-trained models (Sanchez et al., 2020).

By Sanchez et al. (2020), our earlier discussion delved into diverse architectures like MobileNet, Inception, and ResNet. Shifting the focus to object recognition models within the Keras TensorFlow framework, noteworthy mentions include Faster R-CNN, R-FCN, SSD, and YOLO. These models are categorized into region-based detectors (Faster R-CNN, R-FCN, FPN) and single-shot detectors (SSD and YOLO). Despite originating from distinct pathways, they currently exhibit notable similarities while competing for the coveted

title of being the faster and more accurate detector.
Various metrics play a crucial role in enhancing object detection algorithms, focusing on achieving more precise positioning, faster processing speed, and improved classification accuracy. Prominent among these metrics are Intersection over Union (IoU), mean average precision (MAP), and rendered frames per second (FPS). IoU, as highlighted by Rezatofighi et al. (2019), serves as a measure indicating the proximity between the predicted image and the actual image.
The mean average precision (MAP) is a comprehensive metric that evaluates both accuracy and the recovery of detection bounding boxes. It serves as an effective measure to assess the network's sensitivity to objects of interest and its ability to minimize false alarms. A higher MAP score indicates a more precise network performance, although this precision may come at the expense of execution speed (Li et al., 2019). Additionally, processed frames per second (FPS), introduced by (T.-Y. Lin et al. in 2017), is employed to gauge the system's speed, providing insights into its efficiency and real-time processing capabilities.

Datasets

Architectures and the aforementioned models heavily rely on datasets, with recent emphasis placed on freely available datasets accessible on the internet. Examples include Microsoft COCO (Common Objects in Context) and PASCAL Visual Object Classes (VOC). Microsoft COCO comprises a dataset of 300,000 images featuring 90 common objects. Supported by an API, it offers diverse models for object detection, balancing speed, and accuracy through bounding boxes suitable for identified objects (M. Everingham et al., 2014). PASCAL Visual Object Classes (VOC) is a pivotal resource for object category recognition and detection. Established in 2005 and ongoing, VOC consists of standard image data, annotations, and evaluation procedures, making it a key reference in the field (Wang, L., & Sng, D., 2018).

Comparison Between Deep Learning Algorithms for Object Detection

Defining a standardized metric for evaluating different object detectors proves challenging, as real-life scenarios may yield varied solutions. Accurate and swift decision-making necessitates a consideration of various factors influencing performance. These factors encompass the type of feature extractor, extraction steps, image input resolutions, coincidence strategy, and threshold settings. Additional considerations include the absence of maximum suppression ratios for positive and negative anchors, the number of proposals or predictions, limitations on frame coding, expanded training dataset size, and the utilization of multi-scale images during training or testing, including clipping. The significance of map layer features in object detection should be acknowledged. It's crucial to recognize that technology is in constant evolution, rendering any comparisons subject to swift obsolescence (Sanchez et al., 2020).
A thorough examination of scholarly articles and academic research focused on assessing the performance of various object detection models within the TensorFlow framework revealed notable findings. In their study titled "Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks," Shaoqing Ren, Kaiming He, Ross Girshick, and Jian Sun conducted analyses on diverse test sets. The results, encompassing metrics such as medium accuracy (map) and the count of predictions, varied across different experiments employing the Faster R-CNN methodology, as outlined in Table 1 (Ren et al., 2017).

GTTS (Google Text-to-Speech)

The TTS library is primarily employed for converting audio strings into text, typically representing the response that a voice assistant intends to provide to the user. The language chosen for the text is English, denoted by the code "en." The entire functionality is encapsulated within the "tts" function. The resulting text, essentially an audio file with the ".mp3" extension, is saved, and each file is uniquely identified by a randomly generated number ranging from 1 to 20,000,000, achieved through the "random. randint()" command. The saved audio file is then named "audio file." The final step involves using the "tts. save(audio file)" command to store the generated audio file (Subhash, S. et al., 2020).

B. Conceptual Framework

The conceptual framework of the Enhanced Audio- Based Smart Cane involves capturing input from both an integrated camera and ultrasonic sensor. These inputs are processed through several stages to provide meaningful audio feedback to the user.

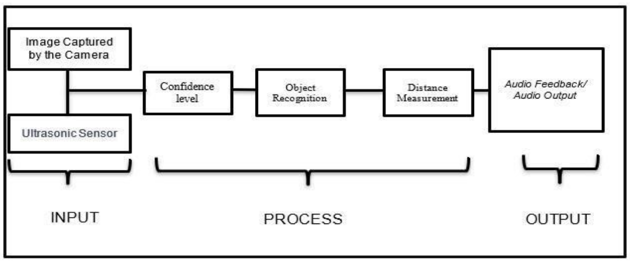

Figure 1. Conceptual Framework

Initially, the input undergoes object recognition and distance measurement processes. Object recognition identifies obstacles in the user's path, while the ultrasonic sensor measures their distance. Subsequently, the system calculates the confidence level associated with the detected objects. This confidence level reflects the system's certainty regarding the accuracy of detection and measurement. Based on this confidence level and the identified objects, the system generates audio feedback to inform the user about their surroundings, aiding in navigation and enhancing situational awareness. Overall, this framework utilizes input from the camera and ultrasonic sensor to process object recognition and distance measurement, facilitating the provision of valuable audio feedback for visually impaired individuals.

C. *Definition of Terms*

Computer vision algorithms- software programs that use mathematical algorithms to analyze digital images or videos to extract useful information and detect objects within them.

Infrared sensors- a type of sensor technology that uses infrared light to detect the presence of objects and measure distances between the sensor and the object.
Micro-controller- a small computer that controls the behavior of electronic devices and systems, such as smart canes or navigation systems.
Motion-supporting device- a device that helps individuals with mobility impairments navigate through their environment, such as a wheelchair or cane.
Multiple sensor systems- object detection systems that use a combination of different types of sensors, such as cameras, ultrasonic sensors, and laser scanners, to detect and recognize objects.
Object detection- the process of identifying and locating objects within an image or video.
Single sensor systems- object detection systems that use only one type of sensor technology, such as a camera or ultrasonic sensor, to detect and recognize objects
Smart canes- a type of white cane that integrates technological features, including object detection technology, to enhance independence and mobility for individuals with visual impairments.
Synthetic speech output- a computer-generated voice that provides auditory feedback to users of assistive technology devices, such as smart canes or navigation systems.
Ultrasonic sensors- a type of sensor technology that uses sound waves to detect the presence of objects and measure distances between the sensor and the object.

II. OPERATIONAL FRAMEWORK

A. *Materials*

Material to be used

The various hardware and software packages used in the proposed Audio-Based Smart Cane for Visually Impaired People are explained below. Let us discuss the software packages followed by the hardware component.

Software Requirements

The requirements below show the hardware specifications used to create this system.

Components	Specifications
Operating System	Raspberry Pi OS 64-bit
Programming Language	Python
Database Software	Firebase Realtime Database
Server	Firebase
Object Detection API	TensorFlow Lite Object Detection API
Libraries	OpenCV, GTTS, NumPy, Firebase Admin

Table 1. Software Requirements

Table 1 presents the software requirements essential for developing the Enhanced Audio-Based Smart Cane for Visually Impaired People. The components include Operating System (OS), Programming Language, Database Software, Server, Object Detection API, and Libraries.
Hardware Requirements
The requirements below show the hardware specifications used to create this system.

Components	Specifications
Camera	Raspberry pi Camera v2.1
Microprocessor	Raspberry Pi 3 Model B+
Memory	1GB LPDDR2 SDRAM
SD Card	EVO Plus microSD Memory Card 32GB

detect obstacles more effectively, providing timely feedback to users for safer navigation.

System Design

The system design combines hardware and software components including sensors, Raspberry Pi for processing, and algorithms for obstacle detection and audio feedback. User testing ensures alignment with visually impaired users' needs.

Sensor	Ultrasonic Distance Sensor - HC-SR04
Powerbank	Orashare O10 Pro Powerbank
Cane	Foldable Aluminum Walking Cane
Headset	Headset

Development

Development includes hardware assembly and software creation using Python, TensorFlow API for object detection, and OpenCV-Python for camera operations. Integration and testing ensure functionality.

Testing

Table 2. Hardware Requirements

Table 2 displays the components and specifications employed in the development of the system. The components encompass a camera, microprocessor, memory, SD card, sensor, powerbank, cane, and headset.

B. Methods

Software Development Methodology

The researcher used the Waterfall model for its very easy to understand and use, and it is the earliest SDLC approach that was used for software development. The whole process of the software development life cycle is divided into phases. Typically, the outcome of one phase acts as the input for the next phase sequentially.

Waterfall Model

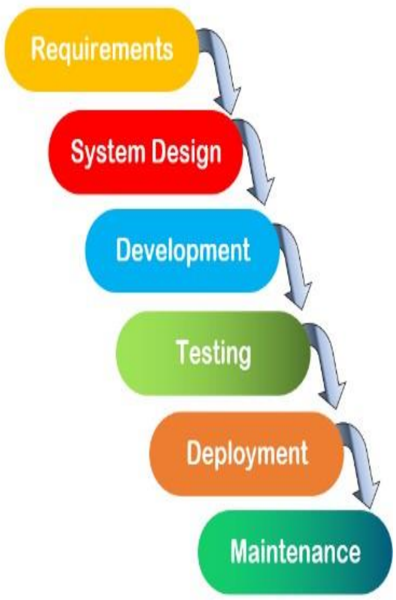

Figure 2. Waterfall Software Development Methodology

Requirement Analysis

The researcher begins by examining the manual methods used by visually impaired individuals for navigation and obstacle detection. Through this analysis, they identify challenges and limitations faced by users and plan the process of the smart cane system accordingly. To enhance the operation of the smart cane, the researcher proposes the integration of Real-Time Monitoring for Object Detection. This involves assessing current cane functionality and implementing real-time monitoring to

Testing validates system effectiveness, usability, and reliability through software and hardware testing stages including unit testing, integration testing, system testing, functional testing, usability testing, and field testing.

Deployment

Deployment involves fabricating a standalone device with all hardware components, installing software, and powering the device. The system provides audio feedback about obstacles and distances.

Maintenance

Maintenance ensures optimal performance through bug fixes, upgrades, patches, and testing. A reliable support system and user feedback monitoring are essential for efficient maintenance.

C. System Flowchart of Existing System

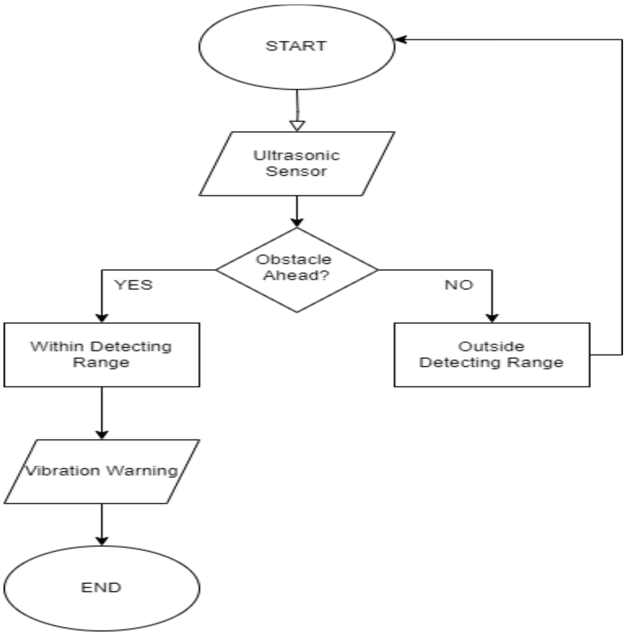

Figure 3. System Flowchart of Existing System

The flowchart represents a recurrent loop in which the system consistently measures distance, verifies its alignment within the detection range, identifies obstacles,
and initiates vibration signals as needed. This repetitive process persists until either the system is deliberately halted or powered off.

D. System Flowchart of Proposed System

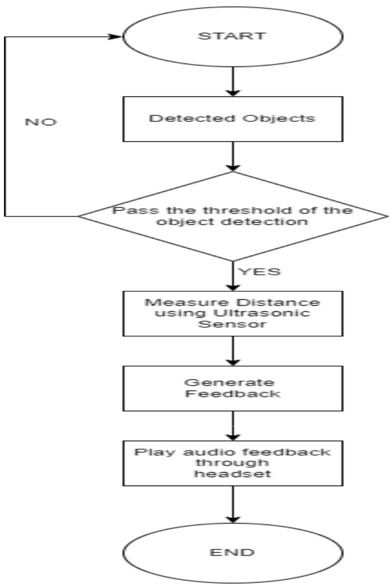

Figure 4. System Flowchart of Proposed System

System Flowchart of Proposed System
The interaction sequence with the Enhanced Audio-Based Smart Cane begins with the camera detecting objects in the user's vicinity. Following this, the system processes the detected objects, passing them through a threshold check for a minimum accuracy score of 60 percent. If the threshold is met, the system proceeds to the next step, involving the measurement of distances using an ultrasonic sensor. In case the threshold is not met, the system returns to the object detection phase until a satisfactory accuracy level is achieved.

Once the distance measurement is completed, the system advances to the next phase of generating audio feedback. This feedback is tailored to provide the user with clear and relevant information about the detected obstacles.

The audio feedback is then played through a headset attached to the smart cane, contributing to the user's situational awareness and navigation.

This streamlined process ensures that the smart cane prioritizes accuracy in object detection and distance measurement, subsequently delivering meaningful audio feedback to enhance the user's understanding of their surroundings. The systematic flow concludes the interaction, aiming not only for real-time user support but also for laying the groundwork for continuous system improvement through ongoing evaluations and insights stored in the database.

E. Context Diagram

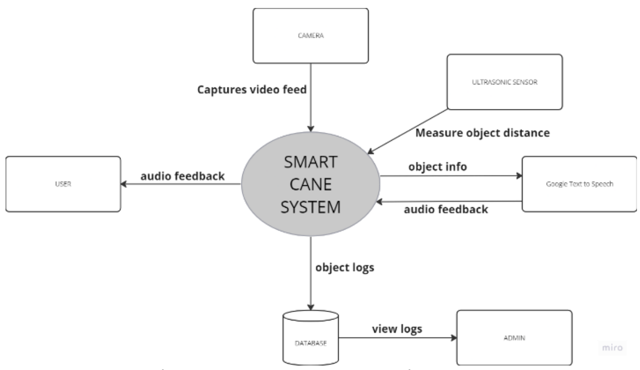

Figure 5. Context Diagram

Our project revolves around a smart system called the "Smart Cane System." It's like the brain of our smart cane, helping it identify obstacles and provide important details like what the obstacle is, how far away it is, and when it was detected. This system ensures the cane gives users clear and quick audio feedback about any obstacles they encounter, making it easier and safer for them to navigate their surroundings.

The main user of our smart cane system is someone who is visually impaired. They interact directly with the cane and get immediate audio updates about any obstacles nearby, helping them move around confidently.

We've also included a "Database" in our system, using Firebase to store information about obstacles detected by the cane. This helps us keep track of how well the system is working and allows us to make any necessary improvements.

The "Admin" is another important part of our project. They can access the database and oversee how the system is performing. By checking the stored data, they can ensure that the smart cane accurately detects obstacles in different situations.

F. Use Case Diagram

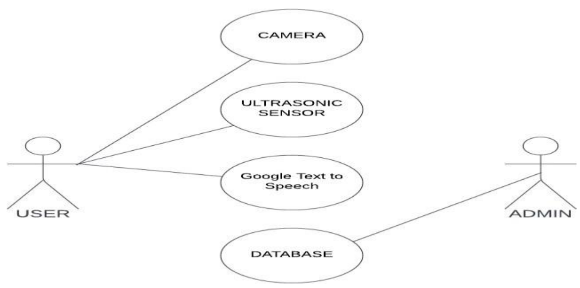

Figure 6. Use Case Diagram

Use Case Diagram

In the Enhanced Audio-Based Smart Cane system, there are two primary actors: the User (Visually Impaired) and the Admin. The User interacts directly with the Smart Cane, utilizing it for navigation and receiving real-time audio feedback. The Smart Cane incorporates an Object Detection System that detects obstacles, ultrasonic sensor on the other hand measures distances, and provides relevant audio feedback to the User. This direct interaction empowers visually impaired users to navigate their surroundings with increased confidence and safety.

On the other hand, the admin role is focused on oversight and evaluation. The admin utilizes the Database, which stores information about detected obstacles, to review and assess the accuracy of the object detection system. By accessing the stored data, the admin ensures that the Smart Cane operates effectively across various real-world scenarios. In summary, the User engages with the Smart Cane for navigation and immediate feedback, while the admin utilizes the Database to evaluate and ensure the system's overall accuracy and performance.

G. Data Flow Diagram

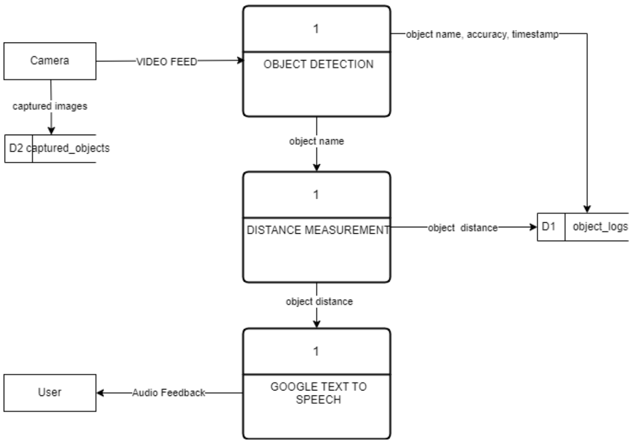

Figure 7. Data Flow Diagram

The user interaction initiates with the "Camera" entity capturing detected objects and storing them in "Database 2 - captured_objects." The video feed data flows to the object detection process, where information including object name, accuracy, and timestamp is systematically stored in "Database 1 - object_logs." Subsequently, the system advances to "Process 2 - Distance Measurement," measuring object distance and updating "Database 1 - object_logs." Moving forward to "Process 3 - Google Text-to-Speech," audio feedback is generated, containing the object name and distance. This final output is directed to the user, creating a seamless and coordinated process within the enhanced smart cane system. Users receive comprehensive and user-friendly feedback based on the detected objects and distances, ensuring an effective and inclusive navigation experience.

H. Entity Relationship Diagram

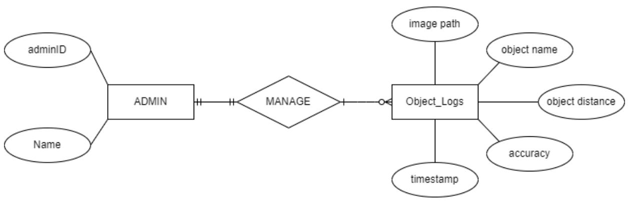

Figure 8. Entity Relationship Diagram

The Entity-Relationship Diagram (ERD) for the proposed system comprises two main entities: "object_logs" and "Admin." The "object_logs" entity represents log entries for detected objects, with each entry being uniquely identified by an auto-generated key. The attributes inside the " object_logs " include "Object_name," "Distance," "image_path," "Timestamp," and "Accuracy." In the "Admin" entity, administrators overseeing the system are represented, each identified by an auto- generated key ("-AdminID"). The "Name" attribute holds the administrator's name as a string. Although both entities are logically associated, the relationship is not explicitly modeled in the diagram. It is assumed that administrators can view and manage all object logs. Unique identifiers for entries are auto-generated by Firebase, reflecting the keys used for efficient storage and retrieval.

I.System Environment

Desktop Application Output and Admin Interface Design

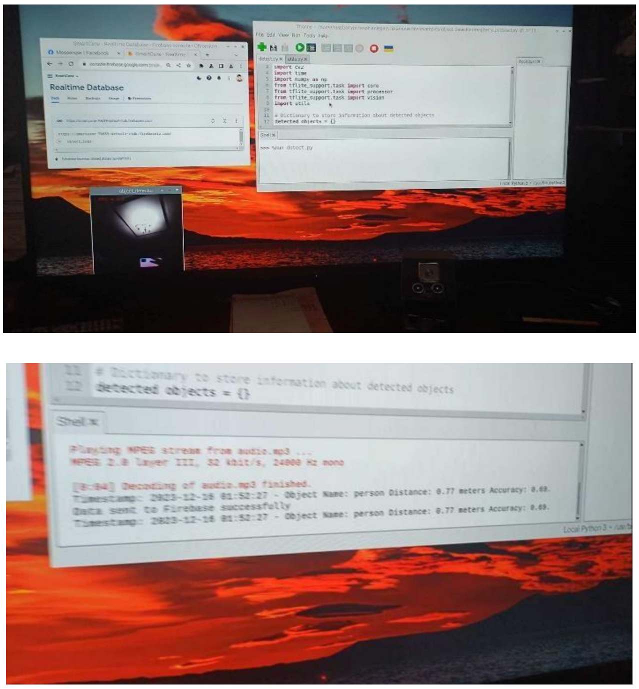

Figure 9. Monitoring for Desktop

Figure 9 shows the object logs for the admin side, where the admin can monitor what's, the object detected including the accuracy, timestamp of which the object detected, also the object distance.

Web Application Output and User Interface Design

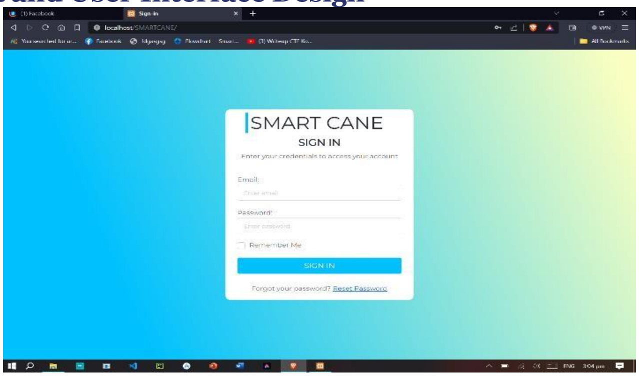

Figure 10. Login Interface

Figure 10 shows the Login Interface for the Admin where Admin can access the Real-Time Database and monitor the performance of smart cane system.

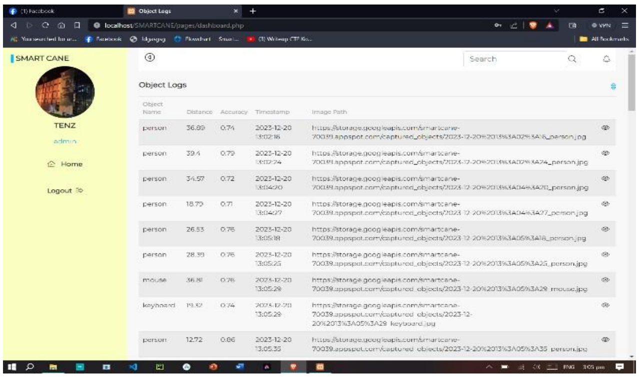

Figure 11. Object Logs Monitoring

Figure 11 shows the object logs, the admin can see the object name, distance, accuracy, timestamp and also the image path connected to Firebase Storage.

J. Questionnaire

Items to be Evaluated	1	2	3	4	5	Mean Rating
How easy was it to activate the smart cane system?						
Were the detected objects correct, and were there any false positives or negatives?						
How accurate were the distance measurements provided by the smart cane?						
Was the information conveyed clearly?						
Did the system provide timely information during navigation?						
Was it comfortable to use for an extended period?						
Did it enhance your ability to navigate?						

III.RESULT AND DISCUSSION

A. Testing and Evaluation

Testing and Evaluation

During the rigorous testing phase, the Enhanced Audio-Based Smart Cane system underwent comprehensive evaluations across key functionalities.

Object Detection Testing

Outcome: The object detection component demonstrated exceptional performance, with 1 error observed out of 10 tests.

Analysis: The accuracy and reliability of the object detection system are commendable, providing users with precise information about their surroundings.

Distance Measurement Testing

Outcome: Out of 10 distance measurement tests, 4 errors were encountered.

Analysis: The distance measurement component exhibited some inconsistencies, leading to errors in approximately one-third of the tests. This highlights an areafor improvement to enhance the precision of distance measurements.

correct, and were there any false positives or negatives?					
How accurate were the distance measuremen ts provided by the smart cane?	3	2		3.4	Agree
Was the information conveyed clearly?		1	4	4.8	Strongly Agree
Did the system provide timely information during navigation?		5		4	Agree
Was it comfortable to use for an extended period?		4	1	4.2	Strongly Agree

Audio Feedback Testing

Outcome: 2 errors were identified out of 10 tests, specifically related to instances where the system did not vocalize the detected objects.

Analysis: While the majority of audio feedback tests were successful, the system's occasional failure to provide spoken feedback is a concern. Investigating and resolving this issue is crucial for a consistent user experience.

Firebase Data Sending Testing

Outcome: Of 2 of 10 tests for sending data to Firebase, 8 were successful.

Analysis: The high success rate in sending data to Firebase is promising, indicating robust functionality.

B. Statistical Treatment

The data collected from the System Evaluation Questionnaire were analyzed and subjected to statistical treatment by computing the Mean Rating of the responses on every question. The formula applied is:

$$x = \frac{\sum x}{n}$$

C. *Interpretative Scale used to Interpret the Mean*

Range of Mean	Interpretation
4.21 - 5.00	Strongly Agree
3.41 – 4.20	Agree
2.61 – 3.40	her Agree nor Disagree
1.81 – 2.60	Disagree
1.00 – 1.80	Strongly Disagree

A questionnaire constructed as a five-point Likert rating scale with the following equivalents: 1 – strongly disagree; 2 – strongly disagree; 3 - neither agree nor disagree; 4 - agree; 5 - strongly agree.

D. *Questionnaire Evaluation Result*

Items to be Evaluated	1	2	3	4	5	Mean Ratin g	Interpretati on
How easy was it to activate the smart cane system?			4	1		3.2	Agree
Were the detected objects					5	5	Strongly Agree

The user evaluations of the smart cane system reflect positive reception across various aspects. Activating the system was perceived as moderately easy, with a mean rating of 3.2, indicating general agreement among users, suggesting room for improvement to enhance ease of use.
Object detection accuracy received the highest mean rating of 5, interpreted as "strongly agree." Users expressed high confidence in detected objects' correctness, highlighting the system's precision and reliability without significant false positives or negatives.

Distance measurements received a mean rating of 3.4, indicating agreement among users regarding accuracy. While not rated as high as object detection, positive agreement suggests users found distance measurements sufficiently accurate for effective navigation.

Clear conveyance of information received a high mean rating of 4.8, indicating "strongly agree." Users felt the system effectively communicated information about obstacles, enhancing situational awareness through clear audio feedback.

Timeliness of information during navigation received a positive rating with a mean score of 4, indicating general agreement. Opportunities for optimization exist to enhance real-time responsiveness.

Comfort during extended use received a well- received mean rating of 4.2, interpreted as "strongly agree."
Users found the smart cane comfortable for extended use, without causing discomfort or fatigue.
The system's impact on enhancing navigation abilities received a mean rating of 4.4, interpreted as "strongly agree." Users strongly agreed that the smart cane significantly improved their navigation abilities, aligning with its intended purpose.
In conclusion, user feedback indicates a positive experience with the smart cane system, affirming its effectiveness in object detection, distance measurement, information conveyance, and overall usability for navigation. Constructive feedback can guide future refinements to further enhance performance and user satisfaction.

E. *System Accuracy*

The data collected from the system accuracy evaluation checklist were analyzed and subjected to statistical treatment by computing the accuracy percentage of the system in every feature in the proposed system. The formula applies is:
System Accuracy
The results of the evaluation provide valuable insights for refining the system's precision and reliability in real-world scenarios. While the majority of tests were successful, the identification of 2 errors in Firebase data sending emphasizes the need for further investigation. Despite these errors, the overall success rate still indicates robust functionality in data logging. Addressing and resolving these specific issues will contribute to maintaining a reliable data-logging process and further improving the system's overall performance.

F. Overall Test System Accuracy

			Overall System Performance Questionnaire			
			System Performance			
	Poor	Fair	Good	Very Good	Excellent	System Accuracy Rate (%)
Object Detection				5	5	90%
Distance Measurement		4	1	4	1	60%
Real-Time Performance			1	3	6	90
Audio Feedback		2			8	80%
Usability				1	9	98%
Data Transmission to Firebase				5	5	90%
Hardware and Maintenance				8	2	84%
False Positive Handling				2	8	86%
User Experience				7	3	86%
User Feedback			1	8	1	80%
			Overall System Accuracy Rate:			84.4%

Overall Svstem Accuracv= $\frac{\text{sum of the system accuracy percentage per resp}}{\text{number of respondents}}$

Overall System Accuracy= ~~(90%+60%+90%+80%~~

Overall System Accuracy

Overall Sy

The overall system accuracy of the smart cane, based on the provided percentages from different features, is approximately 84.4%. This percentage represents the average accuracy across various aspects of the smart cane system, including object detection, distance measurement, audio feedback, and data sending to Firebase. It indicates that, on average, the smart cane system performs accurately and reliably according to the evaluations conducted by the respondents across different features. While specific features may have encountered some errors, the overall

The System Accuracy, calculated based on the number of working features (5), encountered errors in distance measurement (1), and data sending to Firebase (2) out of a total of 5 features, stands at approximately 83%. This percentage reflects the system's accuracy in successfully delivering the intended functionalities. While the system showcased robust performance in object detection and audio feedback, addressing observed inconsistencies in certain distance measurement scenarios and the identification of 2 errors in data sending Firebase present opportunities for enhancement.

performance suggests a promising and effective system with room for further improvement in specific areas.

IV. SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

The testing and evaluation phase of the Enhanced Audio-Based Smart Cane has provided comprehensive insights into its performance, strengths, and areas for improvement. The system showcases exceptional accuracy and reliability in object detection, as evidenced by 1 error in 10 tests. This feature significantly contributes to providing precise information about the user's surroundings, enhancing the overall user experience.

In contrast, the distance measurement component encountered some inconsistencies, resulting in four errors out of 10 tests. While most distance measurements were accurate, the observed errors highlight an area for improvement to enhance the precision of distance measurements. Addressing these inconsistencies will contribute to the overall effectiveness of the system in providing reliable distance information to users.

The audio feedback testing revealed two errors in 10 tests, specifically in instances where the system did not vocalize the detected objects. While the majority of audio feedback tests were successful and contributed to positive user feedback, resolving these occasional failures is crucial for maintaining a consistent and reliable user experience.

On a positive note, the Firebase data-sending functionality demonstrated robust performance, with 2 errors out of 10 successful tests. This high success rate indicates the system's reliability in sending data to Firebase, contributing to effective data logging and oversight.

User engagement testing, involving visually impaired individuals, provided valuable insights into the system's overall user experience. Users expressed satisfaction with the clear and intuitive audio feedback, enhancing their awareness of detected obstacles. Additionally, the majority found the system easy to use, providing valuable assistance in navigating their surroundings.

Conclusion

In conclusion, the Enhanced Audio-Based Smart Cane presents a promising solution for visually impaired individuals, offering accurate object detection, clear audio feedback, and reliable data logging. While specific areas for improvement have been identified, such as refining distance measurements and addressing occasional audio feedback failures, the overall performance indicates the system's potential effectiveness. Continuous feedback, iterative design, and further enhancements will play a crucial role in optimizing the system for real-world scenarios and ensuring a positive and empowering user experience.

Recommendation

In considering the enhancement of the Enhanced Audio-Based Smart Cane, several strategic recommendations could significantly elevate its performance and user experience. Firstly, the integration of LiDAR technology as a ranging device is proposed. LiDAR, with its laser-based distance measurement capabilities, can offer more precise and reliable distance information compared to traditional ultrasonic sensors. Moreover, upgrading the processing power of the system by adopting a newer Raspberry Pi model, such as the Raspberry Pi 5 with 8GB RAM, is suggested. This advancement can contribute to better real-time performance, allowing for faster data processing and more efficient execution of complex algorithms, particularly beneficial for object detection and distance measurement.

Additionally, to enhance user comfort and mobility, the recommendation includes the adoption of Bluetooth headsets for wireless audio connectivity. This modification eliminates the need for wired headsets, providing users with more freedom of movement and reducing potential hindrances during navigation.

By incorporating LiDAR technology, upgrading the processing unit, and introducing Bluetooth connectivity, the Enhanced Audio-Based Smart Cane can further elevate its accuracy, real-time responsiveness, and overall user satisfaction, aligning with the latest advancements in technology and user preferences.

REFERENCES

1. Lin, B., Lee, C., & Chiang, P. (2017b). Simple Smartphone-Based Guiding System for Visually Impaired People. Sensors, 17(6), 1371. https://doi.org/10.3390/s17061371
2. Kuriakose, B., Shrestha, R., & Sandnes, F. E. (2020). Tools and Technologies for Blind and Visually Impaired Navigation Support: a review. IETE Technical Review, 39(1), 3–18. https://doi.org/10.1080/02564602.2020.1819893 Acoustical Society of America. (2017, June 26).
3. Exploring the potential of human echolocation. ScienceDaily. Retrieved January 1, 2024 from www.sciencedaily.com/releases/2017/06/170626093624.h tm
4. Bhowmick, A., & Hazarika, S. M. (2017). An insight into assistive technology for the visually impaired and blind people: state-of-the-art and future trends. Journal on Multimodal User Interfaces, 11(2), 149–172. https://doi.org/10.1007/s12193-016-0235-6
5. Jeamwatthanachai, W., Wald, M., & Wills, G. (2019). Indoor navigation by blind people: Behaviors and challenges in unfamiliar spaces and buildings. British Journal of Visual Impairment, 37(2), 140–153. https://doi.org/10.1177/0264619619833723.
6. Jin, Y., Kim, J., Kim, B., Mallipeddi, R., & Lee, M. (2015). Smart Cane. Proceedings of the 3rd International Conference on Human-Agent Interaction. doi:10.1145/2814940.2814952.
7. Kuriakose, B., Shrestha, R., & Sandnes, F. E. (2020b). Tools and Technologies for Blind and Visually Impaired Navigation Support: a review. IETE Technical Review, 39(1), 3–18. https://doi.org/10.1080/02564602.2020.1819893
8. Ghani, F. B. A. (2019). Smart Cane based on IoT. International Journal of Education, Science, Technology, and Engineering, 2(1), 12–18. https://doi.org/10.36079/lamintang.ijeste-0201.15
9. Abu-Abdoun, D. I., Alsyouf, I., Mushtaha, E., Ibrahim, I., & Al-Ali, M. (2022). Developing and Designing an Innovative Assistive Product for Visually Impaired People: Smart Cane. 2022 Advances in Science and Engineering Technology International Conferences (ASET). https://doi.org/10.1109/aset53988.2022.9734902
10. Cabrera-Sosa, L. E. Lopez- Garcia, A. Diaz-Sanchez, J. M. Rocha-Perez, V. H. Carbajal-Gomez and G. Zamora-Mejia, "Design and Implementation of a White-Cane Based on the Vibration- Distance Sensing Technique for Blind People," 2020 IEEE International Conference on Engineering Veracruz (ICEV), Boca del Rio, Mexico, 2020, pp. 1-8, doi: 10.1109/ICEV50249.2020.9289667.
11. S. Subbiah, S. Ramya, G. Parvathy Krishna and S. Nayagam, "Smart Cane For Visually Impaired Based On IOT," 2019 3rd International Conference on Computing and Communications Technologies (ICCCT), Chennai, India, 2019, pp. 50-53, doi: 10.1109/ICCCT2.2019.8824893.
12. P. Malini, S. Karpakam, E. Saranya, P. Selvaraju, T. Murugajothi, G. Ranjith, "An Efficient System for Visually Impaired by using LORA RA01", 2023 5th International Conference on Inventive Research in Computing Applications (ICIRCA), pp.78-83, 2023.
13. K, K. P, A. T, and J. S, "Assistance For Visually Impaired People Using Deep Learning," 2023 2nd

International Conference on Vision Towards Emerging Trends in Communication and Networking Technologies (ViTECoN), Vellore, India, 2023, pp. 1-6, doi: 10.1109/ViTECoN58111.2023.10157205.
14. S. Suresh Kumar, B. Prasanna and S. Pratheep Kumar, "Visual Impaired Assist Mobile App using CNN," 2023 5th International Conference on Smart Systems and Inventive Technology (ICSSIT), Tirunelveli, India, 2023, pp. 1193-1197, doi: 10.1109/ICSSIT55814.2023.10061033.
15. R. Johari, N. K. Gaurav, S. Chaudhary and A. Pramanik, "START: Smart Stick based on TLC Algorithm in IoT Network for Visually Challenged Persons," 2020 Fourth International Conference on I- SMAC (IoT in Social, Mobile, Analytics and Cloud) (I- SMAC), Palladam, India, 2020, pp. 605-610, doi: 10.1109/I-SMAC49090.2020.9243517.
16. R. K. Megalingam, A. Nambissan, A. Thambi, A. Gopinath, and M. Nandakumar, "Sound and touch-based smart cane: Better walking experience for visually challenged," 2014 IEEE Canada International Humanitarian Technology Conference - (IHTC), Montreal, QC, Canada, 2014, pp. 1-4, doi: 10.1109/IHTC.2014.7147543.
17. R. L. Routson, M. Bailey, I. Pumford, J. Czerniecki and P. M. Aubin, "A smart cane with vibrotactile biofeedback improves cane loading for people with knee osteoarthritis," 2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Orlando, FL, USA, 2016, pp. 3370-3373, doi: 10.1109/EMBC.2016.7591450.
18. Hapsari, G. A. Mutiara and D. T. Kusumah, "Smart cane location guide for blind using GPS," 2017 5th International Conference on Information and Communication Technology (ICoIC7), Melaka,
19. Malaysia, 2017, pp. 1-6, doi: 10.1109/ICoICT.2017.8074697.
Ahmed, Z. Tasnim, M. Rana and M. Khan, "Development of Low-Cost Smart Cane with GPS," 2022 IEEE World AI IoT Congress (AIIoT), Seattle, WA, USA, 2022, pp. 715-724, doi: 10.1109/AIIoT54504.2022.9817322.
20. N. S. Ahmad, N. L. Boon and P. Goh, "Multi-Sensor Obstacle Detection System Via Model- Based State-Feedback Control in Smart Cane Design for the Visually Challenged," in IEEE Access, vol. 6, pp. 64182-64192, 2018, doi: 10.1109/ACCESS.2018.2878423.
21. T. Lavanya Narayani., M. Sivapalanirajan., B. Keerthika., M. Ananthi. and M. Arunarani., "Design of Smart Cane with integrated camera module for visually impaired people," 2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS), Coimbatore, India, 2021, pp. 999-1004, doi: 10.1109/ICAIS50930.2021.9395840.
22. Husin, M. H., & Lim, Y. K. (2019). InWalker: smart white cane for the blind. Disability and Rehabilitation: Assistive Technology, 15(6), 701–707. https://doi.org/10.1080/17483107.2019.1615999
23. Hung, D. N., Vo, M., Nguyen, M., Huy, Q., & Cuong, V. T. (2017). Design and implementation of smart cane for visually impaired people. In IFMBE proceedings (pp. 249–254). https://doi.org/10.1007/978-981-10-4361- 1_41
24. T. Wang, R. Grobler, and E. Monacelli, "EVAL Cane: An IoT-based Smart Cane for the Evaluation of Walking Gait and Environment," 2020 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Paris, France, 2020, pp. 1-4, doi: 10.1109/BMSB49480.2020.9379468.
25. M. J. Ghafoor, M. Junaid and A. Ali, "Nav-Cane A Smart Cane for Visually Impaired People," 2019 International Symposium on Recent Advances in Electrical Engineering (RAEE), Islamabad, Pakistan, 2019, pp. 1-4, doi: 10.1109/RAEE.2019.8886919.
26. Hapsari, G. I., Mutiara, G. A., & Tarigan, H. (2019). Face recognition smart cane using haar-like features and eigenfaces. TELKOMNIKA Telecommunication Computing Electronics and Control, 17(2), 973. https://doi.org/10.12928/telkomnika.v17i2.11772
27. Summer Asad, Brittany Mooney, Ishfaq Ahmad, Manfred Huber, and Addison Clark. 2020. Object detection and sensory feedback techniques in building smart cane for the visually impaired: an overview. In Proceedings of the 13th ACM International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '20). Association for Computing Machinery, New York, NY, USA, Article 11, 1–7. https://doi.org/10.1145/3389189.3389201
28. Zou, Z., Chen, K., Shi, Z., Guo, Y., & Ye, J. (2023). Object Detection in 20 Years: A Survey. Proceedings of the IEEE, 111(3), 257–276. https://doi.org/10.1109/jproc.2023.3238524
29. Sanchez, S. a. G., Romero, H., & Morales, A. D. (2020). A review: Comparison of performance metrics of pre-trained models for object detection using the TensorFlow framework. IOP Conference Series: Materials Science and Engineering, 844, 012024. https://doi.org/10.1088/1757-899x/844/1/012024
30. Rezatofighi, H., Tsoi, N., Gwak, J., Sadeghian, A., Reid, I., & Savarese, S. (2019). Generalized Intersection Over Union: A Metric and a Loss for Bounding Box Regression. Computer Vision. https://doi.org/10.1109/cvpr.2019.00075
31. Ren, S., He, K., Girshick, R., & Sun, J. (2017). Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks. IEEE Transactions on Pattern Analysis and Machine Intelligence, 39 (6), 1137-1149. p.8 https://doi.org/10.1109/TPAMI.2016.257703.
32. Subhash, S., Srivatsa, P. N., Siddesh, S., Ullas, A., & Santhosh, B. (2020). Artificial Intelligence- based Voice Assistant. 2020 Fourth World Conference on Smart Trends in Systems, Security, and Sustainability (WorldS4). doi:10.1109/worlds450073.2020.921Subhash,

33. S., Srivatsa, P. N., Siddesh, S., Ullas, A., & Santhosh, B. (2020). Artificial Intelligence-based Voice Assistant. 2020 Fourth World Conference on Smart Trends in Systems, Security, and Sustainability (WorldS4). doi:10.1109/worlds450073.2020.921