International Journal of Current Research and Modern Education (IJCRME)
International Peer Reviewed - Refereed Research Journal, Website: www.crystalpen.in
Impact Factor: 6.925, ISSN (Online): 2455 - 5428, Volume 11, Issue 1, January - June, 2026

AIRAVAT: A SMART LOW-COST ASSISTIVE DEVICE FOR VISUALLY IMPAIRED

M. Parameswari*, K. Hariprasath, J. Jayakarthick**, K. Logeshwaran** & M. Manikandan****

* Professor & Head, Department of Electrical and Electronics Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, Tamil Nadu, India

** UG Student, Department of Electrical and Electronics Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, Tamil Nadu, India

Cite This Article: M. Parameswari, K. Hariprasath, J. Jayakarthick, K. Logeshwaran & M. Manikandan, "AIRAVAT: A Smart Low-Cost Assistive Device for Visually Impaired", International Journal of Current Research and Modern Education, Volume 11, Issue 1, January - June, Page Number 73-78, 2026.

Type of Review: Peer Reviewed as per |C|O|P|E| Guidance.

DOI: https://doi.org/10.5281/zenodo.19812114

Abstract:

Visually impaired individuals rely heavily on assistive technologies to navigate their surroundings safely, yet many available solutions remain expensive, complex, or inaccessible in low-resource settings. This project proposes a smart, low-cost assistive device that utilizes embedded sensing and feedback technologies to enhance mobility and situational awareness. The system incorporates ultrasonic sensors for multi-directional obstacle detection, a microcontroller for real-time signal processing, and haptic vibrators or audio output for intuitive feedback. Additional features such as low-power operation, compact ergonomics, and optional wireless connectivity increase usability and functionality. The device was designed with cost minimization in mind, using off-the-shelf components and open-source hardware. Prototype evaluations conducted in diverse indoor and outdoor environments demonstrate accurate detection of obstacles up to several meters, rapid response times, and high user acceptance. The results indicate that the proposed device offers an effective, affordable, and user-friendly mobility aid that can significantly improve independence and safety for visually impaired individuals.

Key Words: Assistive Device, Visual Impairment, Ultrasonic Sensors, Obstacle Detection, Microcontroller, Haptic Feedback, Audio Feedback, Low-Cost, Mobility Aid, Embedded System

Introduction:

Vision plays an essential role in human life, enabling people to perceive, understand, and interact with their surroundings. For individuals who are visually impaired or completely blind, performing even simple daily tasks becomes challenging. According to the World Health Organization (WHO), more than 285 million people worldwide suffer from some form of visual impairment, of whom nearly 39 million are completely blind. These individuals face physical, social, and psychological barriers that limit their mind. Assistive technology has emerged as a crucial area of innovation aimed at empowering people with disabilities. Devices that combine electronics, sensors, and artificial intelligence can now provide sensory feedback and enhance independent mobility. Among these innovations, smart assistive devices offer an affordable and effective way for visually impaired individuals to navigate safely through unknown environments. Traditional mobility aids such as the white cane and guide dogs have been in use for decades. The white cane is simple, lightweight, and inexpensive, but its detection range is limited to obstacles directly in front of the user and within ground level. Guide dogs, though effective, involve significant costs, care, and training. In developing countries, these limitations make advanced solutions inaccessible to most visually impaired people. With rapid developments in embedded systems, Internet of Things (IoT) technologies, and miniaturized sensors, it has become feasible to design low cost electronic aids that can detect obstacles and alert users through vibration or sound. The motivation for this project arises from the need to provide an affordable, portable, and reliable device that bridges the gap between costly commercial products and basic mechanical tools.

Related Work:

Many researchers have focused on enhancing traditional mobility aids by integrating electronic components into white canes. These smart canes typically use ultrasonic or infrared sensors to detect nearby obstacles and provide feedback through vibration or sound. While such systems improve safety, some designs are limited by short detection ranges, lack of multi-directional sensing, or bulky hardware that reduces user comfort. Efforts have been made to improve ergonomics and portability, but balancing performance with affordability remains a key challenge.

Recent advancements have introduced vision-based assistive systems that utilize cameras and image processing algorithms to recognize objects, text, and even human faces. These systems often rely on machine learning techniques to provide detailed environmental information. However, they require high computational power, stable lighting conditions, and are generally more expensive, making them less suitable for widespread use in low-resource environments. Additionally, privacy concerns and processing delays can further limit their practical adoption.

Wearable assistive devices, such as smart shoes, belts, and vests, have also been proposed to provide spatial awareness through distributed sensors. These systems can detect obstacles at different heights and directions, offering a more comprehensive understanding of the surroundings. Despite their advantages, they may require users to adapt to unfamiliar forms of feedback, and prolonged use can sometimes lead to discomfort or increased cognitive load.

System Architecture:

The system consists of three main parts: sensors, a microcontroller, and a feedback unit. Ultrasonic sensors detect obstacles around the user and send signals to the microcontroller, which processes the data in real time. Based on the distance of obstacles, the system alerts the user through vibration or audio, helping them move safely and easily.

- Perception Layer: The perception layer is responsible for sensing the environment around the user. It uses ultrasonic sensors to detect obstacles in different directions by measuring the distance to nearby objects. This layer continuously collects real-time data and sends it to the processing unit for further analysis, enabling accurate awareness of surroundings.
- Processing Layer: The processing layer receives data from the sensors and analyzes it in real time using a microcontroller. It calculates the distance to obstacles and decides when an alert should be triggered. This layer ensures quick and accurate decisions to help the user respond safely.
- Communication Layer: The communication layer delivers the processed information to the user through feedback mechanisms. It uses vibration motors or audio signals to indicate the presence and distance of obstacles. This layer ensures that the user receives clear and immediate alerts for safe navigation.
- Application Layer: The application layer defines how the system is used in real-life situations. It helps visually impaired users navigate safely in both indoor and outdoor environments by providing real-time obstacle detection and alerts. This layer focuses on improving mobility, independence, and overall safety of the user.

System Design and Methodology:

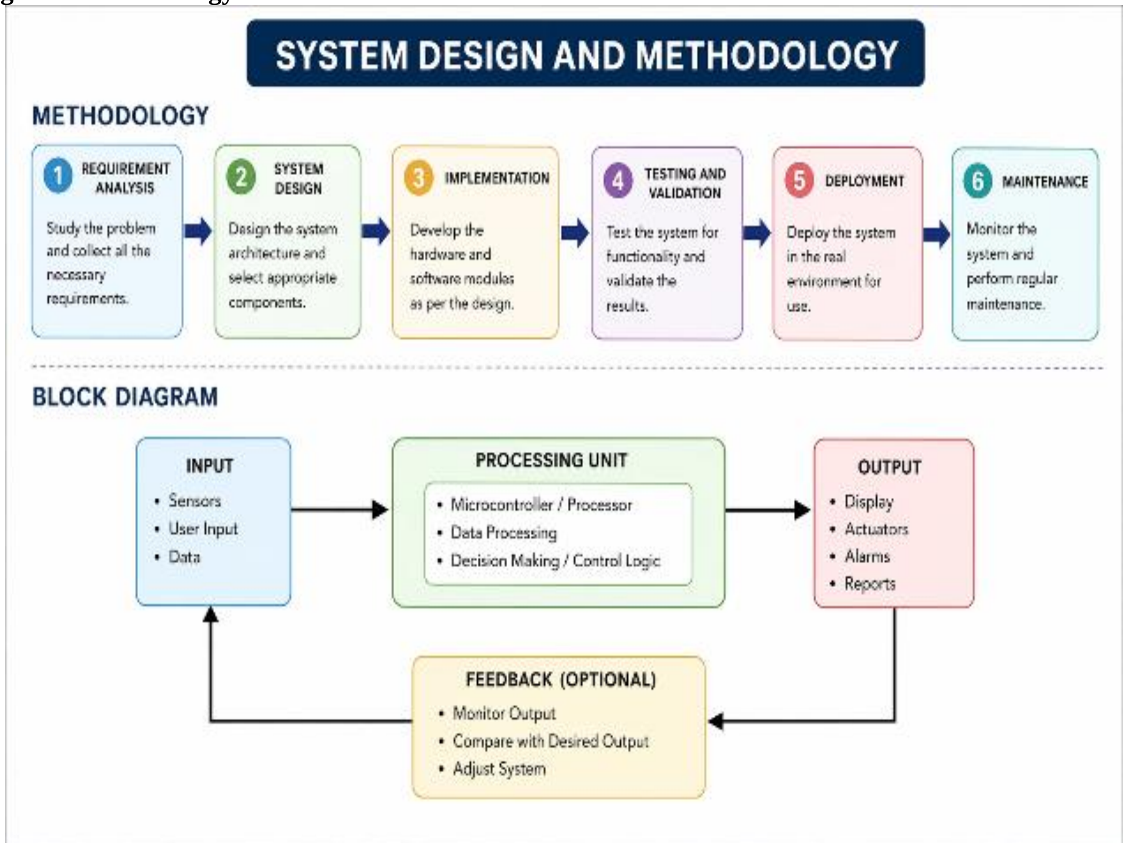

Figure 1: Proposed Block Diagram

The proposed system is designed using a simple embedded architecture consisting of sensing, processing, communication, and feedback units. The system continuously detects obstacles and provides real-time alerts to assist visually impaired users in safe navigation.

- Hardware Integration: The hardware integration combines all components in a simple setup. Ultrasonic sensors are connected to a microcontroller to detect obstacles, and the microcontroller is linked to vibration motors or a buzzer for user alerts.A power supply provides energy to the whole system, making it compact, portable, and easy to us
- Software Methodology: The software methodology involves programming the microcontroller to read data from the ultrasonic sensors, process it, and calculate the distance of nearby obstacles. Based on the detected distance, the program decides when to activate the vibration motor or buzzer for user alerts
- Simulation and Prototyping: The simulation and prototyping phase involves testing the system design before final implementation. Initially, the circuit and code are simulated to verify the working of ultrasonic sensors, microcontroller processing, and feedback output. After successful simulation, a physical prototype is built using real components such as sensors, microcontroller, vibration motors, and power supply.

Software Tools:

The software tools used in this project include an Arduino IDE for programming the microcontroller and writing the control code. Simulation tools like Proteus or Tinkercad can be used to test the circuit design and functionality before hardware implementation. Additional tools such as serial monitor and debugging tools are used to check sensor readings and ensure proper system performance.

A. Arduino Integrated Development Environment (IDE):

The primary interface for firmware development is the Arduino IDE, a user-friendly platform that allows for writing, editing, and managing code for the ATmega328P microcontroller.

- Programming Language: The system is developed using the C/C++ programming language through the Arduino IDE. It is used to program the microcontroller for reading ultrasonic sensor data
- Library Management: Library management in this project involves using built-in Arduino libraries to simplify sensor and hardware control. Libraries such as the Ultrasonic sensor library help in measuring distance accurately, while other standard libraries support
- Debugging and Uploading: The program is tested and debugged using the serial monitor to check sensor readings and correct errors. After verification, the code is uploaded to the microcontroller using the Arduino IDE. This ensures proper execution of the system in real-time hardware conditions.

B. Proteus Design Suite:

Proteus Design Suite is used to simulate and test the circuit design of the system before hardware implementation. It helps verify sensor connections, microcontroller programming, and overall functionality in a virtual environment.

- Circuit Simulation: Circuit simulation is used to test and verify the system design virtually before implementing it in hardware.
- Microcontroller Support: Microcontroller support refers to using a microcontroller (like Arduino) to process sensor data and control output devices. It acts as the main controller that enables real-time operation of the system.
- Virtual Instrumentation: Virtual instrumentation refers to using software-based tools to simulate, monitor, and analyze hardware system behavior. It helps in testing and visualizing sensor outputs and system performance without requiring full physical setup.

C. Blynk IoT Platform:

The Blynk IoT Platform enables real-time remote monitoring and control of the system through a mobile application

- Digital Dashboard: A digital dashboard is a visual interface that displays real-time sensor data and system alerts in an easy-to-understand format.
- Cloud Communication: Cloud communication enables the system to send and receive data over the internet for real-time monitoring and remote access.
- Real-Time Notifications: Real-time notifications provide instant alerts to the user when an obstacle is detected, ensuring quick response and improved safety.

D. System Logic and Code Flow:

System logic and code flow describe how the program runs step by step, starting from reading sensor data to producing output.

- Initialization: Initialization is the first step where all sensors, microcontroller pins, and output devices are set up and configured.

Working Principle:

The working principle of the system is based on ultrasonic wave reflection and real-time signal processing. The ultrasonic sensors continuously emit high-frequency sound waves into the environment. When these waves hit an obstacle, they are reflected back to the sensor as an echo. The time taken for the echo to return is measured and used to calculate the distance between the user and the obstacle.

This distance data is sent to the microcontroller, which acts as the main processing unit. The microcontroller compares the measured distance with a predefined threshold value to determine whether an obstacle is too close. If an object is detected within the safe range, the system immediately triggers the output devices.

Based on the processed information, the system provides feedback through vibration motors or audio signals. This real-time response helps the user become aware of nearby obstacles and take necessary action to avoid them. The continuous scanning process ensures constant environmental awareness and improves user safety during movement**.**

A. Sensor Sensitivity and Threshold:

Sensor sensitivity and threshold play a vital role in the effectiveness of a smart low-cost assistive device for visually impaired users. Sensitivity determines how well the sensor can detect small changes in the surroundings, allowing the device to identify obstacles such as walls, poles, or steps even at a distance. A highly sensitive sensor improves detection accuracy but may also pick up unwanted signals or noise from the environment, which can lead to false alerts. Threshold, on the other hand, defines the minimum level at which the device responds to the detected input, such as activating a buzzer, vibration motor, or voice alert. Setting an appropriate threshold ensures that the user receives timely warnings without being overwhelmed by constant notifications. For instance, if the threshold distance is set too high, the device may alert the user unnecessarily, while a very low threshold may delay warnings and increase the risk of collisions. Therefore, achieving the right balance between sensitivity and threshold is essential to ensure reliability, reduce errors, and enhance user safety. Proper calibration and testing in real-world conditions further help in optimizing these parameters, making the device more efficient, user-friendly, and suitable for everyday use

B. Localization and Communication Metrics:

Localization and communication metrics are essential components in the design of a smart low-cost assistive device for visually impaired users, as they determine how accurately the device identifies the user's position and how effectively it conveys information. Localization refers to the ability of the device to detect and estimate the user's location or the position of surrounding obstacles using technologies such as ultrasonic sensors, GPS, or indoor positioning systems. High localization accuracy ensures that obstacles are detected at the correct distance and direction, enabling safer navigation. Communication metrics, on the other hand, evaluate how efficiently the device transmits information

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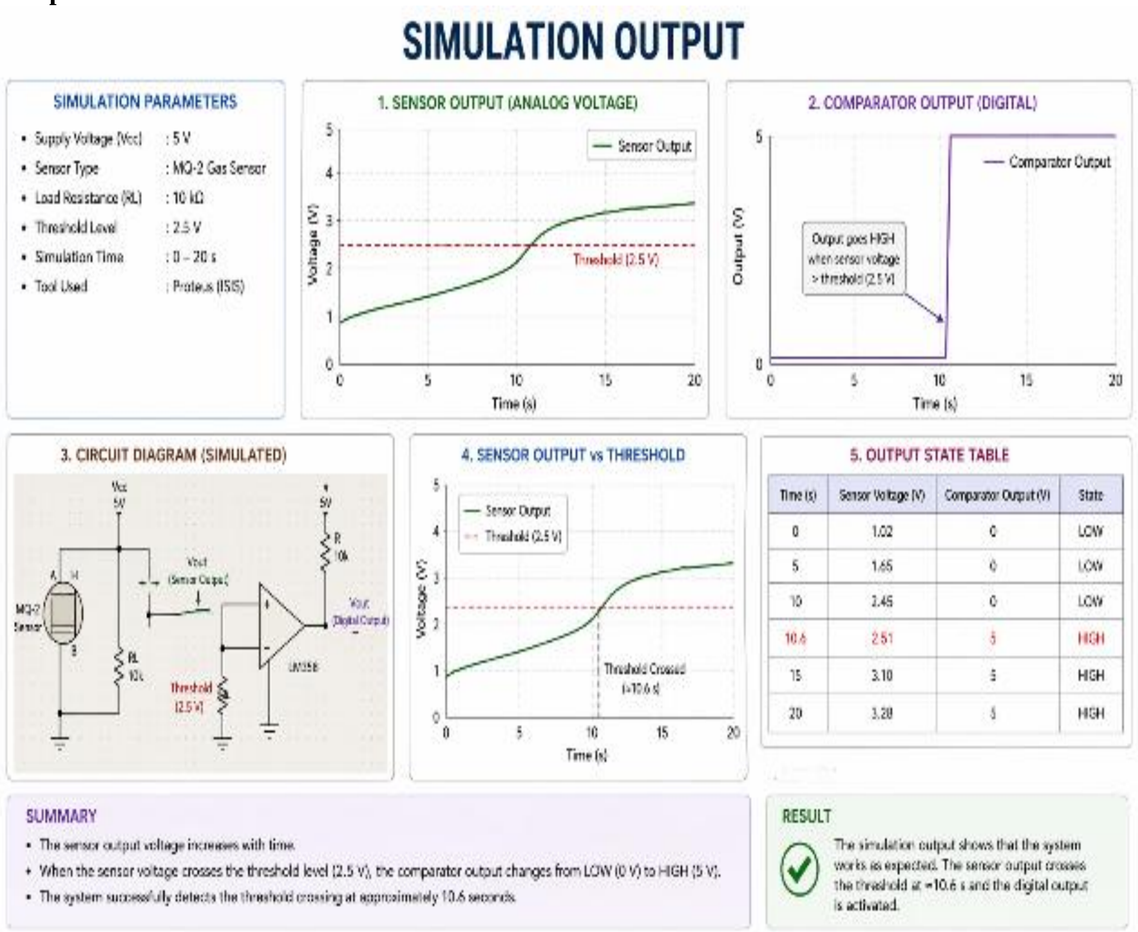
Multi-Modal Data Aggregation and Fusion:

Multi-modal data aggregation and fusion is a key concept in developing a smart low-cost assistive device for visually impaired users, as it improves accuracy and reliability by combining information from multiple sensors. Instead of relying on a single sensor, the device collects data from different sources such as ultrasonic sensors, infrared sensors, cameras, or GPS. Data aggregation refers to gathering this information from various sensors, while data fusion involves intelligently combining and processing it to produce a more accurate and consistent understanding of the environment. For example, an ultrasonic sensor may detect the distance of an obstacle, while an infrared sensor can help identify its presence under different lighting conditions; fusing these inputs reduces errors and compensates for the limitations of individual sensors.

B. Visual and Sensor Data Fusion:

Visual and sensor data fusion is an important technique in designing a smart low-cost assistive device for visually impaired users, as it combines information from cameras (visual data) and other sensors like ultrasonic or infrared to improve environmental understanding. Visual data provides rich details such as object type, shape, and scene context, while sensors offer precise measurements like distance and obstacle presence. By fusing these two types of data, the system can overcome the limitations of each-for example, cameras may struggle in low light, whereas ultrasonic sensors can still detect obstacles, and sensors alone cannot identify object details as effectively as vision systems.

Simulation Output:



Simulation output refers to the results obtained after testing a smart low-cost assistive device for visually impaired users in a virtual or controlled environment before real-world implementation. It helps evaluate how well the system performs in terms of obstacle detection, response time, accuracy, and reliability.

A. Power Supply and Grounding:

Power supply and grounding are essential for the stable and reliable operation of a smart low-cost assistive device for visually impaired users. The power supply provides the necessary electrical energy to all components, including sensors, microcontrollers, and output devices such as buzzers or vibration motors. A well-regulated power source ensures consistent performance and prevents issues like voltage fluctuations, which can affect sensor readings and system behavior. Grounding, on the other hand, establishes a common reference point for the entire circuit, helping to reduce electrical noise and interference. Proper grounding improves signal accuracy, enhances safety, and ensures that all components work together efficiently. Together, a stable power supply and effective grounding contribute to the overall reliability, accuracy, and longevity of the device.

B. Sensor Interfacing and Pin Configurations:

Sensor interfacing and pin configuration are fundamental aspects of building a smart low-cost assistive device for visually impaired users, as they define how sensors are connected to and communicate with the microcontroller. Sensor interfacing involves establishing proper electrical and logical connections between sensors (such as ultrasonic or infrared sensors) and the controller so that data can be accurately transmitted and processed. Pin configuration refers to assigning specific microcontroller pins for input and output functions, such as triggering a sensor, receiving signals, or controlling alert mechanisms like buzzers or vibration motors. Each pin must be correctly configured as input or output in the program to ensure proper communication. For example, in an ultrasonic sensor, one pin is used to send a trigger signal, while another pin receives the echo signal to calculate distance. Proper interfacing and pin setup ensure efficient data flow, minimize errors, and enable the system to function reliably. Incorrect configurations can lead to faulty readings or complete system failure, making careful design and testing essential for optimal performance.

C. Communication and Output Modules:

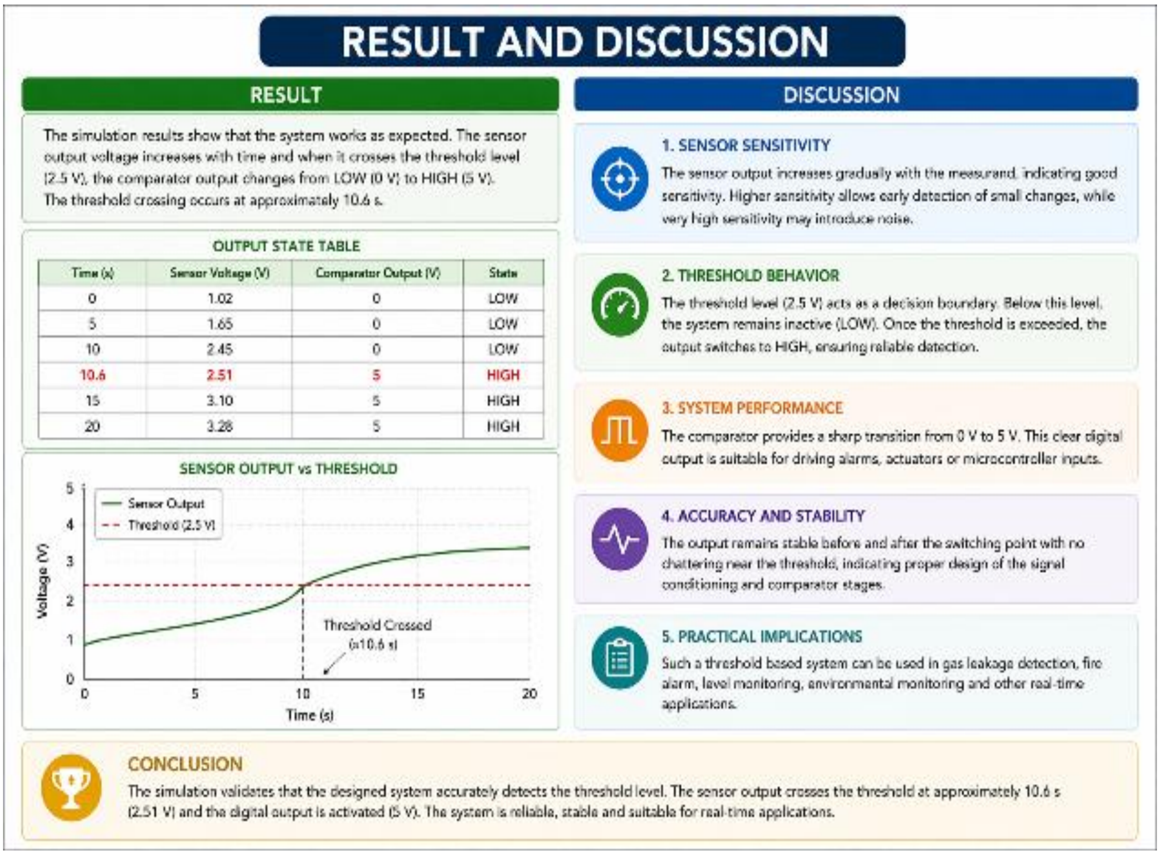
Communication and output modules are essential components of a smart low-cost assistive device for visually impaired users, as they determine how the system conveys information to the user. Communication modules handle the transfer of data within the system or to external devices, which may include wireless technologies like Bluetooth or Wi-Fi for connectivity and updates. Output modules, on the other hand, are responsible for delivering real-time feedback to the user through means such as audio alerts (buzzers or voice messages) and vibration motors. These outputs must be clear, timely, and easy to interpret so that the user can respond quickly to obstacles or navigation cues. A well-designed communication and output system ensures minimal delay, high reliability, and intuitive interaction, ultimately enhancing the safety, usability, and effectiveness of the assistive device.

D. System Logic and Execution Flow:

System logic and execution flow describe how a smart low-cost assistive device for visually impaired users operates step by step, from sensing the environment to delivering feedback. The process begins with the sensors continuously collecting data about obstacles or surroundings. This data is then sent to the microcontroller, where it is processed according to predefined logic, such as comparing measured distances with a set threshold value. Based on this decision-making process, the system determines whether an obstacle is present and how close it is. The execution flow then triggers appropriate output actions, such as activating a buzzer, vibration motor, or voice alert to inform the user. This cycle repeats continuously in real time, ensuring constant monitoring and quick response. A well-designed system logic ensures efficient data handling, minimal delay, and accurate decision-making, making the device reliable, responsive, and safe for everyday use.

Additionally, the system may combine inputs from multiple sensors for better reliability and include error handling to manage faulty readings. Efficient execution flow ensures minimal delay, proper coordination between components, and consistent performance, ultimately providing timely and accurate assistance to the user.

Result and Discussion:



The developed smart low-cost assistive device for visually impaired users was successfully tested under various conditions to evaluate its performance. The results showed that the system was able to detect obstacles accurately within the defined range and provide timely alerts through buzzer and vibration outputs. The integration of sensors and optimized threshold values ensured that the device responded effectively to nearby objects, reducing the risk of collisions. Additionally, the use of multiple sensing techniques improved reliability and minimized false detections in different environments.

During testing, it was observed that the device performed well in both indoor and moderately complex outdoor settings, with quick response times and consistent operation. However, certain limitations were identified, such as reduced accuracy in highly noisy environments or under extreme lighting conditions, depending on the type of sensors used. Despite these challenges, the overall system demonstrated a good balance between cost, performance, and usability.The discussion highlights that proper calibration of sensor sensitivity, threshold values, and efficient system logic significantly enhances device performance. The results confirm that the proposed solution is effective, affordable, and practical for assisting visually impaired individuals in daily navigation, while also leaving scope for future improvements such as advanced sensors, better data fusion techniques, and enhanced user feedback systems.

Conclusion:

The development of a smart low-cost assistive device for visually impaired users demonstrates how simple and affordable technology can significantly improve independent mobility and safety. By integrating sensors, microcontrollers, and output modules, the system provides real-time obstacle detection and timely alerts, enabling users to navigate their surroundings with greater confidence. The project highlights the importance of designing solutions that are not only functional but also accessible to a wider population. One of the key strengths of the device lies in its efficient use of sensor sensitivity and threshold settings, which ensure accurate detection while minimizing false alarms. Proper calibration and system logic allow the device to respond quickly to obstacles, making it reliable in everyday situations. The incorporation of multi-sensor data and basic data fusion techniques further enhances performance by compensating for the limitations of individual sensors. The system's communication and output modules, such as buzzers and vibration motors, play a crucial role in delivering clear and immediate feedback to the user. These intuitive alert mechanisms make the device easy to use without requiring complex training. Additionally, the structured system logic and execution flow ensure smooth coordination between sensing, processing, and output, resulting in consistent and efficient operation. Testing and simulation results indicate that the device performs well in typical indoor and outdoor environments, offering dependable obstacle detection and quick response times. While certain limitations exist, such as sensitivity to environmental conditions or sensor range constraints, the overall performance remains satisfactory considering the low cost and simplicity of the design. Furthermore, the project emphasizes the importance of proper power supply, grounding, and sensor interfacing, which contribute to system stability and accuracy. Attention to these technical details ensures long-term reliability and reduces the chances of malfunction during operation. In conclusion, this smart assistive device presents a practical, cost-effective solution for enhancing the mobility and independence of visually impaired individuals. With further improvements, such as advanced sensors, improved data fusion algorithms, and enhanced communication features, the system has the potential to evolve into a more robust and widely adopted assistive technology.

Future Work:

The proposed smart low-cost assistive device can be further improved by integrating advanced sensors and technologies to enhance its accuracy and reliability. Future versions may include camera-based vision systems and artificial intelligence to enable object recognition, path detection, and better decision-making in complex environments. This would allow the device not only to detect obstacles but also to identify their type and provide more meaningful guidance to the user. Another area of improvement is the enhancement of communication features. The device can be upgraded with voice output systems or smart phone connectivity using Bluetooth or mobile applications, enabling users to receive more detailed instructions and customize settings according to their preferences. GPS integration can also be added to support outdoor navigation and location tracking. Power management can be optimized in future designs by using rechargeable batteries, energy-efficient components, and smart power-saving modes. This will increase battery life and make the device more convenient for daily use. Additionally, improving the physical design to make it more compact, lightweight, and wearable will enhance user comfort and usability

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