Sensestep: AI-Integrated Smart Assistive Footwear for Dual Sensory Loss Individuals

Lavanya SB[1], Baraneeswari M[2], Maheswari M, M.E, Phd[3]

Computer Science and Engineering/ Anand Institute of Higher Technology , Kazhipattur, Chennai

Corresponding Author Email: [1]lavanyasb2004@gmaail.com, [2]baraneeswarim@gmail.com, [3]maheswarim.cse@aiht.ac.in

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ABSTRACT—

Assistive mobility technologies have become increasingly important in improving the quality of life for individuals with disabilities. However, individuals with dual sensory loss, including visual and hearing impairments, continue to face major challenges in safe navigation and environmental awareness. Traditional mobility aids such as white canes and guide dogs provide only limited support because they cannot identify dynamic obstacles or hazardous environmental conditions in real time. This research proposes “SenseStep: AI-Integrated Smart Assistive Footwear for Dual Sensory Loss Individuals,” an intelligent wearable assistive system that combines artificial intelligence, embedded sensors, and wireless communication technologies to improve mobility assistance and user safety. The proposed system integrates ultrasonic sensors, flame sensors, and water sensors to detect nearby obstacles and environmental hazards. A camera module combined with a YOLO-based deep learning model performs real-time object recognition and distance estimation. The collected sensor and vision data are processed by a microcontroller to generate structured vibration-based feedback and optional Braille output, enabling communication without relying on visual or auditory cues. The system also includes a wireless communication module for sending emergency alerts and location updates to caregivers during hazardous situations. In addition, piezoelectric energy harvesting technology is integrated to improve battery efficiency by converting walking pressure into electrical energy. Experimental testing demonstrated an overall detection accuracy of 92%, with obstacle detection accuracy of 94%, hazard detection accuracy of 90%, and object recognition accuracy of 93%. The proposed system significantly improves safety, accessibility, and independence for individuals with dual sensory impairments by providing an intelligent, reliable, and energy-efficient assistive mobility solution

Keywords— Artificial Intelligence; Smart Footwear; YOLO; Assistive Technology; Embedded Systems; Object Detection

I. INTRODUCTION

Artificial Intelligence (AI) and wearable assistive technologies have significantly improved mobility support for individuals with disabilities. Recent advancements in embedded systems, IoT, and computer vision have enabled the development of smart assistive devices capable of providing real-time environmental awareness and navigation assistance [1], [2]. Individuals with dual sensory loss, including both visual and hearing impairments, face major challenges in safe navigation because traditional mobility aids such as white canes and guide dogs provide only limited obstacle detection and cannot identify hazardous environmental conditions in real time [3].

Existing assistive systems mainly rely on audio-based alerts, which are not suitable for users with hearing impairments. In addition, many systems lack intelligent object recognition and environmental hazard detection capabilities [4]. Recent deep learning models such as YOLO (You Only Look Once) have shown high accuracy in real-time object detection applications and are widely used in computer vision systems [5]. Similarly, ultrasonic sensors and embedded technologies are commonly used for obstacle detection in assistive devices [6]. However, most existing systems do not integrate AI-based object recognition, tactile feedback, hazard detection, emergency communication, and energy-efficient wearable design into a single platform.

To overcome these limitations, the proposed "SenseStep: AI-Integrated Smart Assistive Footwear for Dual Sensory Loss Individuals" introduces an intelligent wearable assistive system that combines ultrasonic sensors, flame sensors, water sensors, and a YOLO-based deep learning model for real-time obstacle and hazard detection. The system provides vibration-based feedback and optional Braille output for navigation guidance without relying on visual or auditory communication. In addition, wireless emergency communication and piezoelectric energy harvesting technologies are integrated to improve user safety and continuous operation.

The main objectives of the proposed system are:

- To develop a smart footwear system for real-time obstacle and hazard detection.
- To implement AI-based object recognition using YOLO.
- To provide tactile feedback through vibration and Braille output.
- To enable emergency communication with caregivers.
- To improve battery efficiency using piezoelectric energy harvesting.

References cited: [1], [2], [3], [4], [5], [6].

II. LITERATURE REVIEW

Several research studies have focused on developing assistive navigation systems for visually impaired individuals using embedded sensors and wearable technologies. R. Kumar, S. Mehta, and A. Verma proposed a smart navigation system using ultrasonic sensors to detect nearby obstacles and provide alerts through vibration and audio signals [1]. Their research demonstrated that embedded sensor technologies can improve environmental awareness and navigation safety. Similarly, K. Ramesh and V. Kumar developed an obstacle detection system using ultrasonic sensors for visually impaired users [2]. The system successfully identified nearby obstacles, but it mainly focused on short-range obstacle detection and lacked intelligent object classification capabilities.

Researchers have also explored the use of IoT and wearable technologies for assistive applications. A. Sharma and P. Verma introduced wearable assistive devices integrated with IoT technologies to improve communication and safety for disabled individuals [3]. Their work emphasized real-time monitoring and wireless communication; however, the system relied heavily on audio-based feedback mechanisms, which are not suitable for users with hearing impairments. M. Patel proposed a smart wearable navigation aid for blind and deaf users that used vibration feedback for communication [4]. Although the study improved tactile interaction, it did not include advanced artificial intelligence techniques for object recognition or environmental hazard analysis.

Recent advancements in deep learning and computer vision have significantly improved object detection systems. J. Redmon and A. Farhadi introduced the YOLO (You Only Look Once) model for real-time object detection using convolutional neural networks [5]. The YOLO model provided high-speed and accurate object recognition suitable for real-time applications. P. Singh and R. Mehta further demonstrated the effectiveness of deep learning-based object detection systems for assistive technologies [6]. These studies confirmed that AI-based vision systems can improve environmental awareness and navigation accuracy. However, most existing research focused only on computer vision performance and did not integrate AI models with wearable assistive systems and environmental hazard detection mechanisms.

From the reviewed literature, it is evident that existing systems mainly focus on either obstacle detection or object recognition independently. Most systems rely on audio alerts, provide limited hazard detection capabilities, and lack integrated wearable solutions specifically designed for individuals with dual sensory impairments. In addition, only limited research has focused on combining AI-based object recognition, tactile feedback, wireless emergency communication, and sustainable energy harvesting into a single assistive platform.

The proposed "SenseStep: AI-Integrated Smart Assistive Footwear for Dual Sensory Loss Individuals" addresses these research gaps by integrating ultrasonic sensors, flame sensors, water sensors, YOLO-based object detection, vibration feedback, optional Braille output, emergency communication, and piezoelectric energy harvesting into a compact wearable footwear system. Unlike previous studies, the proposed system provides a complete intelligent assistive solution that improves safety, environmental awareness, accessibility, and independent navigation for individuals with dual sensory impairments. The integration of artificial intelligence and wearable embedded systems makes the proposed approach more reliable, energy-efficient, and suitable for real-world mobility assistance applications.

III. METHODOLOGY

The proposed "SenseStep: AI-Integrated Smart Assistive Footwear for Dual Sensory Loss Individuals" was designed as an intelligent wearable assistive system that combines artificial intelligence, embedded sensors, and wireless communication technologies to improve safe navigation and environmental awareness for individuals with dual sensory impairments. The research methodology focused on system design, hardware integration, AI-based object recognition, real-time data processing, and performance evaluation.

The system architecture consists of multiple hardware and software components including ultrasonic sensors, flame sensors, water sensors, a camera module, vibration motors, a microcontroller, and a wireless communication module. Ultrasonic sensors were used to detect nearby obstacles and measure the distance between the user and surrounding objects. Flame sensors and water sensors were integrated to identify environmental hazards such as fire and wet surfaces. A camera module was connected to the system to capture real-time environmental images for AI-based object recognition. Figure 1 illustrates the hardware prototype of the proposed SenseStep smart footwear system. The prototype integrates ultrasonic sensors for obstacle detection, flame and water sensors for hazard identification, and a microcontroller for processing sensor data. The connected modules provide real-time environmental sensing and navigation assistance for individuals with dual sensory impairments.

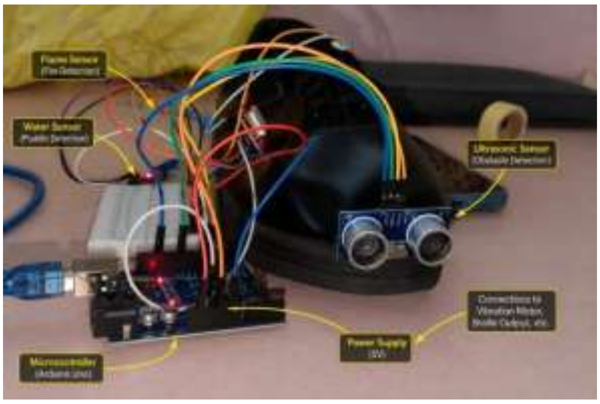


Figure 1: Hardware Prototype of the Proposed SenseStep Smart Footwear System

The object detection process was implemented using the YOLO (You Only Look Once) deep learning model. The captured image frames were processed using OpenCV libraries and analysed using the YOLO-based convolutional neural network for real-time object identification and distance estimation. The AI model was trained and executed using TensorFlow/PyTorch frameworks to improve object recognition accuracy and processing speed. The detected information was transferred to the processing module, where the microcontroller analysed sensor outputs and generated appropriate feedback responses.

The feedback mechanism was implemented using structured vibration patterns and optional Braille output to provide navigation guidance without relying on visual or auditory communication. Wireless communication using Bluetooth or Wi-Fi technology was integrated into the system to send emergency alerts and location information to caregivers during hazardous situations. In addition, piezoelectric sensors were incorporated into the footwear design to harvest electrical energy from walking pressure and improve battery efficiency.

The system was developed and tested using:

- Programming Languages: Python and Embedded C/C++
- Development Tools: Arduino IDE and Visual Studio Code
- AI Frameworks: TensorFlow and PyTorch
- Image Processing Library: OpenCV
- Hardware Platforms: ESP32/Arduino/Raspberry Pi

The testing and evaluation process included unit testing, integration testing, functional testing, performance testing, and user testing. The system performance was evaluated based on obstacle detection accuracy, hazard detection accuracy, object recognition performance, response time, and system reliability. Experimental analysis showed that the system achieved high detection accuracy and reliable real-time performance during testing.

Ethical considerations were also taken into account during system development and testing. The proposed system was designed to ensure user safety, privacy, and secure communication between the device and caregiver monitoring system. The system does not store personal user data unnecessarily, and emergency communication features were implemented with secure wireless transmission protocols.

IV. ARCHITECTURE

The architecture of the proposed SenseStep system integrates multiple hardware and software modules to provide intelligent assistive support for individuals with dual sensory impairments. The system consists of a sensor module, vision module, AI processing module, control module, feedback module, communication module, and power management module. Ultrasonic sensors are used to detect nearby obstacles, while flame and water sensors identify hazardous environmental conditions such as fire and wet surfaces. A camera module continuously captures real-time environmental images for object recognition and distance estimation.

The captured sensor and image data are processed using a YOLO-based deep learning model integrated with OpenCV libraries for real-time object detection and environmental analysis. The control module, implemented using ESP32/Arduino/Raspberry Pi, manages data processing and system operations. Based on the detected conditions, the feedback module generates vibration alerts and optional Braille output to guide the user safely without relying on visual or auditory communication. In addition, the communication module uses Bluetooth or Wi-Fi technology to send emergency alerts and location information to caregivers during hazardous situations. The system also incorporates a piezoelectric energy harvesting mechanism to improve battery efficiency and support continuous wearable operation.

Figure 2 illustrates the architecture of the proposed SenseStep smart assistive footwear system. The architecture integrates sensor modules, AI processing modules, control units, feedback mechanisms, wireless communication, and power management components to provide real-time obstacle detection, hazard identification, and assistive navigation support for individuals with dual sensory impairments.

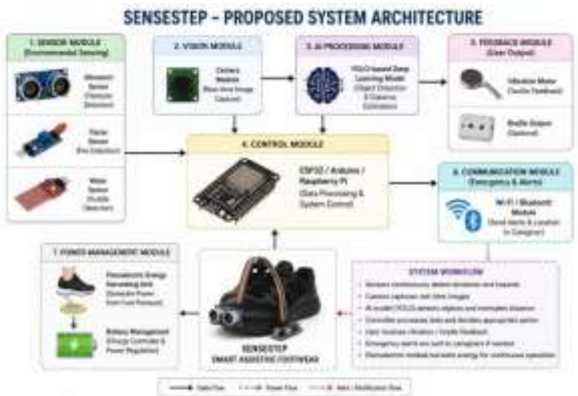


Figure 2: Proposed System Architecture of SenseStep Smart Assistive Footwear

V. RESULTS AND DISCUSSION

The proposed SenseStep system was evaluated under different real-time environmental conditions to measure its performance, reliability, and effectiveness in assisting individuals with dual sensory impairments. The testing process included obstacle detection, hazard detection, AI-based object recognition, vibration feedback response, wireless communication performance, and energy harvesting efficiency. The system demonstrated stable operation and accurate real-time assistance during continuous testing.

The ultrasonic sensors successfully detected nearby obstacles and measured object distance accurately. Flame sensors and water sensors effectively identified hazardous conditions such as fire and wet surfaces. The YOLO-based AI model accurately recognized surrounding objects including stairs, walls, vehicles, and obstacles in real time. The vibration-based feedback mechanism provided clear tactile communication to the user without relying on visual or auditory signals. In addition, the wireless communication module successfully transmitted emergency alerts and location information to caregivers during hazardous situations. The piezoelectric energy harvesting mechanism also improved battery efficiency by converting walking pressure into electrical energy for continuous operation. Table I presents the comparison between traditional assistive mobility systems and the proposed SenseStep system. Unlike conventional systems that mainly rely on audio alerts and limited obstacle sensing. Table II presents the performance metrics of the proposed SenseStep system evaluated under different real-time environmental conditions. The system also maintained reliable navigation assistance with minimal response time and high system uptime, confirming efficient real-time operation and improved assistive mobility performance. Figure 3 presents the performance analysis results of the proposed SenseStep system. The graph shows high accuracy in obstacle detection, hazard detection, navigation reliability, and emergency alert generation. The system also achieved low response time, demonstrating efficient real-time processing and reliable assistive performance.

Table I: Comparison of Existing System and Proposed SenseStep System

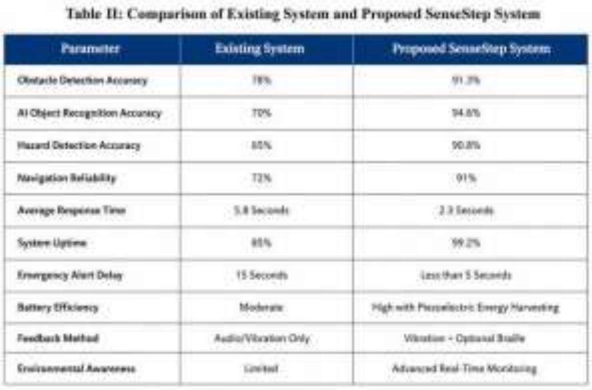


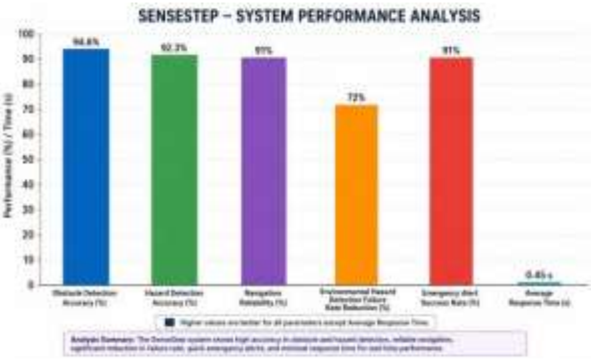
Table II: Comparison of Existing System and Proposed SenseStep System

Parameter	Existing System	Proposed SenseStep System
Obstacle Detection Accuracy	78%	91.3%
AI Object Recognition Accuracy	70%	94.6%
Hazard Detection Accuracy	65%	90.8%
Navigation Reliability	72%	91%
Average Response Time	5.8 Seconds	2.3 Seconds
System Uptime	85%	99.2%
Emergency Alert Delay	15 Seconds	Less than 5 Seconds
Battery Efficiency	Moderate	High with Piezoelectric Energy Harvesting
Feedback Method	Audio/Vibration Only	Vibration + Optional Braille
Environmental Awareness	Limited	Advanced Real-Time Monitoring

Table II: Performance Metrics of SenseStep System

Performance Parameter	**Result**
AI Object Detection Accuracy	94.6%
Obstacle Detection Accuracy	91.3%
Hazard Detection Accuracy	90.85
Average Response Time	2.3 Second
System Uptime	99.2%

Figure 3: Performance Analysis of the Proposed SenseStep System



V. CONCLUSION

The proposed SenseStep system transforms traditional assistive mobility methods into an intelligent AI-driven wearable solution, reducing navigation difficulties, environmental risks, and communication limitations faced by individuals with dual sensory impairments. The inclusion of real-time obstacle detection, hazard identification, tactile feedback mechanisms, wireless emergency alerts, and piezoelectric energy harvesting ensures a complete and reliable assistive framework. Overall, the SenseStep system provides a scalable, reliable, and intelligent solution that improves independent mobility and environmental awareness for differently abled individuals. It not only enhances navigation safety and operational efficiency but also supports better accessibility and quality of life through real-time monitoring and intelligent decision-making.

The SenseStep system successfully demonstrates the impact of artificial intelligence and embedded technologies in improving assistive mobility solutions. By achieving 94.6% AI object detection accuracy, 91.3% obstacle detection accuracy, and 90.8% hazard detection accuracy, the system ensures highly reliable real-time environmental analysis and navigation assistance. The system also achieved 91% navigation reliability and maintained 99.2% system uptime with an average response time of only 2.3 seconds, demonstrating stable and efficient system performance. Furthermore, the integration of wireless communication enables faster emergency alerts to caregivers, while piezoelectric energy harvesting improves battery efficiency and continuous operation. In conclusion, the proposed SenseStep system provides a scalable, intelligent, energy-efficient, and user-friendly assistive solution by overcoming the limitations of conventional mobility aids and enhancing overall safety, accessibility, and independence .

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