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RESEARCH ARTICLE

Smart Assistive Shoe for Blind People Based on IoT

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Abstract: Innovations that help people with special needs are among the most important services scientific research can provide to serve societies. From this standpoint, the idea behind this work is to help blind and visually impaired people live their lives normally. For example, it is difficult for blind people to walk independently; they must rely on others in most of their daily activities. Walking on the streets is one of the most difficult problems that blind people face, as they cannot notice every obstacle on the road using a cane. From this perspective, the proposed model in this work served this sector of society and made it more effective. The model presented in our work includes designing a smart shoe based on Internet of Things technologies, a Mobile App, sensors, Raspberry Pi microcontrollers, a camera, and an integrated alarm device. The smart shoe offers a long-term solution for the visually impaired. Moreover, it will allow them to reach their destination without stress and independently. The model was tested under different conditions, and the results were satisfactory, as the accuracy reached 80%.

Keywords: TensorFlow, IoT, Raspberry Pi, mobile app, Firebase

1. Introduction

Blind and visually impaired (BVI) individuals face significant challenges in navigating their environment independently. Traditional aids such as guide canes and assistance dogs provide some support but remain limited in detecting obstacles effectively, especially in dynamic environments. Of the estimated 39 million blind people, 90% reside in low-income areas, and 82% of blind people are 50 years of age or older [1, 2]. However, using new technologies, the challenges faced by visually impaired people may be reduced [3]. The parallel evolution of wearable sensors, artificial intelligence (AI), Internet of Things (IoT) technology, and fifth-generation wireless technology has created a technological paradigm with the potential to change the lives of the visually impaired [4–6]. The development of smart accessories for visually impaired individuals is a crucial area of research and development that has the potential to significantly enhance their independence and safety. One of the key obstacles that visually impaired people experience is the capacity to navigate their environment safely and successfully. The importance of engineering features of smart shoe applications in the Internet of Health Things (IoHT) field to assist visually impaired individuals will also be discussed.

2. Literature Review

The challenge of independent navigation for BVI individuals has been a persistent focus of assistive technology research. While traditional tools like the white cane and guide dogs offer fundamental support, their limitations in detecting overhead obstacles, ground-level pitfalls, and dynamic hazards in complex environments are well-documented [1, 2]. The convergence of the IoT, AI, and affordable, powerful microcomputing platforms like the Raspberry Pi has catalyzed a new wave of innovative electronic travel aids (ETAs) [3, 4]. This section reviews the existing technological landscape, highlighting the evolution from simple sensor-based systems to more intelligent, multimodal solutions, and identifies the research gap that the current study aims to address.

2.1. Evolution of electronic travel aids (ETAs)

Early ETAs primarily relied on non-visual sensors, most commonly ultrasonic sensors, to detect obstacles. Parihar et al. [7] developed a smart cap utilizing an ATmega microcontroller and multiple ultrasonic sensors to provide auditory feedback to the user. While effective for basic obstacle avoidance, the system's reliance on a limited range of ultrasonic sensors makes it susceptible to missing obstacles in complex environments and provides no semantic information about the nature of the obstacle (e.g., a person vs. a wall). Similarly, Bhuniya et al. [8] proposed smart glasses using ultrasonic waves within a 5–6 meter range. A significant drawback of this and similar systems is their dependence solely on auditory feedback, which can be ineffective in noisy urban settings and does not discretely convey complex information.

To overcome the directional limitations of fixed sensors, some researchers incorporated mechanized components. Das et al. [9] designed a smart blind stick featuring an ultrasonic sensor rotated by a servomotor to cover a 180-degree area. While this

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increased the detection field, it introduced mechanical complexity and potential points of failure. The integration of a GPS module in their design was a step toward navigation, but GPS is notoriously unreliable indoors and in dense urban canyons, limiting the system's overall utility.

A notable approach focusing on wearable comfort was presented by Abu-Faraj et al. [10], who developed a system comprising rehabilitative shoes and spectacles. The shoes were embedded with ultrasonic transducers to detect ground-level obstacles and holes, providing tactile feedback via vibrating motors. The spectacles handled head-level obstacles. While this multi-point detection is commendable, the system's reliance on a separate, belt-worn control unit and the integration of multiple sensors and motors could lead to bulkiness, power consumption issues, and reduced comfort for prolonged use.

2.2. The integration of artificial intelligence and computer vision

The limitations of non-intelligent sensors have steered research toward incorporating AI and computer vision to provide richer environmental awareness. Maduri et al. [11] developed a headgear device employing a Convolutional Neural Network for real-time object detection, which could identify specific obstacles like poles and relay this information verbally through earphones. This represents a significant leap from mere obstacle detection to object recognition. However, implementing full-fledged deep learning models on embedded systems like the Raspberry Pi can be computationally intensive, leading to latency or high power consumption, which is a critical constraint for a wearable device.

Recent trends have focused on leveraging the IoT paradigm to offload processing or enhance functionality. Bhongade et al. [12] explored an IoT-enabled smart shoe, emphasizing connectivity. The integration of IoT allows for data logging, remote monitoring, and potentially accessing cloud-based AI services, which can be more powerful than those running locally on a constrained device. This points to a future where assistive devices are not standalone but part of a larger, connected ecosystem.

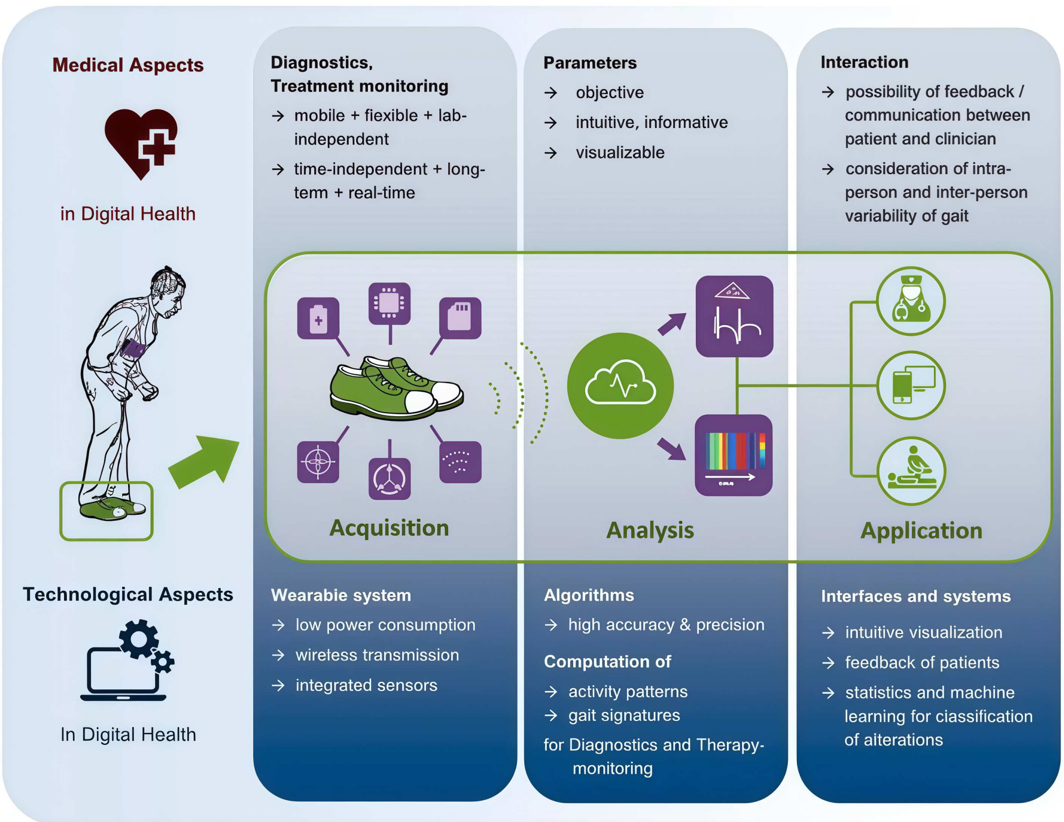
2.3. The niche for smart shoes and research gap

Within the domain of wearable assistive devices, smart shoes present a unique and ergonomic advantage. As noted by Eskofier et al. [13] in their overview of smart shoes for the IoHT, the foot is an ideal location for embedding sensors for gait and mobility analysis, as depicted in Figure 1.

Extending this concept to navigation, a shoe-based system is always in contact with the ground, making it inherently suited for detecting ground-level hazards like potholes, steps, and low-lying obstacles, a common cause of trips and falls. Furthermore, unlike handheld devices, it leaves the user's hands free, and unlike head-worn devices, it is less socially conspicuous and does not interfere with auditory cues from the environment.

Despite these advancements, a review of the literature reveals a distinct gap. Many existing systems excel in either simple obstacle detection (e.g., works by Alhija et al. [6] and Bhuniya et al. [8]) or advanced object recognition (e.g., work by Maduri et al. [11]), but few seamlessly integrate both in a cost-effective, lightweight, and power-efficient form factor suitable for all-day use. There is a lack of systems that combine reliable, low-power ultrasonic

Figure 1
Internet of Health Things for ambulatory gait monitoring



sensing for immediate proximity warnings with optimized, on-device AI for object identification, all while leveraging IoT for an enhanced user experience through a mobile application. Furthermore, many prototypes are not subjected to rigorous, multi-condition testing to validate their real-world accuracy and limitations.

Therefore, this study aims to fill this gap by designing and implementing a smart shoe that synthesizes the strengths of previous work while mitigating their weaknesses. The proposed system utilizes a Raspberry Pi to integrate ultrasonic sensors for reliable distance measurement and a camera with TensorFlow Lite for efficient, on-device object detection. By using TensorFlow Lite, we optimize the AI model for the embedded platform, addressing the computational burden noted in the work by Al-Kababji et al. [14]. The system's connectivity to a Firebase database and a custom Android app provides a dual interface: it offers real-time voice and haptic feedback to the BVI user and allows for remote monitoring by caregivers, creating a comprehensive assistive solution. This research thus contributes a novel, integrative approach to BVI navigation, prioritizing practicality, affordability, and user-centric design.

The novelty and innovation of our proposed project model lie in creating a unique assistance system for the BVI that combines IoT technologies and Android applications with the advanced processing of data and images via Raspberry Pi. The smart shoe features a low-cost design and is safer than the available devices for assisting the blind. Despite these technological advancements, many existing solutions suffer from limitations such as high costs, lack of user adaptability, and limited real-time processing capabilities. Additionally, most current devices focus on obstacle detection rather than comprehensive navigation assistance, leaving users vulnerable in complex and crowded environments.

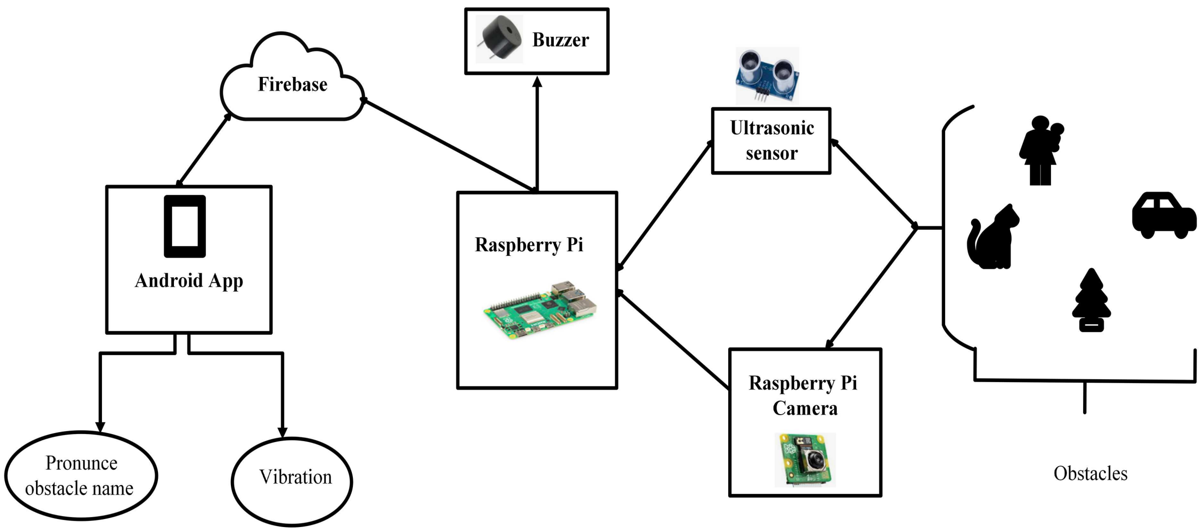
The integration of multiple technologies, including IoT, AI, and cloud computing, is crucial to developing a more efficient and user-friendly assistive system that can adapt to various environments. Our proposed system bridges the gap by combining real-time object detection, environmental awareness, and seamless user interaction through a mobile application. A major challenge in assistive technology adoption is affordability and ease of use. This research prioritizes cost-effective components while ensuring that the system remains intuitive and accessible to users with minimal training. Beyond its immediate benefits, this system has the potential to be expanded with additional AI-based features, such as pedestrian detection and integration with smart city infrastructure, to further enhance mobility for the visually impaired.

3. Research Methodology

The goal of this project is to create an assistive system that will enable blind individuals and those who are unable to travel without the assistance of a specific tool or another person. The technology will help the blind avoid obstacles by alerting them when they are present. An invention to assist the blind is the suggested smart shoe design. The IoT and AI are combined in the smart shoe project for the BVI to create a system that facilitates safe navigation. The project makes use of a Raspberry Pi with an ultrasonic sensor and camera that is linked to a Firebase database to send data to an Android app that shows the specifics of the surrounding area. The block diagram of the suggested model is shown in Figure 2.

The suggested solution depends on several essential libraries, such as Pyrebase for Firebase interaction and TensorFlow Lite for object recognition and image processing. The object detection model employed is MobileNet Single Shot Detector optimized for TensorFlow Lite, pre-trained on the Common Objects in Context dataset for efficient inference on Raspberry Pi. The model also has an ultrasonic sensor that measures the separation between the user and nearby obstructions. After that, TensorFlow Lite is used to create an AI-based object recognition model. To function effectively on the Raspberry Pi, the previously trained object detection model is uploaded and transformed into a suitable format. The model uses the photos taken by the camera to identify items in the

Figure 2
System block diagram



surrounding area. Following object detection, the Firebase Real-time Database receives pertinent data, such as the object's name and distance from the user. The setup connects the Raspberry Pi to Firebase using Pyrebase. Pyrebase makes data transmission and reception between devices easier. Firebase manages data retrieval and storage, making it available to other system components, such as the Android application. The Firebase database serves as a central repository for storing and exchanging data about both identified objects and distance measurements.

In contrast, an Android application is created to retrieve and show the Firebase data. A Google Services JSON file is included with the project to provide seamless communication between the Firebase backend and the application. In an intuitive user interface, the application shows details about the things it has recognized, such as their names and distance from the user. The user will always have the most up-to-date knowledge about their surroundings because the data is updated in real time.

3.1. Overall system connection

Implementing the proposed blind shoe model in this work depends on several hardware components and software requirements that will be discussed, along with their basic specifications, in this subsection.

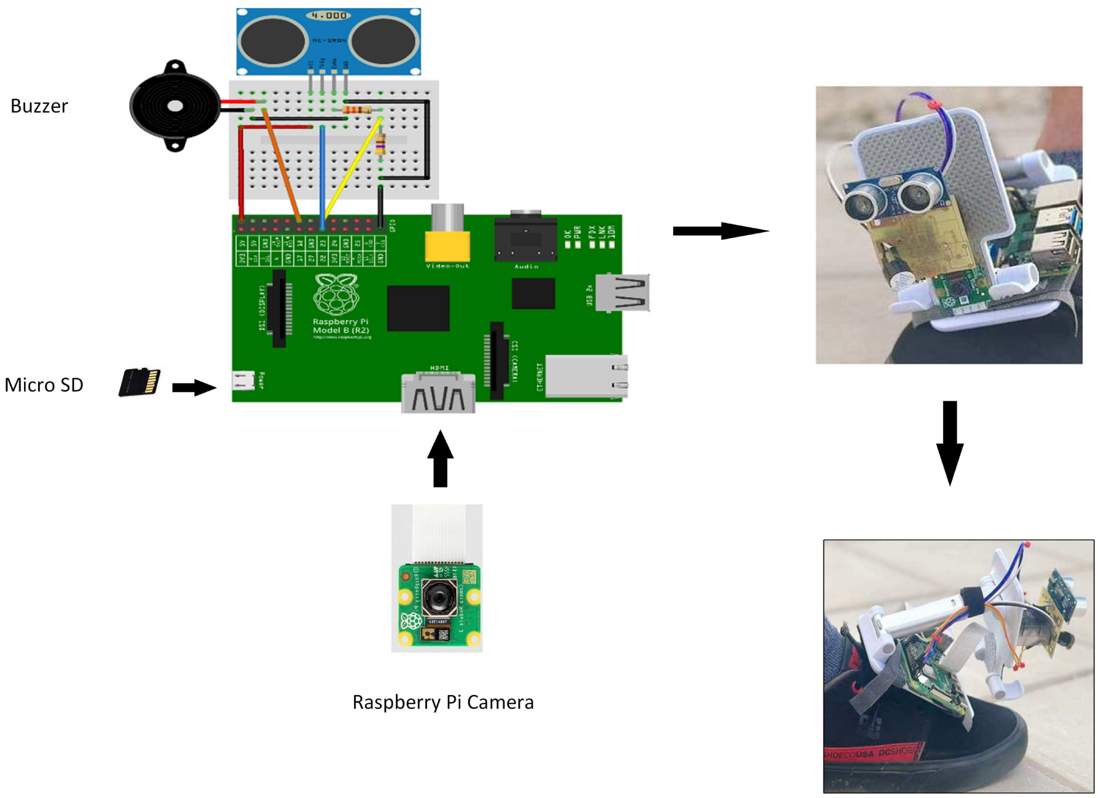
3.1.1. Hardware implementation

In this section, we will present the physical components on which the proposed model for this project depends, and the mechanism for connecting these components to build the proposed model will also be explained. The main components of this project can be listed as follows:

1) Raspberry Pi 4: The Raspberry Pi is the brain of the proposed model, running the UBUNTU operating system (UBUNTU is an open-source software operating system that runs from the desktop to the cloud and all things connected to the Internet). The operating system is installed on a memory card and works as a standalone device [15, 16].
2) Ultrasonic sensor: An HC-SR04 ultrasonic distance sensor is made up of two ultrasonic transducers, one of which functions as a transmitter, converting electrical signals into 40 KHz ultrasonic sound pulses. The other serves as a receiver, listening for transmitted pulses. When the receiver receives these pulses, it generates an output pulse whose width is proportionate to the distance from the object in front [17].
3) Raspberry Pi cam: The Raspberry Pi Camera Module v2 is a high-quality 8-megapixel camera that uses the Sony IMX219 image sensor to capture HD video and still images. It is a custom Raspberry Pi add-on board with a fixed focus lens. It supports 1080p30, 720p60, 640 × 480p90 video formats, and 3280 × 2464-pixel static pictures [18].
4) Power supply: The Raspberry Pi 4 requires a power supply that can produce around 3A of continuous current at 5V (estimated as 2.5A for the Pi and 500mA for USB devices).
5) Micro SD Card 16GB
6) Buzzer

As depicted in Figure 3, a completely developed prototype with an obstacle detection system is constructed. The ultrasonic

Figure 3
Overall system implementation



sensor is attached to the General Purpose Input/Output (GPIO) pins of the Raspberry Pi 4, which acts as the main controller and can measure distances and identify obstacles. To reduce the voltage, the ECHO pin is connected to a 1kΩ resistor. The CSI port is used to connect the Raspberry Pi Camera Module for object detection and real-time image capturing. To deliver audio notifications, a buzzer is connected to GPIO 18; if a passive buzzer is being utilized, a 330Ω resistor is used as in the proposed model. A 5V, 3A adaptor powers the system, guaranteeing steady functioning. Through an Android application, the gathered data is processed and sent to Firebase for real-time monitoring and navigation support.

3.1.2. Software implementation

This section will present the basic software programs that underpin this project, along with a detailed explanation of how these programs are linked and integrated to perform several essential tasks. These include reading and analyzing signals from sensors to detect obstacles facing the blind person and determining the distance from them, as well as processing captured images to determine the type of object or obstacle facing the blind person. Among the most important programs the project relies on are:

1) Raspberry Pi OS: The Raspberry Pi Imager is used to install Raspbian on an SD card, which is the quickest and most efficient method. The Raspberry Pi is then connected to the physical components [19].
2) Pyrebase: Pyrebase is a Python wrapper for the Firebase Realtime Database API [20]. It simplifies interacting with Firebase from Python applications, allowing you to easily read, write, and manage data in Firebase's NoSQL database [21]. Pyrebase provides a Pythonic interface for Firebase's features, making it convenient for developers working with Python to integrate Firebase functionality into their applications. To establish Pyrebase on Raspberry Pi OS for working with Firebase [22, 23]. The basic steps shown in the code in Figure 4 must be performed.
3) Android Studio: Android Studio, the official integrated development environment for Google's Android operating system, was employed in this effort to create a mobile application that would be directly connected to the blind shoe. Android apps can be built using Firebase as a backend service [24, 25]. Firebase provides a comprehensive set of tools and services that integrate seamlessly with Android app development, making it easier to build, manage, and scale apps.

Figure 4
Steps of Pyrebase configuration on Raspberry Pi OS

```
import pyrebase

config = {
    "apiKey": "MY_API_KEY",
      "authDomain": "MY_AUTH_DOMAIN",
    "databaseURL": "MY_DATABASE_URL",
    "storageBucket": "MY_STORAGE_BUCKET"
}
firebase = pyrebase.initialize_app(config)
db = firebase.database()




Writing data to Firebase
data = {"name": "John", "age": 30}
db.child("users").child("1").set(data)

Reading data from Firebase
users = db.child("users").get()
for user in users.each():
        print(user.val())
```

In this work, we used Kotlin, a modern programming language developed by JetBrains, the creators of IntelliJ IDEA and Android Studio. It is designed to be concise, expressive, and secure, with full compatibility with Java. Kotlin is widely used for Android application development and is also used in backend development, web development, and desktop applications [26]. Figure 5 shows the Graphical User Interface (GUI) of the Android application that was built. This application is an aid for the blind, as it produces a vibration to alert the blind person of the proximity of an obstacle, and it also produces a voice message with the name of the obstacle. The application is also a means for the relatives of the blind to follow them, track them, and know their location.

3.1.3. System flowchart

The system diagram shown in Figure 6 illustrates how the smart shoe works. When the system boots up, the Raspberry Pi is ready to receive commands from the mobile app. The operating mode is then selected, and the system begins reading the pin values of the ultrasonic sensor. The Pi's camera then begins capturing and processing images to detect objects. When an object is detected, the system sends the data to Firebase. The type and distance of the obstacle are identified, and all details are displayed on the app's GUI. A buzzer is activated if an object or obstacle is detected less

Figure 5
Android application GUI

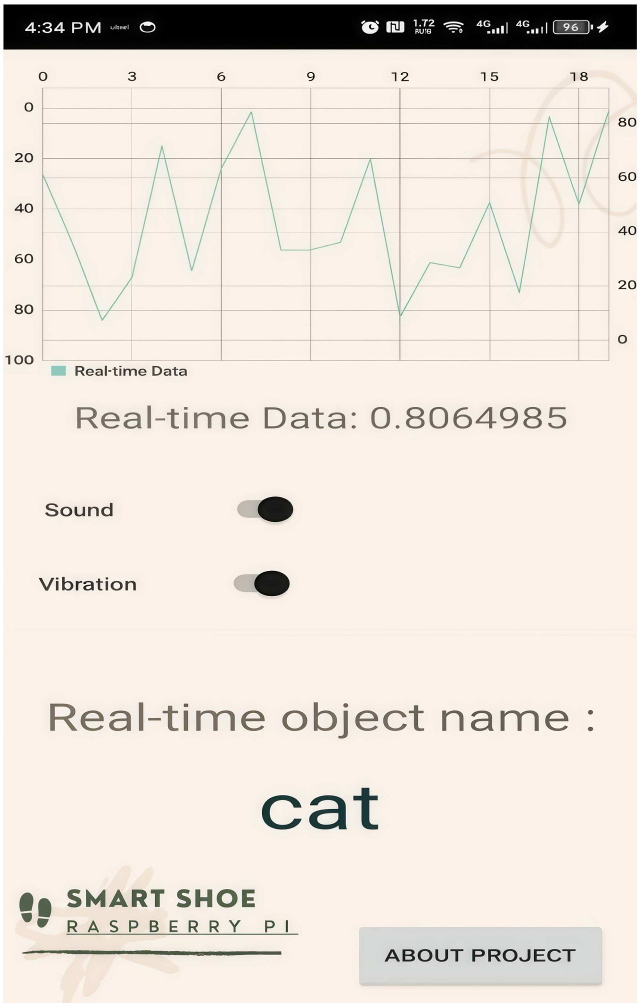
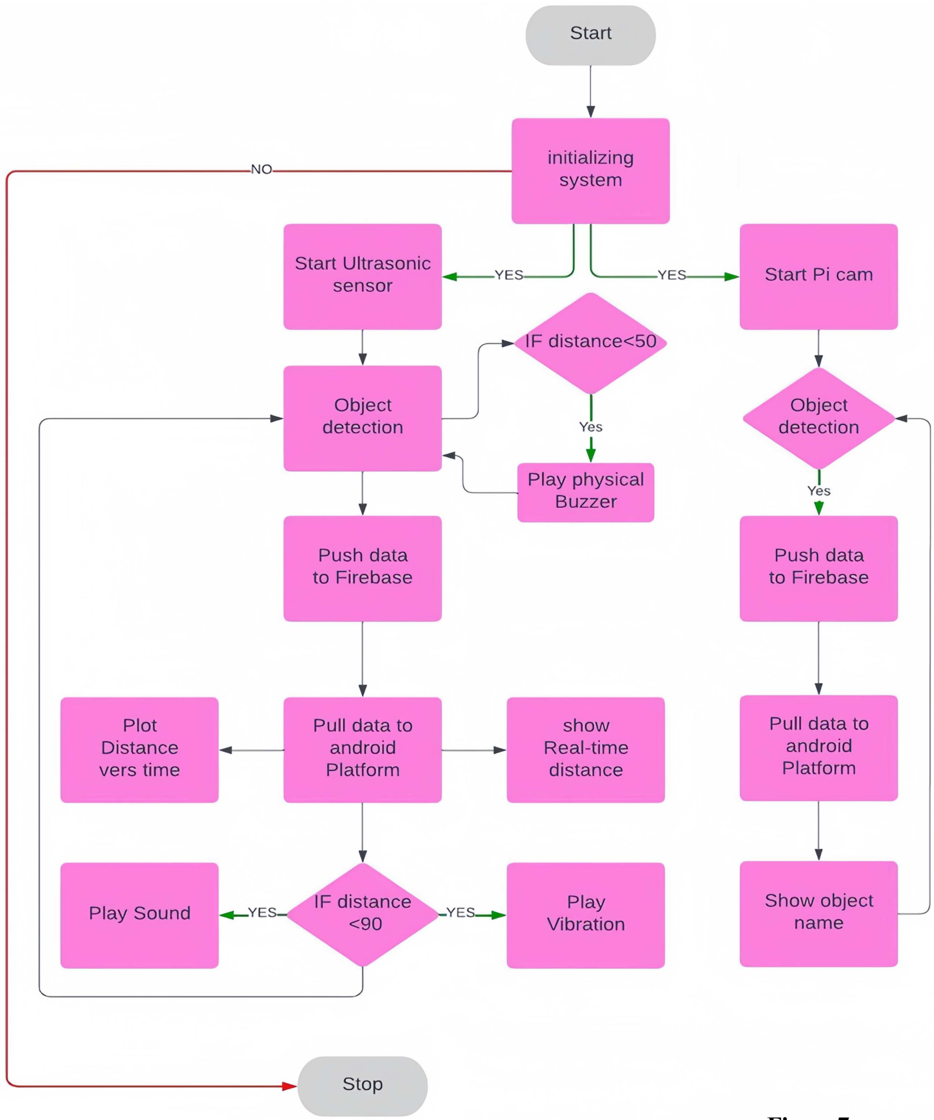


Figure 6
System flowchart



than 50 cm away, and the Android app speaks the name of the detected object.

4. Model Testing and Validation

Testing the proposed model in several conditions reveals the accuracy of the system and its ability to detect obstacles, inform the blind person of the type of obstacles, and alert them promptly. In this work, we note that testing the system reveals the accuracy with which it works, as the distance that the body is away from is determined by the ultrasonic sensor that sends signals to the system to be analyzed and sent to Firebase and retrieved according to the distance measured from the sensor.

The Android application receives the data and then represents it in a graph over time and tracks the detected objects, as depicted in Figure 7. The blind person's family can follow the data by installing the same application on their mobile phones. In this

Figure 7
Real-time data chart

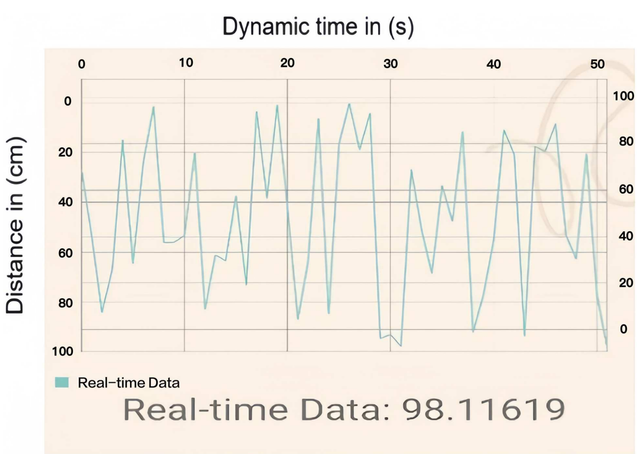


Table 1
System verification

Test ID	Test case description	Test data/inputs	Expected result	Number of successful	Comments/difficulties
T001	Ultrasonic sensor detects obstacles at a distance	Obstacle at 50 cm, 100 cm, 150 cm	Distances of 50 cm, 100 cm, and 150 cm are shown correctly	8 (80%)	Sensor accuracy is off by ±5 cm beyond 100 cm; check calibration
T002	Ultrasonic sensor triggers vibration alert	Obstacle at 40 cm	Vibration motor activates	10 (100%)	Worked as expected
T003	Ultrasonic sensor triggers sound alert	Obstacle at 30 cm	"Beeb" sound plays	10 (100%)	The issue with sound playback or triggering system
T004	Object detection accuracy using the camera	Static objects: ball, cup, pen	Objects correctly identified and displayed	7 (70%)	Detection of missed smaller objects; optimize for object size and shape
T005	Ultrasonic sensor and camera work together	Object 80 cm away, obstacle at 40 cm	Detects both obstacle and object	8 (80%)	Simultaneous operation affecting camera performance
T006	The system integrates with Firebase for data logging	Sensor data: 60 cm, Object: "Ball"	Data sent to Firebase with distance and object	10 (100%)	Smooth integration with Firebase
T007	Blind user navigation with smart shoe	User-guided in a small room (3 m × 3 m)	The user receives alerts (vibration, sound)	10 (100%)	A user reported clear alerts; effective guidance
T008	Outdoor environment testing	Sunny weather, temperature 25°C	The system works without issue	6 (60%)	Device overheats outdoors; improve heat management
T0 09	Outdoor environment testing	Rainy weather	The system works with some issues	6 (50%)	The most obvious issue is raindrops adhering to the lens, which obstruct the field of view and make the image blurry or unfocused.
T10	Outdoor environment testing	Foggy weather	The system works with some issues	6 (50%)	Fog affected the camera's performance, resulting in blurry, obscured, or completely blocked images in some cases due to temperature differences between the camera surface and the external environment.
T11	The camera captures objects in motion	Moving ball at 1 m/s	Object detected and identified	7 (70%)	Motion detection struggles with identifying fast-moving objects
Accuracy (AVG)				80%	

work, the proposed model was examined in several conditions, such as its ability to sense fixed or moving objects, or test it at night or during the day. All conditions are described in Table 1. The innovative system proved its ability to detect obstacles and alert the blind person by pronouncing the name of the object and identifying the object that is far away with high accuracy, reaching an average of 80%, as shown in Table 1.

5. Discussion

System validation tests demonstrate the smart shoe's effectiveness in assisting visually impaired individuals through real-time obstacle detection, object recognition, and cloud data capture. With an overall accuracy of 80%, the system proved to be a reliable mobility aid, particularly for indoor navigation,

Table 2
Comparison of the suggested models with those of earlier research

Study/year	Technologies
[2]/2019	Arduino UNO, ultrasonic sensors, Li-Fi
[3]/2022	Arduino UNO, ultrasonic sensors, water sensor
[7]/2020	ATmega microcontroller, Arduino board, three ultrasonic sensors, and a buzzer
[8]/2020	Arduino, IVRS, microcontroller, ultrasonic, voice-assistant
[10]/2012	Microcontroller, ultrasonic sensors, buzzer
[12]/2022	NodeMCU, ultrasonic sensors, LDR, GPS
[13]/2017	Arduino UNO, ultrasonic sensors, IVR system
Proposed	IoT, Mobile App, ultrasonic sensors, Raspberry Pi 4, camera, TensorFlow, Firebase

achieving 100% accuracy in guiding users, ensuring timely feedback for safe movement. However, the system's ability to detect fast-moving objects and retain accuracy beyond 100 cm varied depending on the environmental conditions. Furthermore, overheating problems that affected accuracy were discovered during outdoor testing. Future developments will concentrate on heat dissipation, AI model optimization, sensor recalibration, and resource allocation enhancements to avoid system lag in order to overcome these obstacles. Notwithstanding these drawbacks, the smart shoe is a viable way to improve the mobility and independence of people with visual impairments.

On the other hand, when comparing the performance and novelty of the proposed model presented in this paper, it can be noted, as shown in Table 2, that the proposed model outperforms its counterparts according to the literature studies mentioned in the introduction. This is attributed to the innovation and excellence of this work, which lies in using multiple technologies, including IoT, AI, and cloud computing, to build a user-friendly assistive system that can adapt to various environments.

6. Conclusion and Future Work

In order to improve mobility for those with visual impairments, this study introduces a smart shoe prototype that combines Raspberry Pi and IoT technology. To identify obstructions and give real-time feedback, the system combines ultrasonic sensors, a camera, and a vibration alarm mechanism. An average accuracy of 84.44% was shown in the trial findings, proving the model's usefulness in aiding navigation.

The results show a number of significant ramifications. Better decision-making and environmental awareness are two major benefits of integrating AI-based object identification over conventional ultrasonic-only systems. Additionally, effective data logging and upcoming AI-driven improvements are made possible by the real-time cloud connectivity. Given its excellent indoor precision, the system has a great chance of being used in controlled settings like residences, workplaces, and public spaces. However, problems including restricted motion detection, trouble recognizing small objects, and overheating-related problems with outside performance point to areas that need work.

Future improvements could involve completely integrating the system with a mobile app that uses pre-loaded maps to provide more sophisticated navigation support. Additionally, a Raspberry Pi night vision camera can greatly increase detection accuracy in low-light conditions when used in place of the existing camera. Additional improvements in heat dissipation, sensor calibration, and real-time processing speed will improve overall performance and increase the system's dependability under a variety of circumstances. The suggested changes will guarantee that smart shoes develop into a more intelligent, accessible, and adaptive solution for people with visual impairments, promoting increased safety and independence in day-to-day activities.

7. Limitations

Smart shoes are a cutting-edge form of assistive technology; they have several drawbacks. Their high price is a significant disadvantage, making them less affordable for many consumers. Additionally, they rely on batteries, which means that they need to be regularly charged. If the battery runs out, the safety features stop working. Additionally, performance may be impacted by weather conditions like rain or muddy terrain, and their sensors may not always detect obstacles accurately in busy or complicated surroundings. Functionality might also be affected by connectivity problems, particularly when using smartphone apps or Bluetooth. Additionally, these shoes need upkeep and may be damaged by regular outside use, necessitating expensive repairs.

8. Future Works and Improvements

Future research and development of smart shoes for blind people can concentrate on a number of important topics. Improving sensor accuracy is essential for dependable obstacle detection in challenging settings, such as congested areas and uneven terrain. Enhancing battery life and energy efficiency will guarantee continuous use and lessen reliance on frequent charges. Compared to basic vibrations, integrating multimodal feedback systems like voice guiding, haptic signals, and real-time mapping can offer deeper navigation support. To make the shoes resistant to rain, dust, and challenging outdoor situations, weatherproofing and durability should be given top priority. A larger audience will be able to use the technology by lowering costs through mass production and inexpensive materials. The user experience can be greatly enhanced by integrating IoT connectivity for real-time updates and machine learning for adaptive guidance.

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Ethical Statement

This study was reviewed by the Graduation Projects Committee of the Department of Communications and Computer Engineering at Al-Ahliyya Amman University, and no formal ethical approval was required under institutional regulations. All authors adhere to strict data privacy protocols and the IEEE Code of Ethics.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Muneera Altayeb: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Supervision, Project administration. **Laith Al-mandeel:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – review & editing, Visualization. **Areen Arabiat:** Validation, Resources, Data curation, Writing – review & editing, Visualization.

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