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Robotic guide for the visually impaired through Bluetooth and obstacle avoidance using Arduino

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ABSTRACT

Visual impairment continues to affect a significant portion of the global population, with over 2.2 billion people experiencing some level of vision loss. Conventional aids such as white canes and guide dogs provide essential support but have notable limitations in certain environments. To address this gap, a robotic guide was developed using Arduino-based components, offering real-time obstacle detection through ultrasonic and infrared sensors. Audio feedback is transmitted via a Bluetooth-connected mobile application, and vibration alerts are included for individuals with hearing impairments. The system features a joystick for directional control and incorporates RFID-based security to prevent unauthorized access. Functionality tests with users indicate strong potential for improving navigational independence and safety in urban and controlled settings. The design emphasizes practicality, accessibility, and user adaptability for product innovation.

Contribution/Originality: This work integrates joystick-controlled robotic navigation, dual-mode alerts (audio and vibration), and voice-command features, allowing management via a mobile app. The inclusion of RFID-based access control adds a unique security layer, making the system comprehensive, user-friendly, and more advanced than current assistive technologies for the visually impaired. The system addresses limitations of existing aids by offering multimodal alerts and enhanced security within a compact, user-centered design.

1. INTRODUCTION

Visual impairment remains a deeply impactful condition that significantly restricts an individual's ability to engage in daily life with autonomy. According to the World Health Organization, billions of people worldwide are affected by varying degrees of visual impairment [1]. One of the primary difficulties associated with this condition is the reduction in independent mobility, which in turn influences overall quality of life [2]. This study addresses the specific challenges encountered by individuals whose movement is limited due to visual impairments. Although various assistive tools have been introduced to aid navigation [3] many of these solutions fall short in certain scenarios, often due to technological constraints, lack of adaptability, or usability issues that hinder effective long-term use [4]. In addition, guide dogs may not be suitable for some individuals due to allergies, cultural beliefs, or the inability to undertake the responsibility of caring for a living animal [5]. Consequently, the alternative solutions can help visually impaired individuals navigate their environment with enhanced convenience and ease.

The new IoT technology enables the proposed system to address existing challenges through its advanced design. The Arduino has been selected as the component to create obstacle-detecting and avoiding capabilities. This will provide navigation assistance for visually impaired people. The system will have the ability to provide real-time audio feedback through a Bluetooth-connected mobile application to ensure safety and a seamless experience. Ultrasonic and infrared sensors enable the system to detect obstacles and take appropriate action. The system can be more efficient and reliable compared to traditional walking sticks or guide dogs. Visually impaired individuals will be able to navigate their surroundings with increased independence and lead a higher quality of life. A customized and personalized experience is attainable because the system can be adjusted to match the unique requirements and preferences of each user. The real-time auditory feedback also provides information about landmarks or other nearby areas of interest to enhance the user's navigational abilities.

Living with visual impairment can lead to significant challenges. Individuals who are blind face numerous problems when navigating a world primarily designed for sighted individuals leading a normal life [6]. Although there are many aids designed for the visually impaired, all of these methods have certain limitations [7]. For instance, guide dogs require extensive training and ongoing care, making them unsuitable for users who cannot provide proper care for live animals [7, 8]. Legal restrictions prevent animals from entering various public and private locations, thus reducing their usefulness in particular scenarios [9].

It is important to develop advanced technology to enable visually impaired individuals to navigate their surroundings effectively. The proposed solution consists of a robotic guide designed to perform functions similar to those of guide dogs. The system incorporates an obstacle avoidance mechanism that prevents contact with nearby objects or barriers. Through Bluetooth connectivity, the system links with a mobile application. When the model detects an obstacle, the mobile application generates audio alerts. A handheld joystick control will enable the user to navigate the system with precise and intuitive movements.

2. LITERATURE REVIEW

The main goal of this system is to develop a robotic guide dog to assist individuals with visual impairments through an IoT system [10]. The proposed system implements a joystick-controlled car model with an obstacle avoidance feature, as well as Bluetooth connectivity to provide audio feedback in the event of an obstacle. The obstacle detection system within the joystick-controlled car model operates through sensors to identify surrounding objects. When sensors detect obstacles, the system is activated through signals that trigger the car's obstacle avoidance mechanism to steer clear of the obstacle. Through Bluetooth connectivity, the system sends audio notifications to users. The system detects obstacles and provides notifications to users through alerts that specify detected obstacle locations. The system provides an easy-to-understand navigation experience and reliable accessibility features which serve people who are visually impaired in accordance with the Sustainable Development Goals (SDG) shown in Figure 1.

Figure 1. Sustainable development goals.

The proposed system is capable of addressing three key areas of the Sustainable Development Goals as outlined in Figure 1. These goals include good health and well-being, industry, innovation, and infrastructure, and reduced inequalities. The system enhances the well-being of visually impaired individuals by providing a solution that enables them to navigate their environment more effectively. It utilizes IoT technology, which is a rapidly expanding field of innovation. People with visual impairments can achieve greater mobility and independence, thereby reducing inequalities within this group.

The proposed system consists of three main features. The first feature enables users to control the model's movement using a joystick module. This feature is beneficial for the target audience because visually impaired individuals can physically interact with the joystick for navigation. The second feature is real-time obstacle detection and avoidance. It is essential that visually impaired people do not bump into any obstacles during their movement to prevent serious injuries from tripping or falling. The proposed system enhances user safety and navigational efficiency by preventing collisions. Next, the system implements Bluetooth connectivity, allowing the model to connect with Bluetooth devices to expand its functionalities. Specifically, the proposed system connects to a mobile application on the user's smartphone. This enables the user to receive audio feedback when the system detects an obstacle, thereby enhancing accessibility.

Arduino is the main electronic component for developing the proposed system due to several advantages. Arduino provides access to a large community of developers and resources, facilitating troubleshooting and development for real-time processing capabilities. Furthermore, Arduino features a user-friendly interface, making it easy to learn and use due to its straightforward design. Arduino is also energy-efficient and cost-effective, ensuring smooth and efficient development of the proposed system.

Several existing models developed by other researchers were examined, and three different systems were selected for comparison, where the strengths and weaknesses of each were analyzed.

2.1. Robotic Guide using Smartphone Camera and Ultrasound Sensors (2019)

The system was created in 2019 with the objective of developing a mobile robotic platform that can avoid obstacles for the benefit of visually impaired people [11]. Referring to Figure 2, the prototype is a model with two rear wheels for movement and is attached to a stick that the user holds. The front of the model is equipped with sensors and a holder for a smartphone. The prototype was tested with visually impaired persons with a range of 12-15% functional vision, as identified by the IDVC (Catanduva Institute for the Visually Impaired).

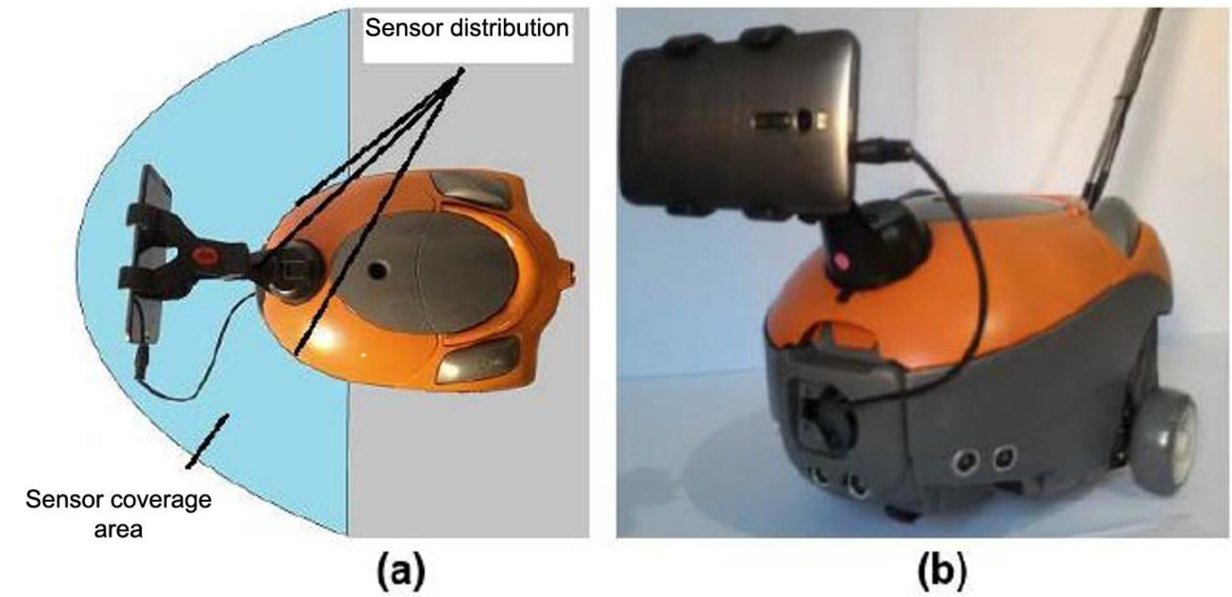

Figure 2. Physical model of a robotic guide using a smartphone camera.

There are several strengths in the system, such as providing audio feedback when an obstacle is detected. This system utilizes a smartphone camera fixed onto the front of the model to capture images of the surrounding environment. Additionally, it can perform route correction when an obstacle is detected.

There are certain limitations identified for this system. Firstly, the coverage area of the sensors is significantly limited. Since the sensors are only placed at the front of the model, only obstacles directly in front of the model can be detected. Additionally, the audio feedback provided by the system is unreliable in noisy environments. Regarding connectivity, the system heavily relies on a strong Wi-Fi internet connection to communicate with the PC. It becomes non-functional when there is no internet connection near the location.

2.2. Quadruped Robot Guide with Fuzzy Control (2020)

The robotic system entered the market in 2020 to aid visually impaired mobility through a four-legged robotic model. The system was designed to allow a more dynamic range of movements, hence the implementation of four legs on the model [12]. The model also features a handlebar that is fixed onto the back to allow users to hold onto the model during movement. The front of the model contains sensors to detect and avoid obstacles in its surroundings. Figure 3 shows the design and real-life implementation of the model.

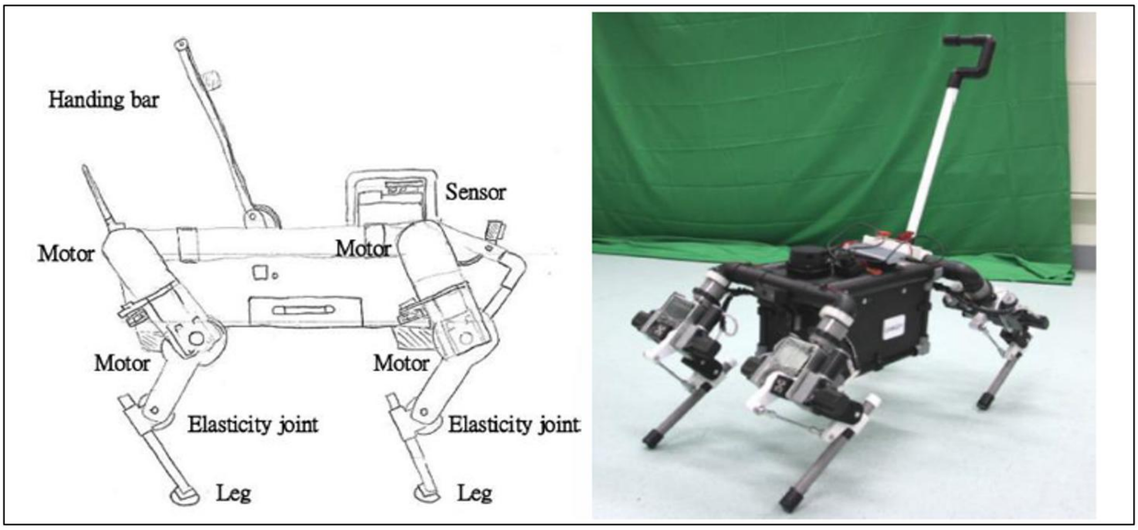

Figure 3. Design of the quadruped robotic dog.

There are several strengths that can be highlighted in this system. Most notably is the four-legged design of the model with bendable joints, which allows for a much wider and more dynamic range of movement. This enables the model to ascend stairs and curbs, which would be very challenging for models with other forms of movement, such as wheels. Additionally, the implementation of a handlebar at the top of the robot's body allows the user to hold on during assisted guidance movement.

Although the model has strong points, it also has some gaps. For example, the system is only equipped with sensors at the front, allowing it to detect obstacles only from that direction. If there are obstructions from the back or sides, the front sensors will not detect them. Although the design of the model provides excellent mobility, it also comes with a higher price point, which might be beyond the budget of many visually impaired individuals. Some users may find that the cost of this robotic model is roughly equivalent to caring for a living guide dog. Another issue is that the size of the model is significantly larger than a typical guide dog, which may be more obstructive than helpful. It is important to note that this model's size is considerably larger than a regular guide dog and may hinder movement. Additionally, the handlebar is positioned in the middle of the model, which may be harder for the user to reach and could put the user's arm in an awkward position, potentially causing fatigue over extended periods.

2.3. Autonomous Path Guiding Robot for Visually Impaired People (2019)

Figure 4 depicts a system developed in 2019 by researchers in India with the goal of creating a low-cost navigation system that is easily accessible to visually impaired individuals. The system aims to guide users in both indoor and outdoor environments through a combination of location mapping and image processing algorithms [13]. The model is capable of navigating narrow spaces such as corridors and back lanes. Experiments were performed to assess the system's accuracy in adhering to predefined paths.

Figure 4. Design of keypad-controlled path guiding robot.

The visually impaired can use the keypad and joysticks at the end of the handlebar to interact with the model. With the handlebars, a user gains control to direct the robot according to their chosen path. Economical materials used in this system establish it as a cost-effective solution for people who are visually impaired. Some restrictions have been identified within the system.

The system lacks sufficient feedback mechanisms to provide appropriate responses. When an obstacle is detected, there is no noticeable alert to notify the user, which could pose potential danger to the user and their surroundings. Additionally, the design of the model is somewhat unconventional, as the body of the robot is positioned too close to the user's side. This may hinder the user's ability to walk comfortably.

Table 1 shows the gaps and limitations which have been identified for each system respectively. The column on the right shows the solution implemented in the proposed system to overcome these limitations and establish a competitive advantage.

Table 1. Gaps and limitations in existing systems and solutions implemented in the proposed model.

System	Gaps / Limitation	System's Solution
Robotics guide using smartphone camera and ultrasound sensors (2019).	- Limited coverage area for sensors - Audio feedback is unreliable in noisy environment - Relies on Wi-Fi / 4G Internet connection	- Place sensors at the front, rear and side of the robot. - Audio feedback is given directly to the user's ears using earphones. - Use Bluetooth connectivity.
Quadruped robot guide with fuzzy control (2020)	- Modal is too large and obstructing - Awkward position of handlebar in the middle	- Make a model which is small to medium sized. - Place a handlebar at the back of the model, nearest to the user.
Autonomous path-guiding robot for visually impaired people (2019)	- No alert to notify the users when obstacle detected. - Placement of robot body too near the user's side	- Produce sound alert sounds when obstacles have been detected. - The body of the robot placed in front of the user.

3. METHODOLOGY

The research followed the waterfall model to guide its system development method. The waterfall model allows developers to achieve a systematic sequence of work activities when creating telehealth systems, ensuring that each phase is completed fully before proceeding to the next. This development method facilitates detailed record-keeping and effective stakeholder communication, thereby supporting the successful deployment of secure and efficient telehealth systems. Developing the framework enables early hazard and concern identification, allowing for immediate implementation of solutions during the initial stages of development. The following stages describe the research methodology in this study, which consists of six phases.

3.1. Requirements Gathering and Analysis

The fact-finding approaches, such as stakeholder interviews, surveys, user behavior observations, and system analysis, were used to gather needs from the target audience. Since it defines the system's completion criteria, this stage is essential for defining exact needs.

A quantitative method was used to gather valuable information that is reliable, valid, and effective. It serves to collect data from the target audience efficiently. Several considerations were taken into account when designing the questionnaire to make it as effective and convenient as possible for participants to answer. The questionnaire consisted of 15 questions of various types, including open-ended and closed-ended questions. The main objectives were to identify whether respondents had previously used technology for navigation and whether they are open to adopting new innovations. Additionally, it helps to determine the key aspects and features that respondent expect from the robotic guide system.

3.2. Prototype Designing

The preliminary design of the prototype was developed using data gathered during the requirements analysis phase. To provide a clear understanding of system usage and user experience, the functionalities of the system were defined. The prototype design phase is useful for identifying design problems in the development process.

The representation of the robotic model's system design follows the established specifications for requirements and functional features. The system design includes various UML diagrams that illustrate features and components.

A detailed visual illustration enables users to both capture and communicate complex system operations within challenging circumstances. The visual illustration combines words with symbols and images to depict system components, their relationships, and dynamics. The capabilities of the robotic model can be clearly and concisely represented through the implementation of UML diagrams during system development. The conceptual frameworks presented through these diagrams become understandable to interested stakeholders, regardless of their technical expertise. Visual diagram components facilitate clear communication of system features, relationships, and dynamic behavior patterns. The detailed representations enhance understanding of system functions and support the identification of potential improvements.

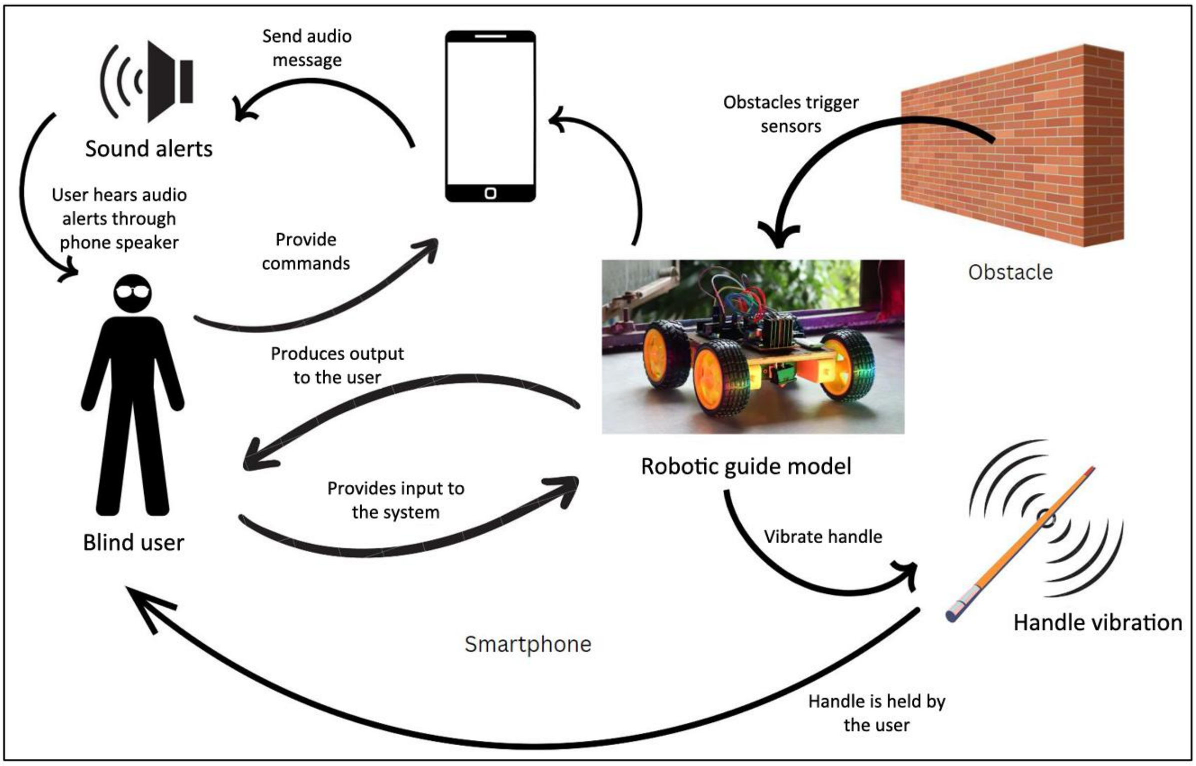

Figure 5. Rich picture diagram.

Figure 5 shows the proposed robotic guide system, which contains the central focus point, the Robotic Guide Model. The main actor in this system is the blind user. The primary external factor for this system is obstacles. The device peripherals include the handle and a smartphone. As shown in the rich picture diagram, the system handles a variety of inputs and outputs. The sensors receive the main input when an obstacle is detected. The sensors then relay this input as data to the system, which processes it to produce the appropriate output. The audio from the smartphone speakers is the main output of this system. When the system detects an obstacle, the user will hear audio alerts through the smartphone speakers. There is an additional option to produce vibrations at the handle when an obstacle is detected. This feature is especially useful for hearing-impaired individuals who cannot hear sound alerts. The system is also paired with the user's smartphone via Bluetooth connectivity. The user can configure the device through the smartphone.

3.3. Prototype Development

The primary objective during this phase was the development of a functioning prototype, as illustrated in Figure 6. At this point, the essential features of the system have been implemented, with the application fully coded and operational. The integration of both hardware and software components has been completed, laying the groundwork for subsequent evaluation. The Arduino Mega microcontroller serves as the central unit, interfacing with critical modules such as ultrasonic and infrared sensors, Bluetooth, joystick, and vibration components. These elements form the foundation of the system's interactive capabilities. A carefully organized wiring setup has been adopted to ensure reliable communication across components, contributing to consistent system performance. Prior to advancing into later stages of development, individual connections have been thoroughly tested to detect and resolve any hardware-related issues that could affect overall stability.

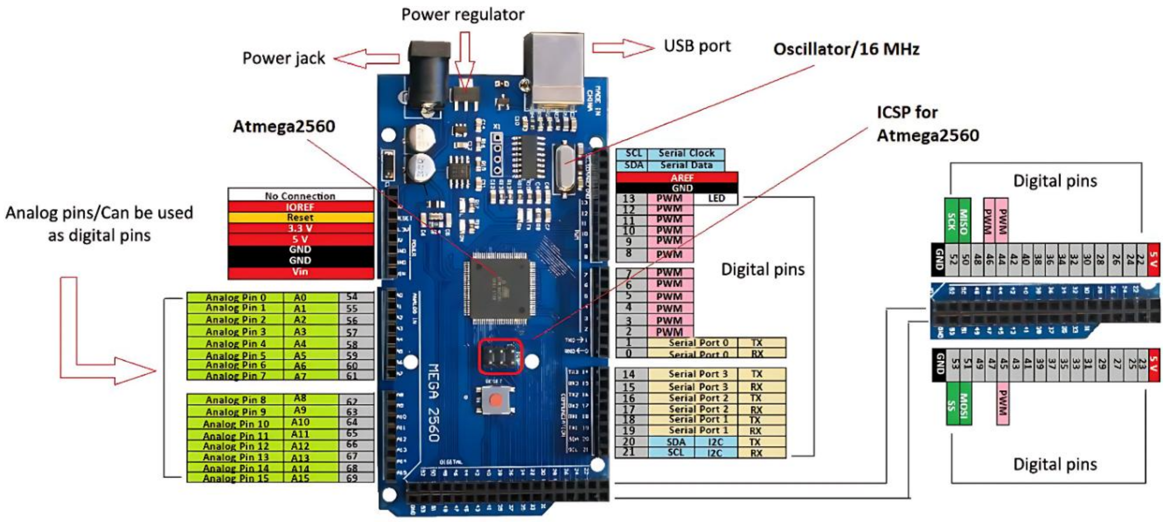

Figure 6. Model of prototype design.

3.4. Testing and Evaluation

The system underwent a structured series of evaluations to identify functional issues and areas requiring refinement. A combination of testing approaches was employed, spanning functional, performance, and usability assessments to evaluate the prototype from multiple perspectives [14]. The insights gained from these activities played a key role in shaping subsequent iterations of the design. A comprehensive test plan was developed to guide the evaluation process of the Arduino-based system, ensuring consistency and clarity throughout. This plan detailed the overall methodology, including the testing scope, expected outcomes, and specific benchmarks for progression. Clearly defined entry and exit criteria were also established to support a methodical validation of the system's performance and ensure that all essential features were examined with precision.

3.4.1. Unit Testing

Unit testing was conducted to ensure the functionality of the system. It involves testing small, independent sections of code or hardware to verify their intended performance. Unit testing helps identify and resolve errors early and increases the accuracy of implementation. The test results were effective for all components, including the Bluetooth module, joystick, vibration motor, sensors, DC motor, and Omni-wheels. The test results were accepted for the mobile application, which includes Bluetooth status, ID status, and display data code.

3.4.2. Integration Testing

The integration testing phase examined the proper functionality of interconnected system modules while they work together. The testing phase verifies smooth connection and information flow between individual system components to assess the proper functioning of a complete integrated system. The system's success and reliability depend significantly on proper criteria for data transfer operations, joystick control functions, motion adjustments, and sensor status management procedures.

3.4.3. Acceptance Testing

An acceptance testing procedure was executed to verify the system's performance relative to the requirements and needs of its target users. The assessment helps evaluate system quality while verifying deployment readiness. Acceptance testing verifies that the system executes its designated functions accurately in a practical environment. Acceptance testing is conducted by administering a usability questionnaire to a cohort of volunteers within the target demographic, which includes individuals with visual impairments. The results demonstrate the system's efficacy in achieving the Sustainable Development Goals (SDGs).

3.4.4. Refining the Prototype

The system's performance was enhanced and fine-tuned through insights gained during earlier testing and evaluation phases. Functions and features were revisited, leading to the development of an improved prototype that resolved previously observed issues. This repeated refinement helped ensure the final version met design expectations and operated consistently. A key strength of the system is its ability to rotate 360 degrees in both clockwise and counterclockwise directions, made possible through the omniwheel configuration, which enables smooth and flexible motion in all directions. The Arduino-based platform communicates wirelessly with the RoboGuide mobile application via Bluetooth, allowing seamless real-time interaction between the two. Additionally, ultrasonic sensors detect obstacles and automatically stop movement to prevent collisions. Infrared sensors are included to identify changes in surface levels, reducing the risk of the user falling from curbs or into unseen openings. The system also produces audio alerts in response to several triggers, such as obstacle detection, surface irregularities, Bluetooth connection status, and voice command input. For users with hearing difficulties, vibration alerts are provided when obstacles are detected. Using the mobile application, users can control this vibration feature with voice commands, enabling personalized accessibility. To maintain system security and protect user privacy, an RFID authentication system is implemented. Only approved RFID tags can unlock system access, while the mobile application allows for easy management and updating of RFID credentials, combining both convenience and secure control in one interface.

3.4.5. Product Implementation and Maintenance

The final prototype was progressively refined through several development cycles. Routine maintenance was conducted on both hardware and software components to uphold system stability and minimize the risk of operational faults. This concluding phase confirmed the system's readiness for practical application, ensuring long-term reliability and secure performance. As shown in Figure 7, the final version incorporates numerous improvements made during the development process. Enhancements include the addition of new functionalities and the integration of current technological advancements. These updates strengthen the system's overall value, positioning it as a practical, forward-thinking solution within the assistive technology sector [15, 16].

Figure 7. The final product produced is dubbed Roboguide.

4. CONCLUSION AND FUTURE ENHANCEMENT

The development of this project demonstrates a solid application of technical knowledge aimed at solving practical challenges through a user-focused design. The prototype has been upgraded with extended features and integrated with current technologies, resulting in a solution that aligns with competitive standards in the assistive technology field. Central to the system is a joystick-operated robotic guide that replicates the functional purpose of a traditional guide dog. It incorporates obstacle avoidance using embedded sensors to detect nearby barriers and halt movement to prevent collisions. When an obstruction is identified, the system delivers audio alerts through a mobile application connected via Bluetooth. Additionally, vibration responses are provided for users with hearing difficulties, allowing obstacle notifications to be received through tactile feedback. This function can be activated or deactivated using voice input in the mobile interface, enabling users to customize the experience based on their preferences. To uphold privacy and prevent unauthorized use, RFID-based access control has been included. System features are available only through authorized tags, which can be easily updated and managed via the app. Collectively, this system offers a practical solution for supporting independent navigation among individuals with visual impairments. Testing conducted with the intended user group confirmed its effectiveness in achieving safe, confident mobility, reinforcing its value as a purposeful innovation.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics. All methods, findings, and conclusions have been reported accurately.
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