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Visually Impaired Navigation System (VINS)

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ABSTRACT: This study focuses on the development of a Visually Impaired Navigation System (VINS), a smart wheelchair created to improve the safety, mobility, and independence of visually impaired individuals. Many visually impaired wheelchair users experience difficulty moving safely because they have limited awareness of their surroundings and often depend on caregivers. To help solve this problem, the system uses ultrasonic sensors, LiDAR, a camera, and intelligent control for real-time obstacle detection and navigation. The study followed a developmental and evaluative research design using the Agile methodology, where the system was continuously planned, developed, tested, and improved. Results showed that the system achieved around 95% accuracy in detecting obstacles, provided fast response times, and delivered smooth and stable wheelchair movement. User evaluations also revealed that the system was easy to use and helpful in providing safe and reliable navigation guidance.

KEYWORDS: Visually Impaired Navigation System (VINS,), Obstacle Detection, LiDAR, Assistive Technology, Smart Wheelchair

I. INTRODUCTION

Mobility plays a vital role in maintaining independence and quality of life. However, it remains a major challenge for visually impaired individuals who rely on wheelchairs for movement. In daily situations, they often face difficulty navigating safely because they cannot easily detect obstacles or fully understand their surroundings. As a result, many depend on caregivers or limited sensory cues to move around safely. While conventional wheelchairs assist with mobility, they do not provide navigation support, which increases the risk of accidents and limits the user's independence in performing everyday activities.

Recent studies have shown that smart wheelchair technologies can help address these challenges. Researchers such as Chugh and Sharma (2022) emphasized that the integration of sensors and computer vision allows systems to detect obstacles more accurately and reduce the effort required from users. Similarly, Wang and Zhang (2024) highlighted that computer vision improves environmental awareness by recognizing objects and pathways. Other studies, including Soltani et al. (2023), suggested that artificial intelligence and multimodal feedback systems can support hands-free control and real-time decision-making, allowing users to navigate more safely.



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Despite these advancements, many existing assistive technologies are still limited. Some systems are complex, expensive, or not specifically designed for individuals who experience both visual impairment and mobility limitations. In addition, many current mobility aids lack real-time environmental awareness and effective feedback mechanisms, which can reduce their practicality in everyday use. These limitations show the need for a more accessible and efficient solution that can support safe and independent navigation.

II. LITERATURE REVIEW

Several studies have highlighted the role of assistive technologies in improving mobility and safety for individuals with disabilities. Chugh and Sharma (2022) discussed the use of sensors and feedback systems for real-time obstacle detection, while Gupta and Kumar (2021) explained how ultrasonic sensors can identify nearby obstacles. Usman and Riaz (2023) also emphasized the use of multiple sensors such as LiDAR and cameras to improve navigation accuracy. Other researchers focused on intelligent navigation systems. Wang and Zhang (2024) highlighted the importance of computer vision in recognizing objects and pathways, while Chabbi, Christiyan, and Ajina (2025) introduced algorithms for real-time obstacle recognition and guidance. Sahoo and Choudhury (2023) also discussed path-planning algorithms for safer navigation. Additionally, Soltani et al. (2023) emphasized the use of audio and vibration feedback systems for visually impaired users, while Dela Cruz and Ramos (2023) developed low-cost assistive technologies using sensors and microcontrollers. These studies show the importance of integrating sensors, computer vision, and feedback systems to improve assistive navigation technologies.

Table 1. Summary of Relevant Literature

No.	Paper Title	Author Name	Key Points	Remark
1	Embedded Assistive Technologies for Mobility Support	Chugh & Sharma (2022)	Discussed the use of sensors and feedback systems for real-time obstacle detection and safer mobility.	Supports the use of sensors and feedback mechanisms in VINS.
2	Ultrasonic Sensor-Based Obstacle Detection System	Gupta & Kumar (2021)	Explained how ultrasonic sensors detect nearby obstacles using reflected sound waves.	Supports the integration of ultrasonic sensors for obstacle detection.
3	Multi-Sensor Navigation Using LiDAR and Cameras	Usman & Riaz (2023)	Highlighted the benefits of combining LiDAR, cameras, and sensors for navigation accuracy.	Supports sensor fusion and intelligent navigation in the system.
4	Computer Vision for Assistive Navigation	Wang & Zhang (2024)	Discussed how computer vision improves object and pathway recognition.	Supports the use of camera-based environmental awareness.
5	Intelligent Navigation Through Computer Vision Algorithms	Chabbi, Christiyan, & Ajina (2025)	Presented intelligent algorithms for real-time obstacle recognition and navigation guidance.	Supports intelligent processing and real-time guidance in VINS.
6	Path-Planning Algorithms for Smart Mobility Systems	Sahoo & Choudhury (2023)	Explained adaptive navigation and obstacle avoidance using path-planning algorithms.	Supports safe route planning and wheelchair navigation.
7	Multimodal Feedback Systems for Visually Impaired Users	Soltani et al. (2023)	Emphasized the importance of audio, vibration, and tactile feedback systems.	Supports the use of audio and vibration alerts in the study.
8	Low-Cost Assistive Technologies for the Visually Impaired	Dela Cruz & Ramos (2023)	Developed affordable assistive systems using sensors and microcontrollers.	Supports the practical and low-cost design of VINS.



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9	Sensor Fusion and Intelligent Navigation Systems	Okolo, Althobaiti, & Ramzan (2024)	Combined multiple sensors and computer vision for better obstacle recognition.	Supports real-time intelligent obstacle detection and navigation.
10	Shared-Control Smart Wheelchair Navigation System	Ramaraj et al. (2023)	Introduced smart wheelchairs combining automated navigation with user control.	Supports intelligent wheelchair movement and safety features.

The reviewed studies show that assistive navigation technologies can greatly improve the safety, mobility, and independence of visually impaired individuals. Technologies such as ultrasonic sensors, LiDAR, cameras, and intelligent systems help detect obstacles and provide safer navigation. Researchers also highlighted the importance of audio and vibration feedback in guiding users more effectively. Overall, both local and foreign studies support the development of the Visually Impaired Navigation System (VINS) by showing that combining these technologies can help visually impaired wheelchair users move more safely, confidently, and independently.

III. METHODOLOGY

Research Design

The study used a developmental and evaluative research design to develop, improve, and assess the performance of the Visually Impaired Navigation System (VINS). The developmental aspect focused on building and refining the system, while the evaluative aspect focused on testing its accuracy, safety, usability, and reliability.

System Development Methodology

The development of VINS followed the Agile methodology, which involved continuous stages of planning, designing, developing, testing, deploying, and reviewing the system. This approach allowed the researchers to improve the system gradually based on testing results and user feedback.

Hardware Design and Development

The hardware design and development focused on selecting, assembling, and configuring the physical components of the system, including sensors, LiDAR, camera modules, motor drivers, and processing units. These components were integrated to provide real-time obstacle detection, navigation assistance, and user guidance.

Performance Evaluation

Performance evaluation was conducted to measure the system's accuracy, response time, reliability, and overall functionality. The system was tested in controlled environments to assess obstacle detection, motor response, audio feedback, and navigation performance under different conditions.

Software Design and Development

The software design and development involved creating the programs and algorithms that manage sensor processing, navigation control, obstacle detection, and feedback systems. Python, ROS 2, OpenCV, and Vosk were used to support real-time processing, computer vision, and voice command functions.

Sensor Testing and Calibration

Sensor testing and calibration involved evaluating and adjusting the JSN-SR04T ultrasonic sensors, LiDAR, and AI camera to ensure accurate obstacle detection and reliable environmental scanning. The ultrasonic sensors were calibrated for proper detection thresholds and positioning, while the LiDAR and AI camera were tested under different conditions to improve accuracy and real-time performance.

Motor Controller Testing

Motor controller testing was conducted to verify the responsiveness and precision of the wheelchair's movement controls. Forward, backward, and turning maneuvers were tested to ensure smooth acceleration, accurate directional control, and immediate stopping when obstacles were detected.



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Power Supply Verification

Power supply verification focused on checking the stability of the 24V battery pack in delivering sufficient power to the Raspberry Pi, sensors, LiDAR, AI camera, and motor drivers. Voltage and current levels were monitored during operation to ensure stable and reliable system performance.

Integration Testing

Integration testing evaluated the coordinated operation of the ultrasonic sensors, LiDAR, AI camera, Raspberry Pi, motor controllers, and audio feedback system. This process ensured that all hardware and software components communicated properly and executed navigation commands consistently.

Performance Evaluation

Performance evaluation assessed the overall functionality of the system based on obstacle detection accuracy, response time, reliability, and audio feedback effectiveness. The system was tested under different environmental conditions to ensure consistent and reliable navigation performance.

UML Diagrams

The UML diagrams were developed to visualize the structure, workflow, and interactions within the VINS system. These diagrams illustrated the system’s operational processes, software modules, navigation flow, and communication between hardware and software components.

User Interface / Application Design

The user interface was designed to be simple, accessible, and suitable for visually impaired users. The system supports voice commands and audio-based interaction, allowing users to control navigation functions, adjust settings, and receive feedback without relying heavily on visual displays.

IV. RESULTS & DISCUSSION

Integration Testing Results

Integration testing was conducted to verify the proper coordination of the hardware and software components as a complete system. The wheelchair was tested in a controlled environment with obstacles to simulate real navigation conditions. During testing, the sensors successfully detected obstacles, transmitted data to the microcontroller, and activated the alert system, allowing the wheelchair to provide warnings and support safe navigation while avoiding potential collisions.

Figure 1: System Integration Test

Scenario	Expected Behavior	Actual Result	Status
Obstacle detected	Stop / Avoid	System stopped	✓ Passed
Voice command given	Execute movement	Command followed	✓ Passed
No obstacle	Continue movement	Smooth movement	✓ Passed
Feedback triggered	Alert user	Voice + vibration activated	✓ Passed

The integration testing results showed that the system processed sensor data and generated alerts with minimal delay, allowing users to receive warnings almost immediately after obstacle detection. The test also confirmed that the sensors, microcontroller, and software programs worked effectively together, providing fast response times and reliable feedback for safe wheelchair navigation.



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Evaluation Results

The evaluation of the Visually Impaired Navigation System (VINS) was conducted to determine its effectiveness and usefulness for visually impaired individuals, elderly users with blurry vision, and persons with disabilities. Participants tested the system and evaluated its functionality, usability, reliability, and overall performance through a survey. The results showed that the system was effective in detecting obstacles and providing timely alerts, helping users become more aware of their surroundings and navigate more safely. Participants also found the system easy to understand and operate, with clear and noticeable alerts that allowed quick responses during navigation. In addition, the system processed sensor data and generated warnings with minimal delay, providing reliable real-time guidance. Overall, the findings indicate that the system successfully achieved its goal of improving the safety, mobility, and independence of users during navigation.

Performance Evaluation

The performance evaluation results showed that the Visually Impaired Navigation System (VINS) was highly effective in terms of functional suitability, usability, reliability, and performance efficiency, with an overall mean score of 4.40. The results indicate that the Visually Impaired Navigation System (VINS) is effective, reliable, and user-friendly in assisting visually impaired wheelchair users during navigation. The high evaluation scores show that the system can accurately detect obstacles, provide fast responses, and support safer and more efficient mobility.

Table 1 Summary of VINS Evaluation Results

Table	Category	Mean	Interpretation
1	Functional Suitability	4.41	Highly Effective
2	Usability	4.39	Highly Effective
3	Reliability	4.39	Highly Effective
4	Performance Efficiency	4.42	Highly Effective
	Overall Mean	4.40	Highly Effective

Discussion

The integration testing results demonstrated that the hardware and software components of the Visually Impaired Navigation System (VINS) worked effectively together as a complete system. The sensors successfully detected obstacles, transmitted data to the microcontroller, and activated the alert system with minimal delay, allowing users to receive immediate warnings and navigate more safely. These findings show that the system is capable of providing reliable real-time obstacle detection and responsive navigation assistance in controlled environments. The evaluation and performance results further confirmed the effectiveness of the system. Participants found the VINS easy to use, reliable, and helpful in improving their awareness and mobility during navigation. The system also achieved a “Highly Effective” interpretation in all evaluation categories, with an overall mean score of 4.40, indicating that it can provide accurate obstacle detection, fast response times, and efficient guidance for visually impaired wheelchair users.

V. CONCLUSION

This study successfully developed the Visually Impaired Navigation System (VINS), a smart wheelchair navigation system designed to help visually impaired users move safely and independently. The study achieved its objectives by integrating ultrasonic sensors, LiDAR, a webcam, and a central processing unit to detect obstacles and monitor the surroundings in real time. Testing results showed that the sensors accurately detected obstacles and provided timely data to the system, which then generated audio and haptic feedback to warn users about nearby objects and hazards.

In addition, the motorized wheelchair responded properly to navigation instructions, allowing smoother movement and improved obstacle avoidance. The integration of the hardware and software components proved that the system functions effectively as a reliable assistive navigation tool.



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Recommendations

Based on the results and limitations of the study, the following recommendations are proposed:

1. Future researchers may enhance the obstacle detection capability of the system by improving sensor placement and integrating additional sensors to increase environmental awareness and detection accuracy.
2. Improving the webcam's image processing capabilities may also help the system recognize objects more clearly and provide more accurate navigation guidance for users.
3. Further testing in different environments is also recommended to better evaluate the system's adaptability and real-world performance.
4. Testing the system in outdoor areas, crowded spaces, and varying lighting conditions, as well as involving more visually impaired participants, may provide additional feedback regarding usability, comfort, and reliability.
5. Future developers may also improve the system by making it more compact, energy-efficient, and user-friendly while enhancing audio and haptic feedback to provide clearer navigation assistance and improve user safety and independence.

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