An-Najah National University

Faculty of Engineering & Information Technology Computer Engineering

Smart Walker

Students:

Lama Enad Hag

Omar Alaa Jarbou

Supervisor:

Aladdin Masri

Date:

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Disclaimer Statement

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Abstract

Smart Walker is an intelligent mobility assistance system developed to support visually impaired and elderly individuals during daily navigation. The project aims to enhance user safety, independence, and environmental awareness through the integration of sensing, embedded systems, and artificial intelligence technologies.

The system combines an OAK-D camera for object detection and recognition with a LiDAR sensor for obstacle detection and distance measurement. Sensor data are processed by a Raspberry Pi to determine safe navigation paths, while an Arduino Mega manages steering assistance, braking control, authentication, and monitoring functions. Real-time voice guidance is provided to inform users about surrounding obstacles and detected objects. Additional features include RFID-based authorization, banknote recognition, battery monitoring, guardian monitoring, and automatic lighting control.

Experimental testing demonstrated the system's ability to reliably detect obstacles, recognize objects, provide navigation assistance, and perform integrated safety functions. The developed prototype offers a practical and cost-effective assistive solution that improves mobility, safety, and quality of life for visually impaired and elderly users.

Chapter 1: Introduction

Mobility and independent navigation are among the most significant challenges faced by visually impaired individuals and elderly people. Everyday environments contain numerous static and dynamic obstacles such as walls, furniture, pedestrians, vehicles, and other objects that can create dangerous situations and limit a person's ability to move safely and confidently. While traditional mobility aids, such as white canes and standard walkers, provide basic assistance, they offer limited information about the surrounding environment and cannot identify obstacle types or suggest safe navigation paths.

Our aim was to develop a Smart Walker that enhances the user's awareness of the environment and provides intelligent assistance during movement. The system combines computer vision, LiDAR sensing, embedded systems, and artificial intelligence technologies to create an assistive platform capable of detecting obstacles, identifying objects, estimating safe directions, and providing real-time guidance. The walker remains fully controlled by the user while offering additional support features that improve safety and navigation efficiency.

The project requires the integration of multiple hardware and software components working simultaneously in real time. Environmental data is collected through sensors and processed by embedded computing units that continuously analyze the surroundings and generate navigation decisions. The importance of the project lies in transforming a traditional mobility aid into an intelligent system capable of assisting users in complex environments while maintaining ease of use and reliability.

In this report, we present the design and implementation of the Smart Walker system. We discuss the technologies used, the hardware and software components developed, and the methodologies adopted to achieve the desired functionality. Furthermore, we explain the testing procedures, system performance, and the challenges encountered during the development process.

The increasing growth of the elderly population and the number of individuals living with visual impairments has created a growing demand for advanced assistive technologies. Recent developments in artificial intelligence, computer vision, and embedded systems have enabled the creation of intelligent devices capable of providing environmental awareness and decision support. However, many existing solutions remain expensive, limited in functionality, or unsuitable for daily use in different environments.

This project addresses these challenges by designing and implementing a Smart Walker system that integrates object recognition, obstacle detection, voice guidance, steering assistance, safety mechanisms, and user authentication into a single platform. The system utilizes an OAK-D camera to recognize and classify surrounding objects, while a LiDAR sensor continuously measures distances and detects obstacles. A Raspberry Pi processes sensor data and generates navigation decisions, while an Arduino Mega controls steering assistance, braking mechanisms, monitoring functions, and other hardware components.

Objectives of this project include:

1. To design and develop an intelligent walker that assists visually impaired and elderly users during navigation.
2. To detect and identify surrounding objects using computer vision techniques.
3. To detect obstacles and estimate safe navigation paths using LiDAR sensing.
4. To provide real-time voice guidance and environmental awareness.
5. To implement steering assistance and safety mechanisms that enhance user protection.
6. To integrate Raspberry Pi, Arduino Mega, camera systems, and sensors into a unified platform.
7. To implement user authentication and monitoring features.
8. To evaluate the system under different navigation scenarios and operating conditions.

The scope of this project includes the development of a prototype Smart Walker equipped with sensing, processing, and assistive technologies. The project focuses on object recognition, obstacle detection, navigation assistance, voice feedback, steering control, braking functionality, authentication, battery monitoring, and guardian monitoring. The system is intended to assist users during navigation rather than operate as a fully autonomous mobility device. Therefore, the user remains responsible for movement decisions while benefiting from the guidance and assistance provided by the system.

The significance of this work lies in its contribution to the field of assistive technology and smart mobility systems. By combining artificial intelligence, computer vision, LiDAR sensing, and embedded control, the proposed Smart Walker provides a practical and cost-effective solution that can improve mobility, safety, and independence for visually impaired and elderly individuals. The project demonstrates how modern technologies can be utilized to address real-world accessibility challenges and enhance quality of life.

Finally, this report is structured as follows: Chapter 2 discusses the theoretical background and previous work. Chapter 3 describes the methodology, system implementation, tools and technologies used throughout the project, constraints, standards, and earlier coursework related to the project. Chapter 4 discusses the results and analysis of the developed system. Chapter 5 provides discussion and interpretation of the findings. Finally, Chapter 6 concludes the report and presents recommendations and future work.

Chapter 2: Theoretical Background and Previous Work

Assistive mobility systems for visually impaired and elderly users have been extensively studied over the past decades, driven by the need to improve independent navigation beyond traditional aids such as white canes and guide dogs. While these conventional tools remain effective for basic obstacle detection, they do not provide contextual environmental understanding or intelligent navigation assistance. This limitation has motivated significant research into sensor-based and AI-driven mobility solutions.

Early assistive navigation systems primarily relied on ultrasonic and infrared sensors due to their low cost, simplicity, and ease of integration. One notable example is the ultrasonic navigation system developed by Bousbia-Salah et al., which provided obstacle detection and audio feedback for visually impaired users. Although the system demonstrated improved navigation capabilities, it was limited by the sensing characteristics of ultrasonic technology and lacked object recognition functionality [1]. Similarly, Dakopoulos and Bourbakis reviewed numerous wearable electronic travel aids and concluded that single-sensor solutions often suffer from limitations in accuracy, environmental adaptability, and information richness [2].

With advances in robotics and embedded computing, LiDAR-based navigation systems became increasingly popular. LiDAR sensors provide accurate distance measurements, wide environmental coverage, and reliable operation under varying lighting conditions. Research has shown that LiDAR significantly improves obstacle detection performance compared to traditional ultrasonic approaches [3]. However, LiDAR alone cannot identify or classify objects within the environment, limiting its ability to provide semantic scene understanding.

To overcome this limitation, computer vision and deep learning techniques such as YOLO and SSD have been widely adopted for real-time object detection and recognition [4][5]. These approaches enable assistive systems to identify pedestrians, vehicles, furniture, and other environmental features with high accuracy. Nevertheless, vision-based systems are often sensitive to lighting conditions and may require substantial computational resources for real-time operation.

Recent research has focused on sensor fusion approaches that combine LiDAR and computer vision technologies. By integrating accurate spatial measurements from LiDAR with semantic information obtained from image processing, these systems achieve more reliable navigation and obstacle avoidance performance [6]. Although sensor fusion improves overall system capability, challenges related to synchronization, processing load, cost, and system integration remain significant.

In parallel, modern assistive platforms increasingly employ embedded architectures that separate high-level processing from low-level control. Raspberry Pi devices are commonly used for artificial intelligence and sensor data processing, while Arduino microcontrollers handle real-time control tasks and hardware interfacing [7]. Human-machine interaction research has also demonstrated that voice feedback is an effective method for communicating navigation information to visually impaired users, improving usability and situational awareness when designed appropriately [8]. Additionally, wireless communication modules such as GSM (SIM800L) are frequently integrated to support emergency notifications and remote monitoring functions.

Overall, research demonstrates a clear evolution from simple obstacle detection devices toward intelligent multi-modal assistive systems that integrate sensing, artificial intelligence, embedded control, and communication technologies. Despite substantial progress, challenges related to affordability, portability, real-time performance, and system integration continue to exist. The proposed Smart Walker addresses these challenges by combining LiDAR-based obstacle detection, AI-powered object recognition, voice guidance, user authentication, remote monitoring, and safety features within a single integrated and cost-effective mobility assistance platform.

Chapter 3: Methodology

3.1 System Methodology

3.1.1 System Design

The Smart Walker was designed as an integrated assistive mobility platform that combines environmental perception, intelligent decision-making, mechanical assistance, and remote monitoring capabilities. The system architecture consists of two main processing layers:

1. **High-Level Processing Layer (Raspberry Pi 4)** responsible for object detection, LiDAR processing, navigation decision-making, audio guidance, and communication management.
2. **Low-Level Control Layer (Arduino Mega 2560)** responsible for direct control of motors, actuators, sensors, safety mechanisms, and hardware interfaces.

The design follows a distributed architecture in which the Raspberry Pi performs computationally intensive tasks, while the Arduino handles real-time control operations. Communication between both units is achieved through serial communication, allowing navigation decisions generated by the Raspberry Pi to be translated into physical actions by the Arduino.

The walker incorporates multiple subsystems including obstacle detection, object recognition, steering assistance, automatic braking, vibration feedback, user authentication, battery monitoring, banknote recognition, emergency communication, and guardian monitoring.

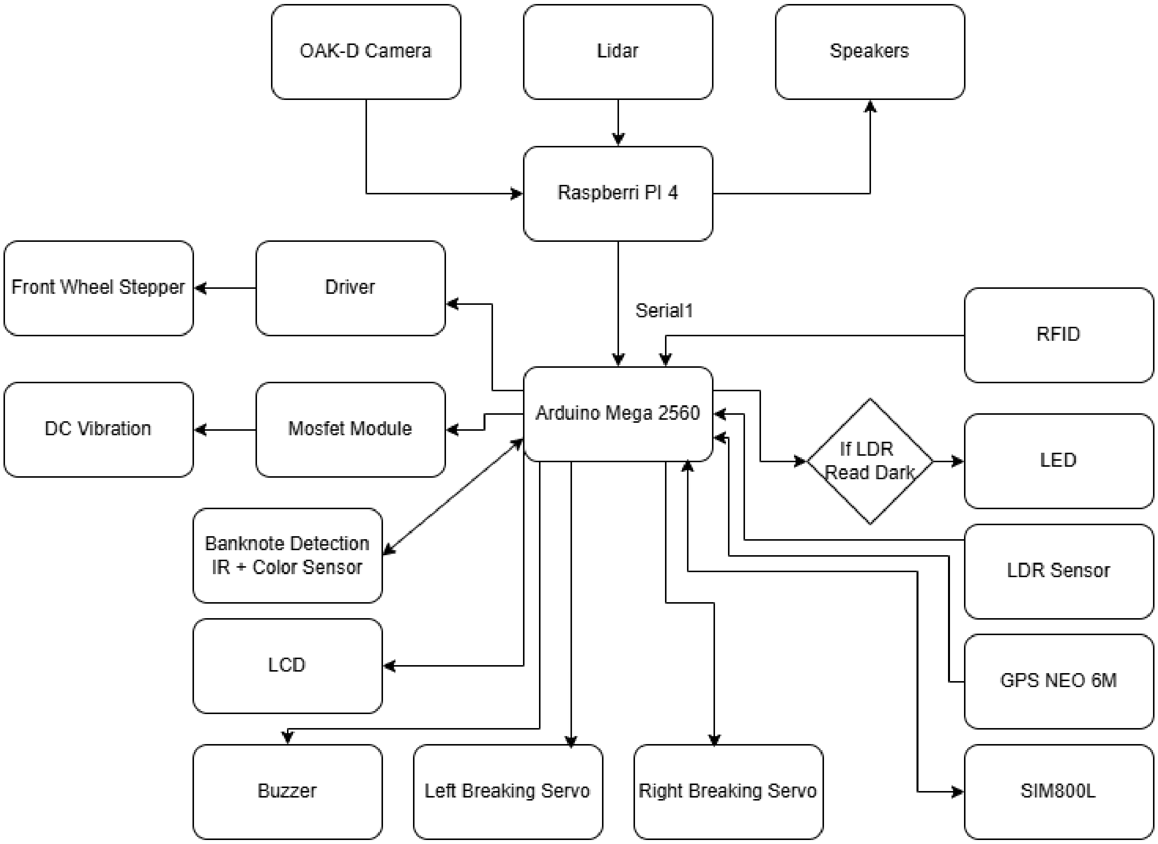

Figure 1: System's Hardware Architecture Diagram

The overall system architecture illustrates the interaction between sensing devices, processing units, control modules, user interfaces, and communication components.

Some Images of the final design:

Figure 2: Smart Walker Final Prototype – Front View

Figure 3: Smart Walker Final Prototype – Side View

Figure 4: Smart Walker Final Prototype – Back View

Figure 5: Smart Walker Final Prototype – Front View

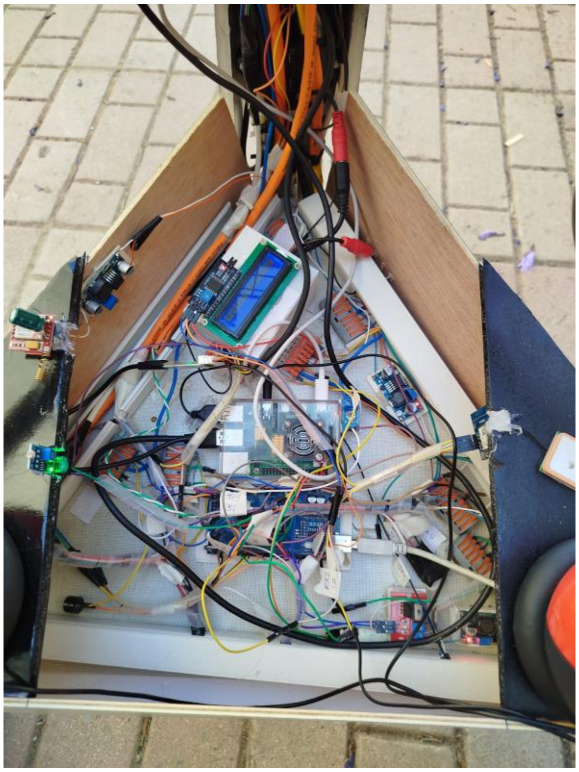

Figure 6: Smart Walker Final Prototype – Detail View 1

Figure 7: Smart Walker Final Prototype – Detail View 2

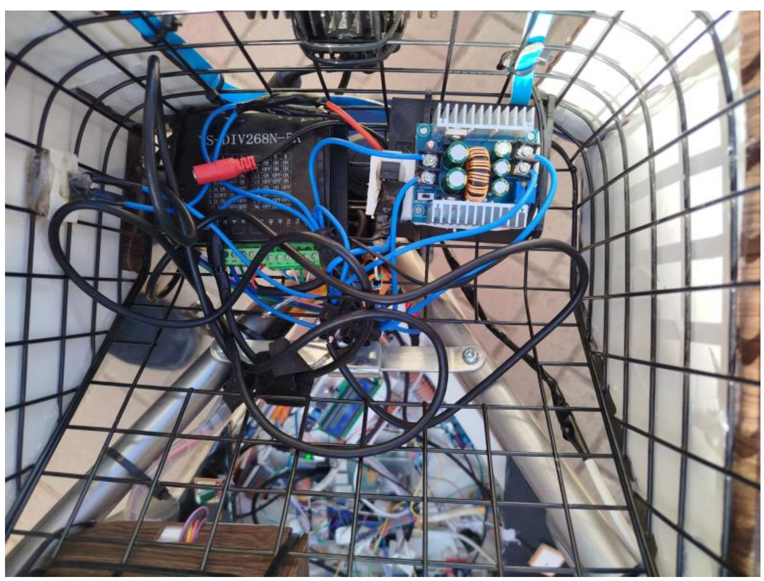

Figure 8: Smart Walker Final Prototype – Detail View 3

3.1.2 Hardware Components

The Smart Walker integrates a variety of hardware components that work together to provide mobility assistance and safety functions.

Processing and Control Units

Raspberry Pi 4 Model B 4GB RAM

Figure 9: Raspberry Pi 4 Model B

Serves as the main processing unit responsible for executing object detection algorithms, LiDAR data processing, navigation logic, audio generation, and communication with external devices.

Arduino Mega 2560

Figure 10: Arduino Mega 2560

Acts as the real-time control unit responsible for motor control, braking operations, sensor acquisition, battery monitoring, and communication with the Raspberry Pi.

Environmental Perception Components

OAK-D Camera

Figure 11: OAK-D Camera

Provides real-time object detection and environmental awareness. The camera identifies surrounding objects and determines their relative positions, enabling the system to provide voice-based notifications to the user.

LiDAR Sensor

Figure 12: LiDAR Sensor

Functions as the primary obstacle detection sensor. It continuously scans the surrounding environment and measures distances to nearby obstacles, allowing the system to determine safe navigation paths.

Mobility Assistance Components

NEMA 23 Stepper Motor with Driver

Figure 13: NEMA 23 Stepper Motor with Driver

Figure 14: Stepper Motor Driver

Controls the steering mechanism of the front wheel. Steering commands generated by the navigation system are executed through this motor to assist the user in avoiding obstacles.

Potentiometer-Based Position Feedback

Figure 15: Potentiometer-Based Position Feedback

Mounted on the steering shaft to provide continuous angle feedback and ensure accurate steering control.

Servo Motor Braking System

Figure 16: Servo Motor Braking System

Figure 17: Braking Mechanism Assembly

Two metal servo motors are used to activate the braking mechanism whenever an unsafe situation or obstacle is detected.

Vibration Feedback System

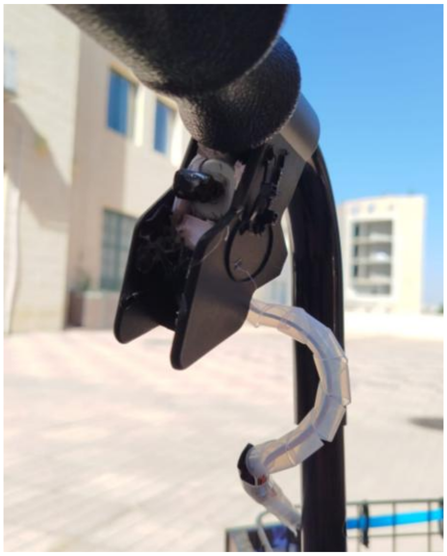

Figure 18: Vibration Motor Mounting

Figure 19: Vibration Feedback Motor

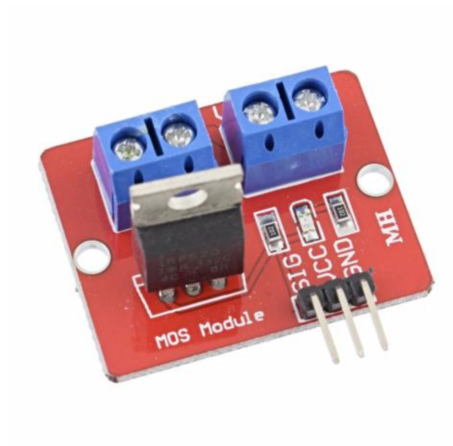

Figure 20: MOSFET Module

A 9-12V DC motor 6000RPM with irregular head (for vibration) controlled through a MOSFET module generates vibration alerts on the walker handles to provide additional user feedback.

User Authentication and Safety Components

RFID Reader Module

Figure 21: RFID Mounting

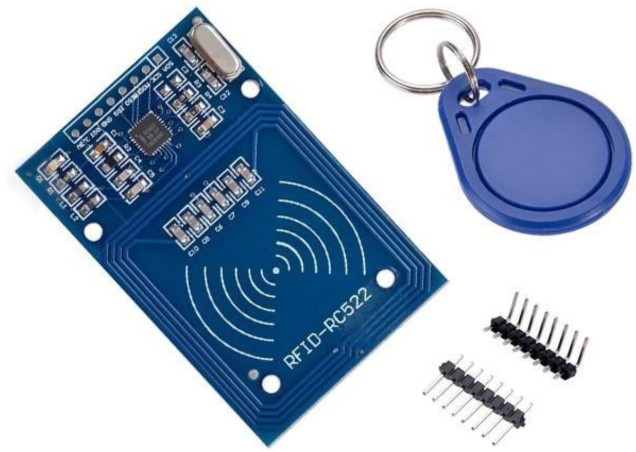

Figure 22: RFID Reader Module (MFRC522)

Restricts walker operation to authorized users by verifying RFID cards before enabling system functionality.

Push Button (SOS Button)

Figure 23: Push Button (SOS Button)

Allows the user to manually trigger emergency alerts when assistance is required.

Buzzer

Figure 24: Buzzer Module

Provides audible notifications related to emergency alerts and communication events.

Communication and Tracking Components

SIM800L GSM Module

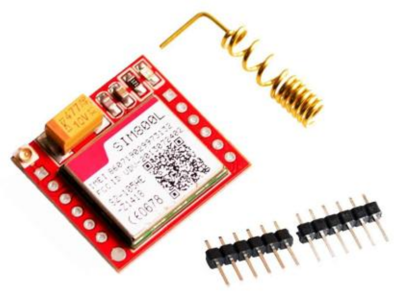

Figure 25: SIM800L GSM Module

Provides wireless communication capabilities between the walker and the mobile application. It is used for emergency alerts, battery status reporting, and location requests.

GPS NEO-6M Module

Figure 26: GPS NEO-6M Module

Provides real-time location information that can be transmitted to guardians through the communication subsystem.

Power Management Components

Dual Battery Architecture

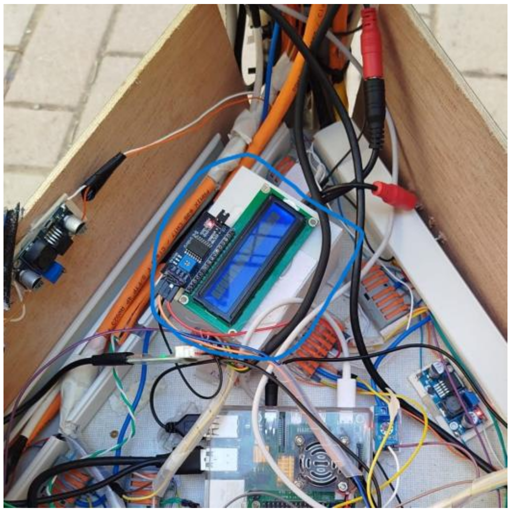

Figure 27: Battery 1 Location

Figure 28: Battery 2 Location

The system utilizes two independent battery systems. One battery powers control electronics such as the Arduino, sensors, servos, and peripheral modules, while the second battery powers high-consumption devices including the Raspberry Pi, OAK-D camera, LiDAR sensor, and lighting system (LED).

Figure 29: Stepper's Powerbank

A 12V-4.5A high capacity powerbank to provide power to NEMA23 stepper only throughout the driver.

Voltage Sensors

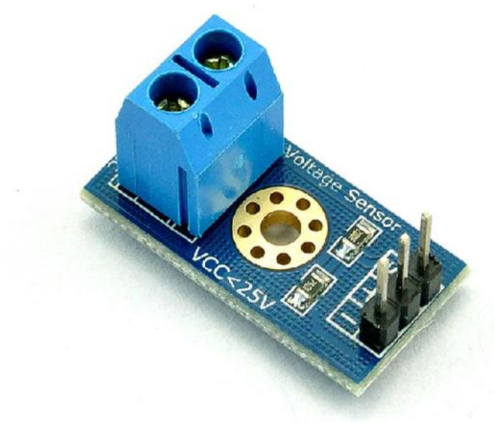

Figure 30: Voltage Sensor

Continuously monitor battery voltages and provide battery status information to the user.

Buck Converters and Voltage Regulators

Figure 31: LM2596 Voltage Regulator

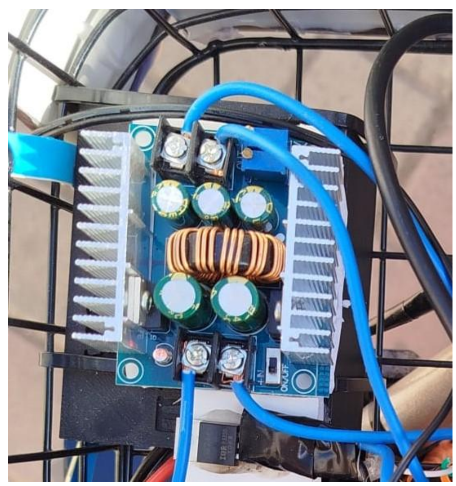

Figure 32: 20A Buck Converter

Used to provide stable operating voltages for different subsystems and communication interfaces.

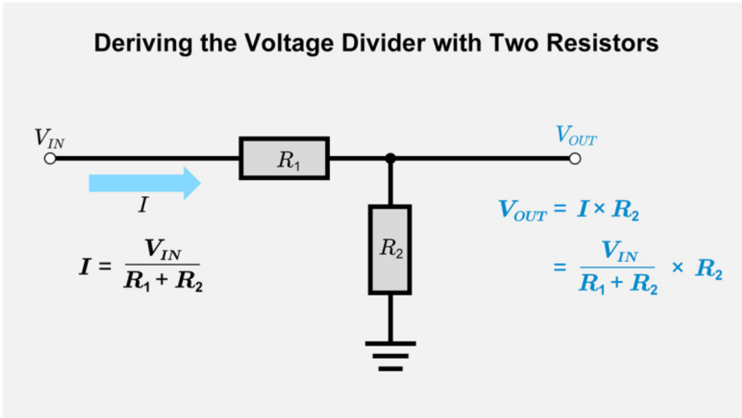

Figure 33: Voltage Divider Circuit Diagram

Also made a voltage divider to step down the 5V from Arduino Mega's TX pin to 3.3V for the Raspberry Pi 4's RX pin. (Used R1=1kOhm, R2=2.2kOhm)

User Interaction Components

Speaker

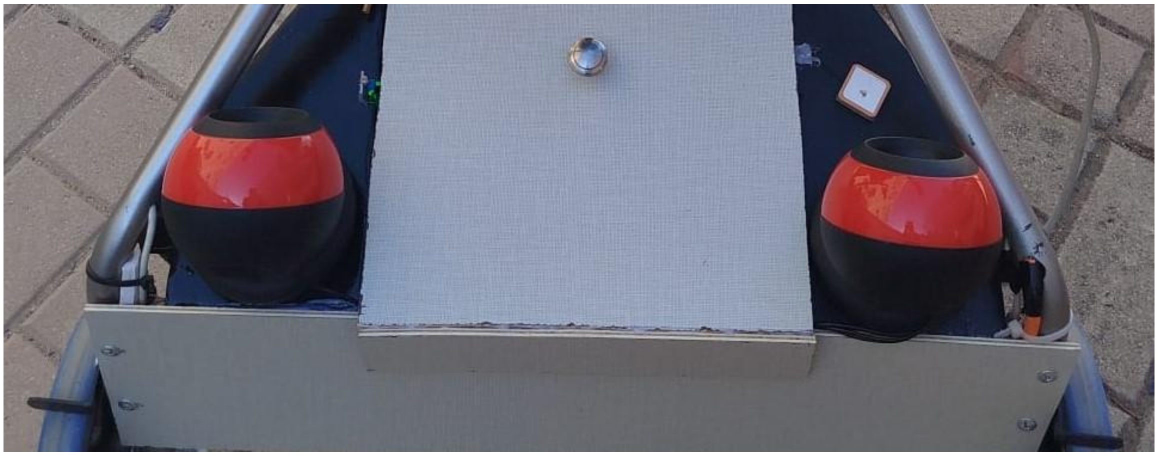

Figure 34: Speaker Module

Provides voice guidance, object announcements, navigation instructions, and banknote recognition feedback.

LCD Display

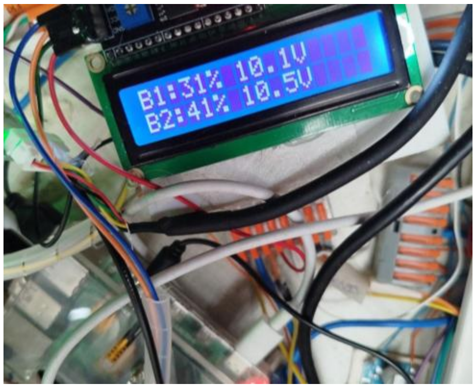

Figure 35: LCD Display

Displays battery status, and voltage readings.

LED Lighting System

Figure 36: LED Lighting Strip

Approximately 70cm 12V LED strip, which automatically illuminates the environment under low-light conditions to improve camera performance and user visibility.

LDR Sensor

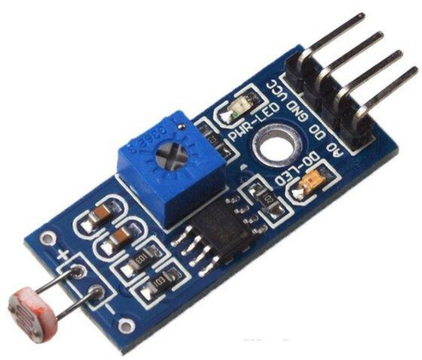

Figure 37: LDR Sensor

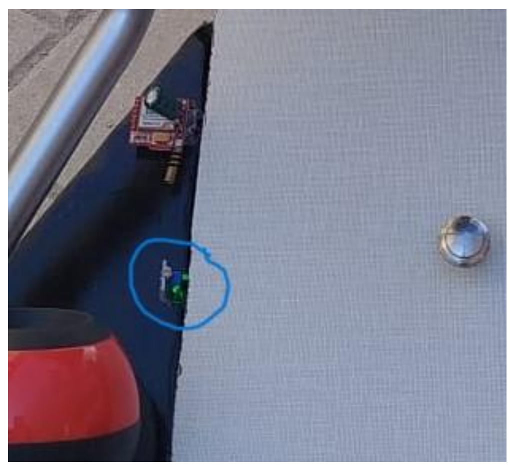

Figure 38: LDR Sensor Mounting

Detects ambient lighting conditions and controls automatic LED activation throughout Arduino.

1RFZ44N MOSFET

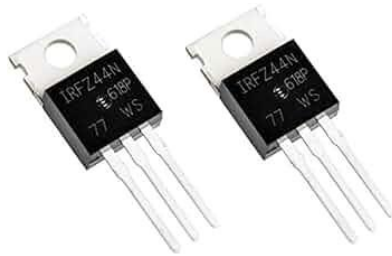

Figure 39: IRF Z44N MOSFET Module

Controls the ON/OFF process for LED by the arduino signals (Acts as a gate).

Banknote Detection Components

Figure 40: Banknote Detection Box

Figure 41: Banknote Detection Box - Top View

IR Sensor

Figure 42: IR Sensor

Detects banknote enterence to the box.

TCS 34725 Color Sensor

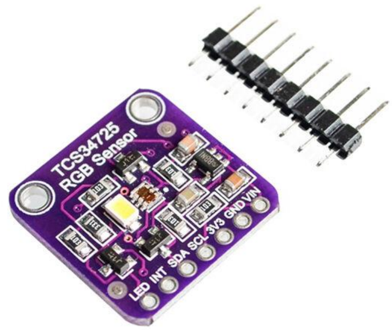

Figure 43: TCS34725 Color Sensor

Detects the color of the banknote (20ILS: red, 50ILS: green, 100ILS: orange, 200ILS: blue), and arduino generated the decision based on this.

3.1.3 Mobile Application

A dedicated mobile application was developed to provide remote monitoring and emergency communication capabilities. The application is intended primarily for guardians or family members responsible for assisting the user.

The application communicates with the Smart Walker through the SIM800L GSM module and provides several functionalities including:

- Receiving emergency SOS alerts.
- Requesting and viewing the current walker location.
- Monitoring batteries status.
- Sending alerts to walker.

The mobile application extends the safety features of the Smart Walker by allowing guardians to monitor the user's condition remotely and respond quickly during emergency situations.

Figure 44: Mobile Application – Home Screen

Figure 45: Mobile Application – Edit Walker's Phone Number

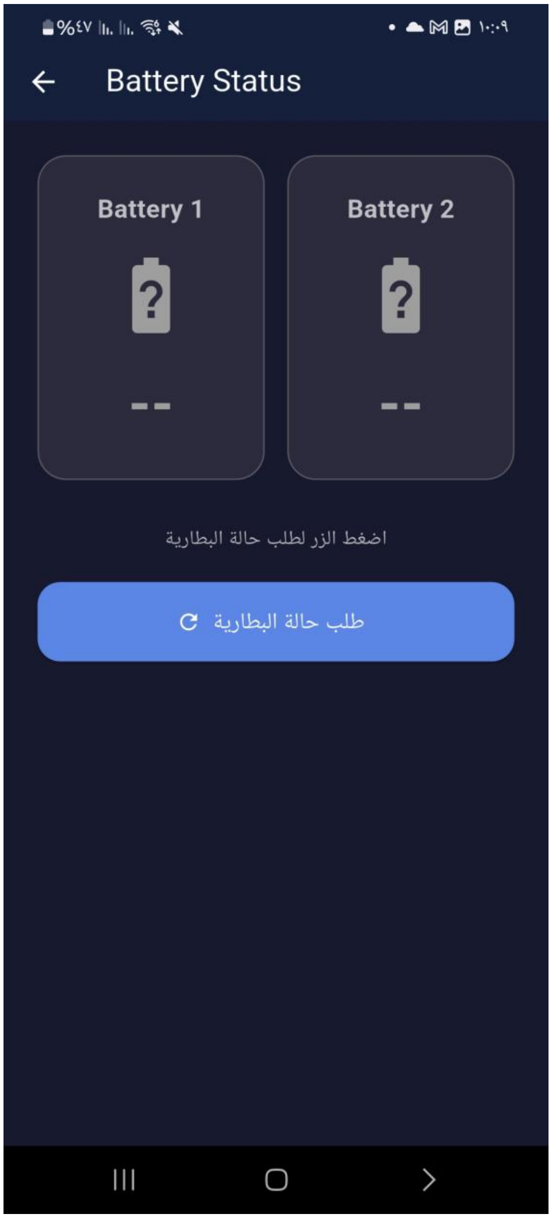

Figure 46: Mobile Application – Empty Battery Status Screen

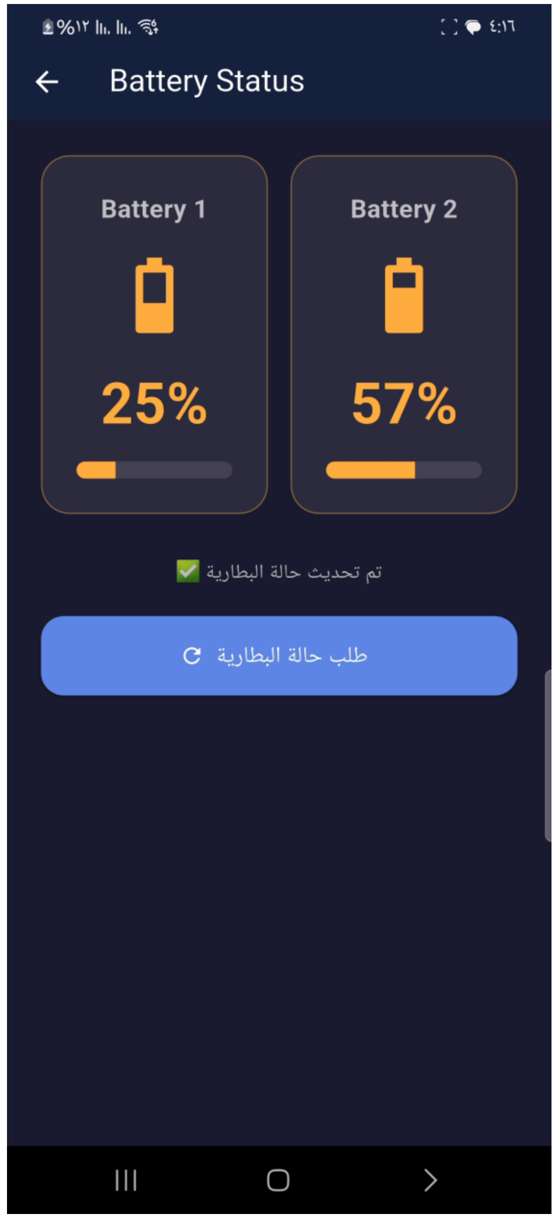

Figure 47: Mobile Application – Battery Status Screen

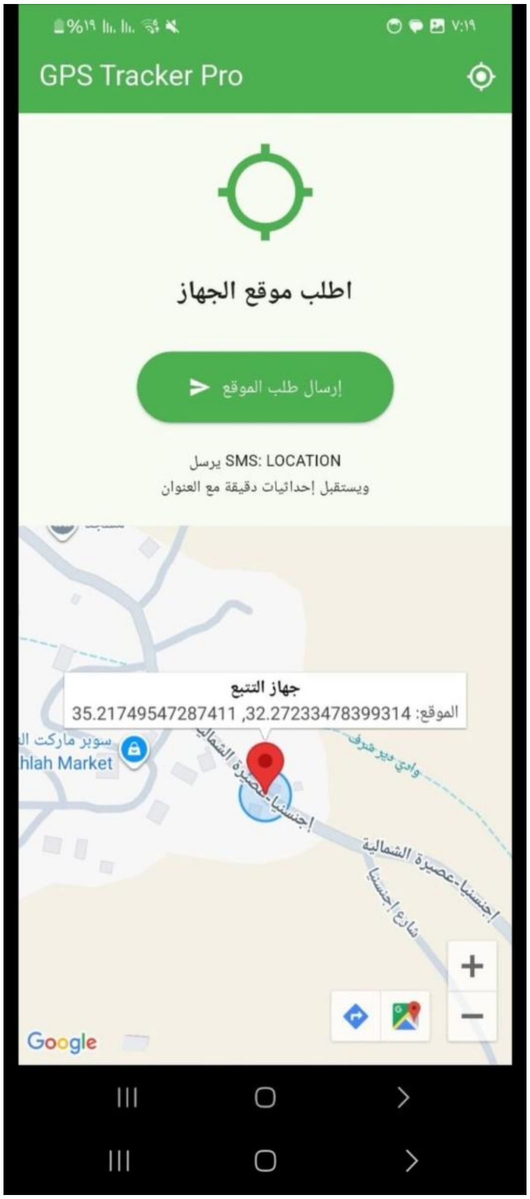

Figure 48: Mobile Application – Location Screen

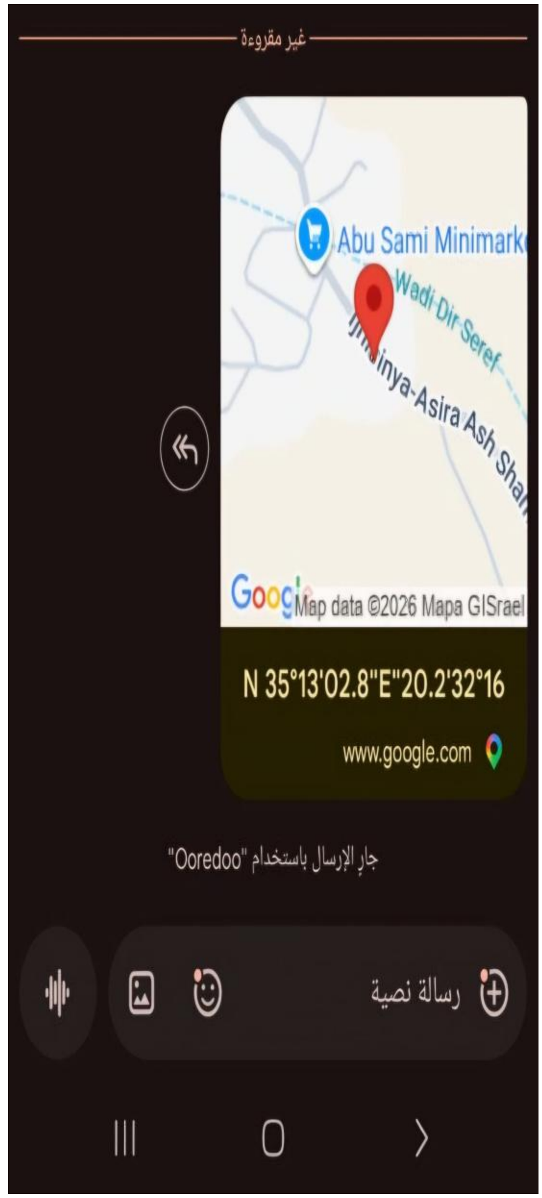

Figure 49: Mobile Application – Location Message

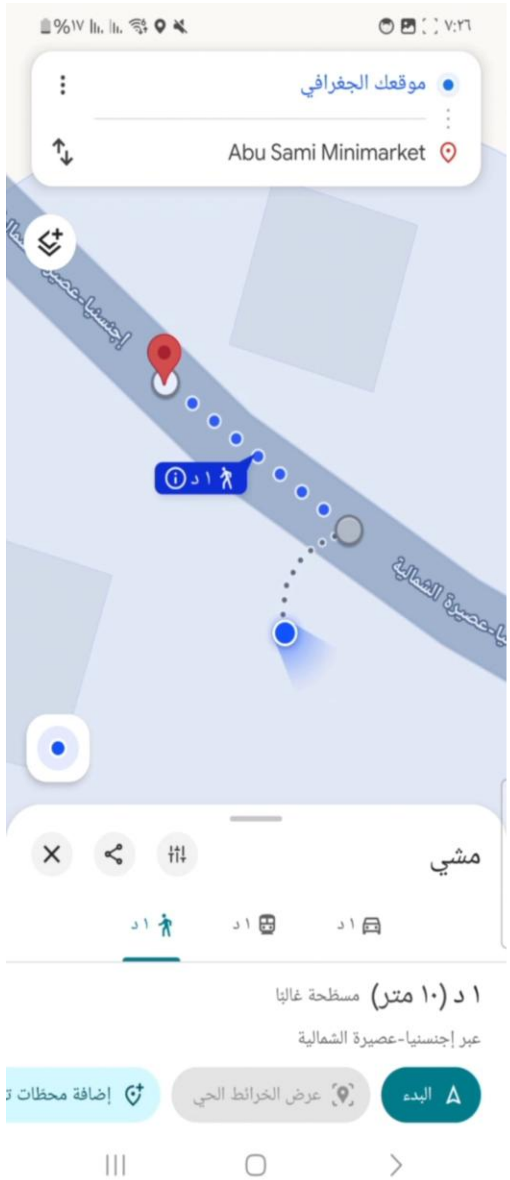

Figure 50: Mobile Application – Route

3.1.4 System Operation

The operation of the Smart Walker begins when an authorized user scans a valid RFID card. Once authentication is successful, the system activates all sensing, processing, and communication modules.

The LiDAR sensor continuously scans the environment and sends distance measurements to the Raspberry Pi. Simultaneously, the OAK-D camera performs real-time object detection and identifies surrounding objects together with their relative directions.

The Raspberry Pi processes both LiDAR and camera data to evaluate the surrounding environment and determine safe navigation decisions. When an obstacle is detected, the navigation algorithm calculates the appropriate action, such as steering adjustment, braking activation, or warning generation.

Navigation commands are transmitted to the Arduino Mega through serial communication. The Arduino then controls the steering motor, braking servos, vibration feedback motor, and other hardware components according to the received instructions.

Voice guidance is generated through the speaker to inform the user about nearby objects and their locations. Example messages include “Person on the left,” “Chair on the right,” or navigation instructions such as “Move slightly left.”

The system continuously monitors battery levels, ambient lighting conditions, and communication status. During low-light conditions, the LED lighting system is activated automatically. Battery information is displayed on the LCD and may also be transmitted to the mobile application.

If the user presses the SOS button, the Arduino immediately triggers the SIM800L communication module, which sends an emergency alert and location information to the guardian through the mobile application.

This process continues continuously in real time, enabling the Smart Walker to provide safe navigation assistance, environmental awareness, and emergency support.

3.2 Constraints

Design Complexity

The Smart Walker system integrates multiple hardware and software subsystems, including computer vision, LiDAR sensing, embedded controllers, communication modules, and mechanical actuation. One of the primary challenges was designing a unified architecture that enables all subsystems to operate together in real time while maintaining system stability, responsiveness, and safety.

Additional complexity arose during the mechanical and electrical design stages. Multiple design iterations were required to determine suitable component placement, wiring routes, and subsystem integration. The braking mechanism underwent several design revisions, including the evaluation of linear actuators and cable-based braking systems. The final implementation adopted a servo motor-based braking mechanism due to its simplicity, reliability, and cost-effectiveness.

Mechanical integration also required structural modifications to mount the NEMA 23 stepper motor onto the steering assembly. Furthermore, several steering feedback approaches were investigated, including encoders and limit switches, before a potentiometer-based solution was selected due to its practical reliability and ease of implementation.

Cable routing presented additional challenges because several components, including RFID modules, vibration motors, and control switches, were installed in different sections of the walker. Internal routing channels and structural modifications were required to maintain a clean and reliable installation. Signal noise resulting from long cable runs was mitigated through the use of CAT7 cabling. The power architecture also evolved from a single-battery configuration to a multi-battery design that separates high-power and low-power subsystems, improving overall stability and reducing electrical interference.

Safety and Reliability Constraints

Since the Smart Walker is intended for visually impaired and elderly users, safety represents a critical design constraint. Any incorrect detection result, navigation decision, or control command may lead to unsafe movement or potential accidents. Therefore, the system was designed with conservative decision-making strategies, obstacle avoidance mechanisms, braking assistance, and multiple validation checks to prioritize user safety over system speed or performance.

Environmental Constraints

The system is designed for operation in both indoor and outdoor environments where lighting conditions, obstacle types, weather conditions, and terrain characteristics may vary considerably. During development and testing, limited access to diverse real-world environments restricted the ability to evaluate all possible operating scenarios, particularly uneven surfaces, dynamic obstacles, and challenging lighting conditions.

Sensor Accuracy and Limitations

The Smart Walker relies heavily on LiDAR and OAK-D camera data for environmental perception. These sensors possess inherent limitations such as measurement noise, reduced performance under specific environmental conditions, and occasional detection inaccuracies caused by reflective surfaces or poor lighting. Consequently, filtering, validation, and sensor fusion techniques were required to improve the reliability of navigation decisions.

Hardware and Resource Constraints

As a student-developed prototype, the project was constrained by limited computational resources, hardware availability, and budget restrictions. Real-time execution requirements for object detection, distance measurement, navigation processing, and actuator control required careful optimization of both software and hardware resources.

Economic Constraints

The project was developed within a limited budget. Therefore, component selection involved balancing performance, reliability, and cost. Several alternative solutions were evaluated during development, and cost-effective components were selected whenever possible without compromising essential system functionality.

Manufacturability Constraints

The system was designed using commercially available hardware components and manufacturing processes that can be reproduced using commonly accessible tools and workshops. This constraint influenced several design decisions related to the walker structure, mounting mechanisms, and mechanical assemblies.

Sustainability Constraints

The Smart Walker was designed using a modular architecture that facilitates future upgrades and maintenance. Major subsystems such as sensors, communication modules, batteries, and software components can be replaced or upgraded independently without requiring a complete redesign of the system.

Ethical and Privacy Constraints

The system incorporates location tracking, guardian monitoring, and user identification features. Therefore, privacy considerations were taken into account by limiting access to user information to authorized individuals only. The system was designed to support user independence while respecting privacy and data confidentiality.

Knowledge and Expertise Constraints

Although the project is highly technical, it also involves practical considerations related to assistive mobility and user behavior. Limited access to rehabilitation specialists and assistive technology experts restricted opportunities for direct professional validation of some design decisions and performance assumptions.

3.3 Standards and Specifications (Codes)

The Smart Walker design follows several widely adopted engineering standards, communication protocols, and hardware specifications to ensure compatibility, reliability, and maintainability.

Serial Communication Standards

Communication between the Raspberry Pi and Arduino Mega is implemented using UART serial communication. This standard provides reliable real-time exchange of navigation commands, sensor readings, system status information, and control signals between high-level and low-level processing units.

RFID Standards

The RFID authorization subsystem is based on the MFRC522 reader module, which supports ISO/IEC 14443 Type A contactless smart card communication standards. This standard enables secure identification and user authentication functionality.

GSM Communication Standards

Remote communication and monitoring functions are implemented using the SIM800L GSM/GPRS module, which operates according to GSM standards in the 850, 900, 1800, and 1900 MHz frequency bands. These standards support emergency notifications, location reporting, and remote status monitoring.

Embedded System Specifications

The system employs an Arduino Mega microcontroller for real-time hardware control and a Raspberry Pi for high-level processing tasks. This architecture follows common embedded system design practices that separate computationally intensive tasks from low-level hardware control to improve reliability and system performance.

Computer Vision Framework Standards

Object detection functionality is implemented using deep learning-based computer vision techniques compatible with modern YOLO object detection frameworks. The system follows standard object recognition methodologies used in intelligent perception applications.

Electrical and Power Specifications

The walker operates using low-voltage DC power systems suitable for embedded and mobile applications. Separate power distribution paths are utilized for high-current actuators and sensitive electronic components to improve electrical stability and reduce interference.

Safety Considerations

Safety measures were incorporated throughout the design process. These include controlled braking mechanisms, obstacle avoidance logic, battery monitoring, emergency communication capabilities, secure electrical wiring practices, and mechanical mounting structures designed to withstand normal operational loads.

3.4 Earlier Coursework

Microcontrollers and Embedded Systems / PIC

These courses provided the theoretical and practical foundation required for programming the Arduino Mega, interfacing sensors, controlling actuators, and implementing real-time embedded control systems.

Artificial Intelligence, Machine Learning, and Image Processing

These courses supported the understanding of computer vision concepts, object detection algorithms, data processing techniques, and intelligent decision-making methods used within the Smart Walker system.

CPU and PIC Laboratories

The laboratory courses provided practical experience with electronic components, motors, sensors, datasheets, circuit implementation, troubleshooting, hardware integration, and embedded system development, all of which contributed directly to the successful implementation of the project.

Chapter 4: Results and Analysis

4.1 Introduction

This chapter presents the results obtained from the implementation and testing of the Smart Walker prototype. The developed system integrates multiple hardware and software subsystems including LiDAR-based obstacle detection, camera-based object recognition, steering assistance, braking control, voice guidance, banknote recognition, remote monitoring, and emergency communication. The performance of each subsystem is discussed and analyzed based on practical testing conducted during the development process.

4.2 Final Smart Walker Prototype

After completing the mechanical, electrical, and software integration stages, a fully functional Smart Walker prototype was successfully developed. The final system combines environmental sensing, intelligent navigation assistance, user interaction, and remote monitoring features within a single platform.

The walker structure accommodates all sensors, controllers, communication modules, batteries, and mechanical assistance components while maintaining stability and usability.

The final prototype demonstrated successful integration of all major subsystems and provided a practical platform for testing and evaluation.

4.3 Obstacle Detection and Navigation Results

The LiDAR-based navigation subsystem successfully detected obstacles located in the walking path and continuously monitored the surrounding environment. Navigation decisions were generated in real time and transmitted to the Arduino controller to activate steering assistance and braking mechanisms when required.

Testing showed that the system was capable of identifying safe movement directions and reacting appropriately when obstacles were detected in front of the walker.

The integration between the LiDAR sensor, Raspberry Pi, and Arduino controller enabled reliable obstacle avoidance behavior and contributed significantly to user safety.

4.4 Object Detection Results

The OAK-D camera successfully detected and classified common objects encountered during daily navigation. Detected objects included people and chairs.

The system generated voice announcements describing the detected object and its relative direction, allowing the user to gain additional environmental awareness beyond basic obstacle avoidance.

The object detection subsystem provided valuable contextual information that complemented the LiDAR-based navigation functionality.

4.5 Steering and Braking System Results

The steering assistance mechanism was successfully integrated with the navigation subsystem. Steering commands generated by the Raspberry Pi were transmitted to the Arduino controller, which adjusted the front wheel orientation using the potentiometer on NEMA 23 stepper motor.

The braking system also operated successfully during testing. When potentially unsafe situations were detected, the braking servos activated and reduced walker movement.

The combined steering and braking mechanisms enhanced navigation safety and demonstrated reliable operation during testing.

4.6 Voice Guidance System Results

The voice guidance subsystem successfully provided real-time audio feedback to the user. Voice messages informed the user about detected objects, their directions, and banknote recognition results.

Examples of generated messages included object announcements such as people, and chairs, as well as navigation-related instructions: person on the left, chair on the right.

The voice feedback system improved environmental awareness and reduced the need for direct interaction with system controls.

4.7 Banknote Recognition Results

The banknote recognition subsystem was implemented using an infrared sensor and a color sensor. When a banknote was inserted into the recognition slot, the system identified its denomination and generated a corresponding voice announcement.

The subsystem successfully distinguished between supported banknote categories and provided immediate user feedback.

This functionality can assist visually impaired users during daily financial transactions.

4.8 Mobile Application and Communication Results

A mobile application was developed to provide remote monitoring and communication features for guardians. The application successfully communicated with the walker through the SIM800L GSM module.

The implemented features included location requests, emergency notifications, battery monitoring, receiving SOS signals.

Testing confirmed successful communication between the Smart Walker and the mobile application, enabling remote monitoring capabilities.

4.9 Battery Monitoring and Power Management Results

The dual-battery architecture with a powerful powerbank successfully supplied power to the various walker subsystems. Voltage monitoring sensors continuously measured battery levels and displayed status information on the LCD screen.

The separation between high-power and low-power subsystems improved system stability and reduced electrical interference between components.

The implemented power management strategy contributed to reliable system operation during testing.

4.10 Overall System Analysis

The final Smart Walker prototype successfully integrated computer vision, LiDAR sensing, embedded control, communication technologies, and user interaction features into a single assistive mobility platform.

The obstacle detection subsystem improved navigation safety, while the object detection subsystem enhanced environmental awareness. Steering assistance and braking mechanisms provided physical support during movement, and the voice guidance system enabled intuitive interaction with the user. Additional features such as banknote recognition, guardian monitoring, emergency communication, and battery monitoring further expanded the functionality of the system.

Although environmental conditions and hardware limitations occasionally affected subsystem performance, the developed prototype successfully achieved the primary project objective of providing an intelligent mobility assistance solution for visually impaired and elderly users.

Chapter 5: Discussion

5.1 Overview

The primary objective of the Smart Walker project was to develop an intelligent mobility assistance system capable of improving the safety, independence, and environmental awareness of visually impaired and elderly users. The developed prototype successfully integrated multiple technologies, including computer vision, LiDAR sensing, embedded control systems, voice interaction, and remote communication, into a single assistive platform.

The results presented in the previous chapter demonstrate that the proposed system was able to perform its intended functions and provide meaningful assistance during navigation and daily activities.

5.2 Achievement of Project Objectives

One of the main goals of this project was to address the limitations of traditional mobility aids such as white canes. While conventional aids can assist users in detecting nearby obstacles, they generally provide limited information about the surrounding environment.

The developed Smart Walker successfully expanded this functionality by combining obstacle detection, object recognition, voice guidance, steering assistance, and emergency communication features. As a result, users are provided with both physical assistance and contextual environmental awareness, allowing safer and more informed navigation.

Therefore, the project successfully achieved its primary objective of creating an intelligent mobility assistance system for visually impaired and elderly users.

5.3 Contributions of the Project

The main contribution of this project is the successful integration of several independent technologies into a single practical platform designed specifically for assistive mobility applications.

Unlike systems that rely on a single sensing technology, the Smart Walker combines LiDAR-based obstacle detection with camera-based object recognition. This combination enables the system to understand both the location of obstacles and their identity, providing richer information to the user.

Additional contributions include:

- Integration of steering assistance and automatic braking mechanisms.
- Real-time voice guidance and environmental awareness.

- RFID-based user authorization.
- Banknote recognition for visually impaired users.
- Guardian monitoring through GSM and GPS technologies.
- Battery monitoring and automatic lighting control.

The integration of these features within a single prototype demonstrates the feasibility of developing a comprehensive and cost-effective assistive mobility platform.

5.4 Comparison with Existing Solutions

Many existing assistive mobility systems focus primarily on obstacle detection using ultrasonic sensors or basic proximity sensing technologies. While such systems can improve navigation safety, they often lack environmental understanding and intelligent decision-making capabilities.

Recent research has increasingly adopted computer vision and LiDAR technologies to improve assistive navigation performance. The Smart Walker follows this trend by combining both approaches. LiDAR provides reliable distance measurements and obstacle detection, while the OAK-D camera supplies object recognition and scene understanding capabilities.

Furthermore, many existing solutions focus solely on navigation assistance. In contrast, the Smart Walker extends functionality by incorporating communication, monitoring, authentication, and banknote recognition features, creating a more comprehensive assistive solution.

5.5 Limitations of the System

Although the developed prototype achieved its primary objectives, several limitations were identified during development and testing.

The performance of the object detection subsystem may be affected by poor lighting conditions or highly challenging visual environments. Similarly, reflective surfaces and complex surroundings may occasionally influence LiDAR measurements.

The system also depends on battery-powered operation, which limits continuous operating time. Additionally, GSM communication performance depends on network availability and signal quality.

Another limitation is that testing was performed within a limited range of environments and user scenarios. Broader field testing with actual visually impaired and elderly users would provide additional validation and opportunities for improvement.

5.6 Practical Implications

The Smart Walker demonstrates the potential of combining artificial intelligence, embedded systems, and sensing technologies to improve assistive mobility devices. The developed system can contribute to increased user independence, enhanced safety, and improved situational awareness.

Beyond mobility assistance, several implemented features such as emergency communication, guardian monitoring, and banknote recognition may provide additional benefits in daily life and increase user confidence while performing routine activities.

The project also demonstrates how relatively affordable hardware platforms can be combined to produce advanced assistive technologies without requiring expensive specialized equipment.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

The Smart Walker project was successfully designed, implemented, and tested as an intelligent mobility assistance system for visually impaired and elderly users. The project integrated multiple technologies, including LiDAR sensing, computer vision, embedded control systems, wireless communication, and voice interaction, into a single assistive platform.

The developed system successfully demonstrated obstacle detection and avoidance capabilities through the use of LiDAR-based navigation. In addition, the OAK-D camera provided environmental awareness by detecting and identifying surrounding objects, allowing the system to generate meaningful voice notifications that informed the user about nearby objects and their locations.

The integration between the Raspberry Pi and Arduino Mega enabled reliable coordination between high-level processing and low-level hardware control. The steering assistance mechanism, braking system, vibration feedback, and voice guidance features worked together to improve navigation safety and user awareness.

Additional functionalities such as RFID-based user authorization, banknote recognition, battery monitoring, automatic lighting control, GPS tracking, and GSM-based emergency communication further expanded the practical usefulness of the system and demonstrated the feasibility of integrating multiple assistive technologies into a single solution.

The project achieved its primary objective of developing a smart mobility assistance platform capable of improving safety, environmental awareness, and independence for visually impaired and elderly users. Furthermore, the project demonstrated that advanced assistive technologies can be implemented using commercially available and relatively affordable hardware components.

Throughout the project, valuable experience was gained in embedded systems, computer vision, sensor integration, mechanical design, communication systems, software development, and system-level engineering. The project also highlighted the importance of interdisciplinary integration when developing real-world assistive technologies.

6.2 Recommendations

Based on the experience gained throughout the design, implementation, and testing phases of the Smart Walker project, several practical recommendations can be made to improve the system and enhance its overall performance.

The mechanical structure of the walker can be further optimized to reduce weight and improve portability without compromising stability. A lighter design would increase user comfort and make the system easier to use during extended periods.

Power management can also be improved by selecting higher-capacity batteries or implementing additional power optimization techniques to extend operating time. This would increase the practicality of the system during daily use.

Future testing should be conducted under a wider variety of environmental conditions, including different lighting conditions, outdoor environments, and uneven terrain. Such testing would provide a more comprehensive evaluation of system performance and reliability.

It is also recommended to involve visually impaired and elderly users in future evaluation stages. Direct feedback from potential users would provide valuable insights regarding usability, comfort, and effectiveness, helping guide future improvements.

Finally, further refinement of the hardware layout and cable management would simplify maintenance, improve system organization, and enhance the overall appearance and reliability of the prototype.

6.3 Future Work

Although the Smart Walker successfully achieved its primary objectives, several opportunities exist for future development and enhancement.

Future versions of the system may incorporate more advanced navigation algorithms capable of providing smoother path planning and improved obstacle avoidance in complex environments. Additional artificial intelligence techniques could also be integrated to improve environmental understanding and object recognition capabilities.

Voice command functionality may be added to allow users to interact with the system more naturally and access certain features without requiring physical controls.

The mobile application can be expanded to provide additional monitoring capabilities, system statistics, and enhanced communication features between the user and the guardian.

Future work may also focus on improving the overall mechanical design by developing a more compact and lightweight structure suitable for long-term daily use and potential commercial deployment.

In addition, larger-scale testing involving visually impaired and elderly users would provide valuable information regarding user experience, usability, and long-term system effectiveness. Such studies could help identify additional improvements and validate the system under real-world operating conditions.

The Smart Walker provides a strong foundation for future assistive mobility technologies, and continued development may further enhance its capabilities, reliability, and practical impact on the lives of visually impaired and elderly individuals.

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