An-Najah National University

Department of Computer Engineering

Hardware Graduation Project

Guide Dog for Visually Impaired People

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Acknowledgment

We begin by remembering our brothers and sisters in Gaza and all across Palestine who continue to face hardship every day under occupation. This work is dedicated to their strength, resilience, and unbroken spirit.

We also express our sincere gratitude to god, whose blessings and guidance gave us the strength and perseverance to complete this project.

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Disclaimer Statement

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Abstract

This project presents the design and implementation of a multifunctional robot dog intended for both assistance and security applications. The robot is designed to support visually impaired users by providing guided navigation and to perform basic guarding tasks such as monitoring its surroundings and issuing alerts. The system integrates multiple sensors, including LiDAR, a camera, and inertial sensors, along with an audio output system for feedback and alerts.

The mechanical structure is based on a quadruped design with servo-driven legs and custom 3D-printed parts made from PLA+. Control and processing tasks are distributed across embedded controllers and a single-board computer to manage movement, sensing, and navigation. Throughout development, several challenges were encountered, including power management, mechanical design, calibration, and component availability. Despite these challenges, the final prototype demonstrates the feasibility of combining guide and guard functionalities in a single robotic platform and provides a strong foundation for future development.

Chapter 1

Introduction

1.1 General Background

In recent years, robotics and artificial intelligence have developed rapidly and are being used in many areas of daily life. Mobile robots are now applied in fields such as security, healthcare, and personal assistance. Among different types of robots, quadruped robots (robot dogs) have attracted attention because they can move more easily on uneven surfaces and in environments where wheeled robots may fail. At the same time, there is an increasing need for technologies that support visually impaired people and improve security in public and private spaces. These developments create an opportunity to design intelligent robotic systems that can assist humans and operate autonomously.

1.2 Objectives

The main purpose of this project is to design and implement a robot dog that can perform two main functions: guiding visually impaired individuals and acting as a guard robot for surveillance purposes. The project aims to develop a system that can navigate using LiDAR, and inertial sensors, allowing the robot to move safely and autonomously in indoor and outdoor environments. A camera is used to support visual detection, while a speaker enable basic human robot interaction through voice commands, alerts, and audio feedback.

Another objective of this work is to integrate different hardware and software components, including microcontrollers, sensors, communication modules, and actuators, into a single coordinated system. Through this project, the goal is not only to build a functional robotic platform, but also to gain hands-on experience in robotics, embedded systems, sensor integration, and intelligent control, while demonstrating how multiple technologies can work together to solve real-world problems.

1.3 Project Scope

This project is designed to be used in situations where assistance and security are needed. The robot dog can help visually impaired people move safely by guiding them and providing audio feedback, and it can also be used to monitor areas and alert users when unusual activity is detected. It combines sensors such as LiDAR, a camera, and speakers to understand its surroundings and interact with people. The system is designed as a prototype, focusing on basic navigation, obstacle detection, and communication, making it suitable for testing and educational purposes.

1.4 Significance of the work

This project is important because it addresses real-life problems related to personal safety and assistance. Visually impaired people often face difficulties in independent navigation, and there is a growing demand for assistive technologies that can improve their mobility and quality of life. In addition, the need for intelligent security and monitoring systems continues to increase in homes, campuses, and workplaces. By combining guiding and guarding functionalities in one robot, this project offers a flexible and cost-effective solution. The work also reflects current market trends toward smart service robots and demonstrates how robotics can be applied to solve practical problems.

Chapter 2

Literature Review

In recent years, quadruped robots have received significant attention in the field of robotics due to their ability to move efficiently in complex and unstructured environments. Unlike wheeled robots, quadruped platforms can handle stairs, uneven terrain, and obstacles more effectively, making them suitable for real-world applications such as assistance, surveillance, and search operations. Several studies have explored the mechanical design, control strategies, and navigation capabilities of quadruped robots, highlighting their potential for human-centered tasks [2], [8].

Assistive robotics is an important research area that focuses on developing robotic systems to support people with disabilities. For visually impaired individuals, safe and reliable navigation is a major challenge. Research has shown that robotic guide systems can enhance mobility by providing navigation assistance, obstacle avoidance, and environmental awareness [1]. Guide dog robots aim to replicate some behaviors of traditional guide dogs, such as leading users safely, avoiding obstacles, and responding predictably to commands. Studies emphasize that such systems must prioritize safety, simplicity, and user trust to be effective [5], [6].

Navigation and localization are core components of autonomous robotic systems. Many researchers have investigated the use of GPS for outdoor navigation and LiDAR for precise obstacle detection and mapping. Combining multiple sensors through sensor fusion techniques improves localization accuracy and reliability, especially in dynamic environments. LiDAR-based navigation using SLAM algorithms has been widely adopted due to its robustness and accuracy, even in low-visibility conditions [4], [8]. These approaches are commonly implemented using robotic frameworks such as ROS, which provide modular tools for navigation, mapping, and sensor integration [10].

Vision-based perception is another important aspect of intelligent robotic systems. Cameras are widely used for object detection, human recognition, and environmental understanding. In assistive and security applications, vision systems allow robots to detect people, recognize objects, and monitor surroundings. Research shows that combining vision data with other sensors, such as LiDAR and inertial measurement units, enhances system performance and safety [3], [7].

Human robot interaction (HRI) plays a critical role in the success of assistive robots. Effective interaction requires clear communication between the robot and the user. Audio feedback through speakers and sound input through microphones are commonly used to improve usability and user confidence. Studies on guide dog behavior and assistive technologies highlight the importance of predictable movement, timely feedback, and intuitive interaction for visually impaired users [5], [6]. These principles are directly applicable to the design of robotic guide systems.

Overall, existing literature demonstrates that combining quadruped mobility, sensor-based navigation, and human-centered interaction can result in effective assistive and security robotic systems. However, many existing solutions focus on single-purpose applications. This project builds upon previous research by integrating guide and guard functionalities into a single quadruped robot platform, aiming to demonstrate a flexible and practical approach to service robotics.

Chapter 3

Methodology

3.1 Overview of the System

The system is implemented using a modular architecture that combines mechanical, electrical, and software components. A quadruped structure driven by high-torque servomotors provides movement, while multiple sensors are used for navigation and environment awareness. Control and processing tasks are distributed across embedded controllers and a single-board computer, allowing reliable coordination between sensing, movement, and user commands.

Figure 1: Side view of the pathy

3.2 Hardware Components

This section describes the main hardware components used in the design and implementation of the robot dog system. Each component was selected based on availability, cost, and suitability for the required tasks.

3.2.1 Raspberry Pi 4 Model B (2GB RAM)

The Raspberry Pi 4 Model B is used as the main processing unit of the system. It is responsible for high-level tasks such as sensor data processing, camera handling, navigation logic, and coordination between different system modules. The Raspberry Pi was chosen due to its processing capability, support for Linux-based systems, and compatibility with cameras and advanced sensors.

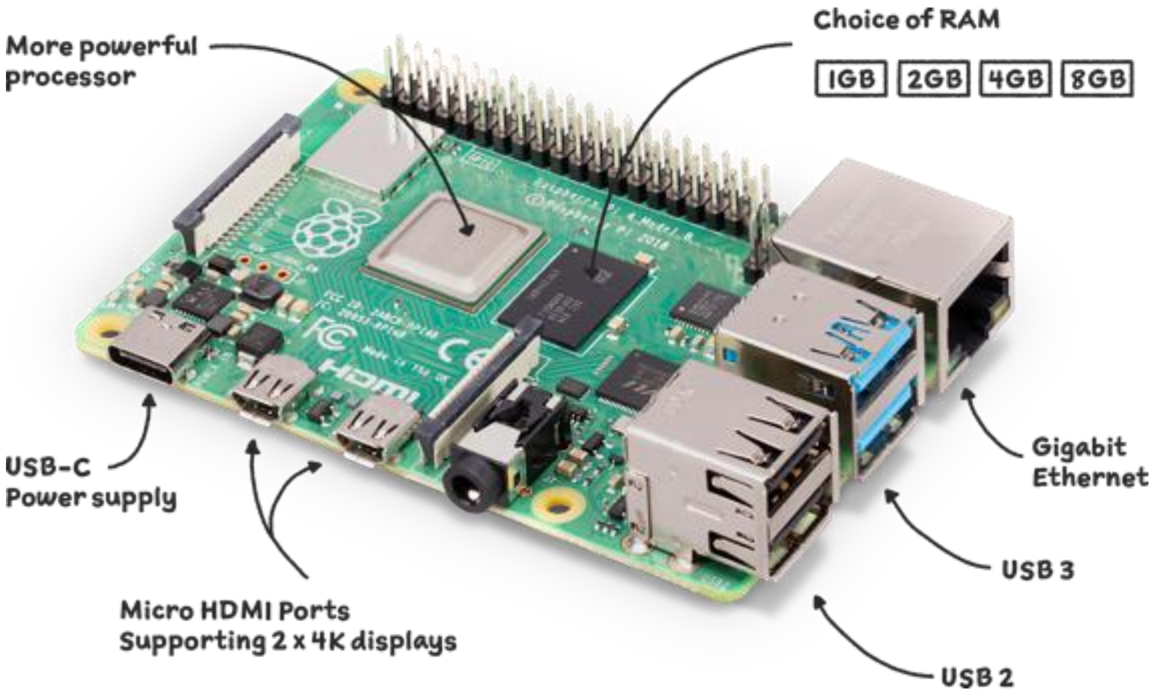

Figure 2: Raspberry Pi 4 Model B (2GB RAM)

3.2.2 Servo Motors and Mechanical Reinforcements

High-torque 270-degree servomotors rated at 40 kg are used to drive the robot's leg joints. Due to the high load and continuous movement during walking, metal (aluminum) servo horns are used instead of plastic horns. Plastic horns were found to deform and weaken over time because of heat and mechanical stress, while metal horns provide better durability, strength, and long-term reliability.

To further improve mechanical performance**,** bearings are installed at critical leg joints. The bearings reduce friction, improve smoothness of motion, and decrease stress on the servomotors, which helps extend their operational lifespan and improves walking stability.

Figure 3: Servo Motors (270° 40kg Torque)

Figure 4: Ball bearing rollers.

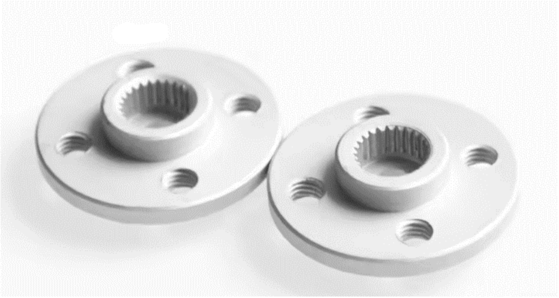

Figure 5: Horns

Additionally, thread locker is applied to screws and mechanical fasteners in high-vibration areas. This prevents loosening during operation and ensures that joints remain secure during prolonged testing and movement.

Figure 6: thread locker

3.2.3 Arduino Mega

The Arduino Mega is used for low-level control tasks, particularly for handling servomotor signals, reading sensor data, and communicating with other controllers. It was selected because of its large number of I/O pins and reliable real-time performance, which are essential for controlling multiple actuators and sensors simultaneously.

Figure 7: Arduino Mega controlling the system.

3.2.4 Servo Control Board (PCA9685)

A PCA9685 servo control board is used to control multiple servomotors through the I2C interface. This board allows precise PWM signal generation while reducing the processing load on the main controller. It also simplifies wiring and improves signal stability.

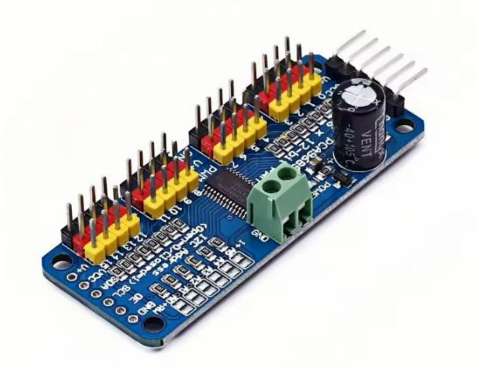

Figure 8: Servo Control Board (PCA9685)

3.2.5 LiDAR Sensor (LD06)

An LD06 LiDAR sensor is used for obstacle detection and distance measurement. It provides real-time environmental scanning, allowing the robot to detect obstacles and adjust its movement accordingly. The LiDAR plays a key role in navigation and safety.

Figure 9: LiDAR Sensor (LD06)

3.2.6 Ultrasonic and PIR Sensors

Ultrasonic sensors are used for short-range obstacle detection, complementing the LiDAR system. PIR sensors are included for motion detection, particularly for guard mode functionality, enabling the robot to detect nearby movement.

Figure 10: Ultrasonic

Figure 11: PIR Sensors

3.2.7 Camera (Luxonis AI Camera)

A Luxonis AI camera is used for visual perception tasks such as object detection and environment monitoring. The camera enhances both guide and guard functionalities by providing visual information for decision-making.

Figure 12: luxonis camera .

3.2.8 Audio System (Speaker and Amplifier)

Audio output is provided using AIYIMA 40 mm mini speakers (4 Ω, 5 W), combined with an external amplifier. This audio system is used to generate guidance messages, warning sounds, and alert notifications during both guide and guard modes. The speaker output improves user awareness and interaction by providing clear audio feedback about the robot's status and surroundings. No microphone or voice input system was included in the current implementation.

Figure 13: Speaker.

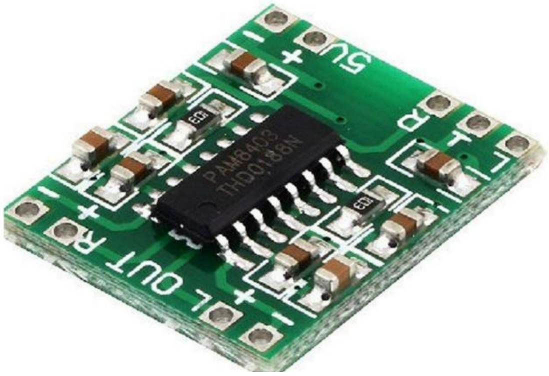

Figure 14: Amplifier.

3.2.9 ESP32 Microcontroller and Wireless Controller

The ESP32 microcontroller is used to implement a wireless manual control system for the robot. It is connected to a set of physical buttons that function as a controller, similar to a keyboard or remote control. Each button is assigned a specific movement or action command, allowing the user to control the robot wirelessly during testing and operation.

The ESP32 transmits control commands to the main system using its built-in wireless communication capabilities. This controller was particularly useful during calibration, movement testing, and debugging, as it allowed real-time control without the need for wired connections. The use of the ESP32 provided a flexible and low-cost solution for wireless robot control and improved overall system usability.

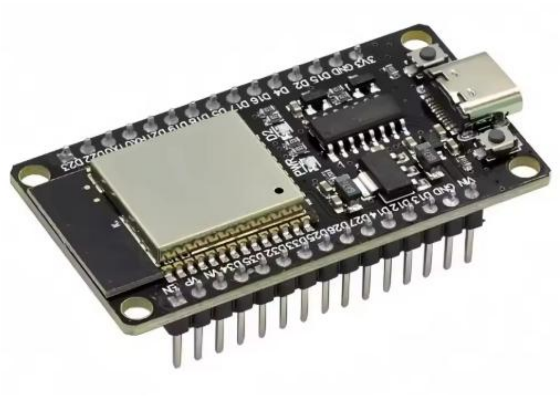

Figure 15: ESP32

Figure 16: keyboard controller.

3.2.10 Materials Used and Design Limitations

Most mechanical parts were 3D-printed using **PLA+ (PLA Plus)** due to its low cost, ease of printing, and improved strength compared to standard PLA. PLA+ was suitable for prototyping and allowed multiple design iterations during development. However, despite its advantages, PLA+ still has limitations in heat resistance and long-term durability, which may affect performance under continuous load.

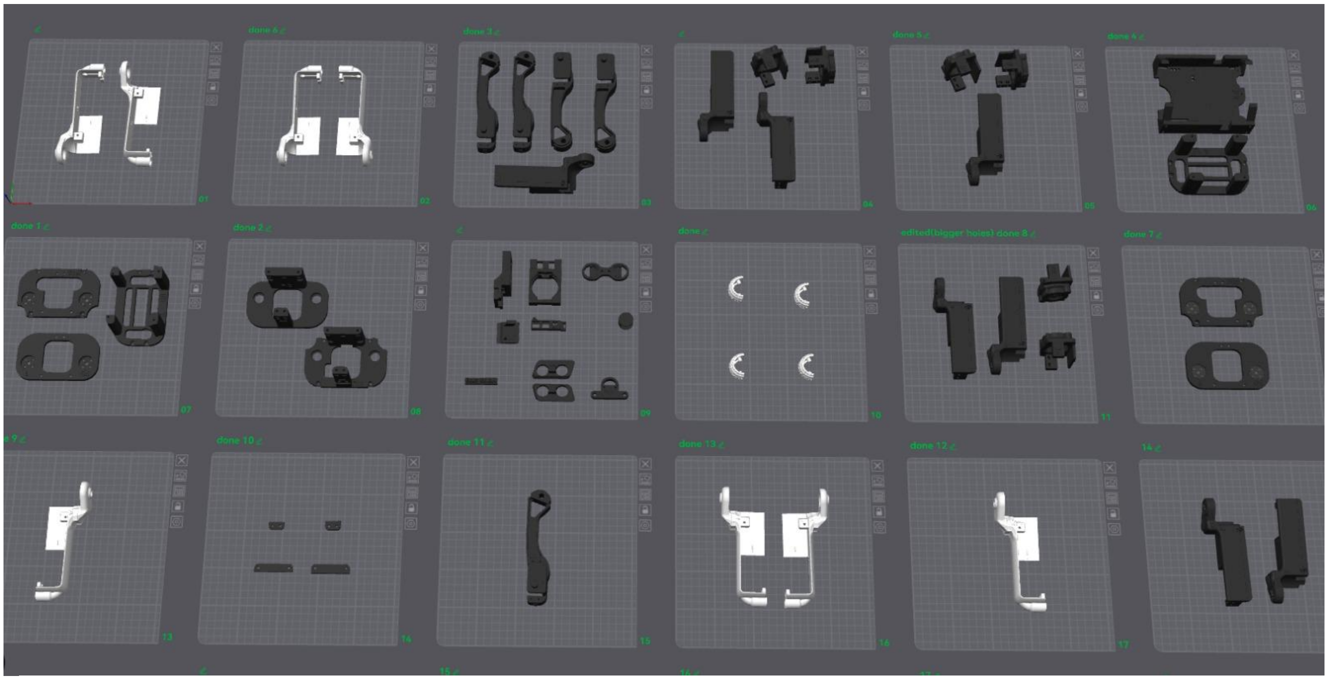

Figure 17: 3d design.

3.2.11 Power System and Battery

The robot is powered by a 3S 3000 mAh LiPo battery. The battery is connected directly to the servo power rail to supply the high current required by the servomotors. A DC-DC step-down buck converter (XL4016, 300W, up to 9A/20A) is used to regulate voltage for other system components, ensuring stable and safe power delivery.

Figure 20: Wires used in the system.

Figure 18: Power battery used to provide stable voltage.

Figure 19: Buck Converter.

3.3 Implementation

3.3.1 System Control Architecture

The control architecture of the robot dog is divided into high-level and low-level control layers. High-level processing is handled by the Raspberry Pi, which manages sensor data processing, navigation logic, and system coordination. Low-level control is handled by the Arduino Mega and the PCA9685 servo controller, which are responsible for generating accurate PWM signals for the servomotors.

Communication between the Raspberry Pi and Arduino Mega is achieved using serial communication, allowing command exchange and system synchronization. This layered architecture improves modularity and simplifies debugging and testing.

3.3.2 Servo Control and Gait Implementation

The robot dog uses high-torque 270-degree servomotors to control each joint of the legs, providing three degrees of freedom per leg. The PCA9685 servo driver board is used to control multiple servos simultaneously through the I2C interface, reducing the processing load on the main controllers.

Walking and movement behaviors are based on predefined gait patterns. These gait patterns define the timing, angles, and sequence of joint movements required for stable motion. Servo angle limits and offsets were modified to match the physical dimensions of the custom 3D-printed PLA+ structure. Extensive calibration was required to ensure that all legs moved synchronously and maintained balance during motion.

3.3.3 Calibration Process

Calibration was a critical part of the implementation process. Each servo was individually tested to determine its neutral position and movement range. Joint offsets were adjusted multiple times to achieve proper leg alignment and posture. The calibration process was repeated several times until stable standing and walking were achieved.

Incorrect calibration initially caused imbalance, excessive servo load, and unstable movement. Through iterative testing and refinement, a reliable configuration was obtained that allowed smooth transitions between standing and walking states.

3.3.4 Sensor Integration

Several sensors were integrated into the system to enable environment awareness and navigation. The LD06 LiDAR sensor was used for obstacle detection and distance measurement, providing real-time scanning of the surroundings. Ultrasonic sensors were added to support short-range obstacle detection, while PIR sensors were used to detect motion during guard mode operation.

An inertial measurement unit (MPU gyroscope) was integrated to monitor orientation and movement, helping improve balance and stability during walking. Sensor data was processed on the Raspberry Pi and used to influence movement decisions and system responses.

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3.3.5 Wireless Manual Control

A wireless manual control system was implemented using an ESP32 microcontroller and a set of physical buttons. This controller functions similarly to a keyboard or remote control, allowing the user to send movement commands such as forward, backward, left, right, and stop.

The ESP32 transmits commands wirelessly to the robot, enabling real-time control during testing, calibration, and debugging. This feature was particularly useful during early development stages, where precise manual control was required to safely test movement and sensor responses.

3.3.6 Robot Movement

The movement of the robot dog is implemented using a state-based control approach. This approach organizes the robot’s behavior into a set of defined states, allowing smooth and safe transitions between different movement modes. The main movement states include *Idle*, *Stand*, and *Walk*, with intermediate transition states used to ensure stability and prevent sudden or unsafe motions.

When the system starts, the robot enters the idle state, where all servomotors are relaxed and no movement is performed. This state is used as the default resting mode. Upon receiving a stand command, the robot transitions to the Transition to stand state. In this state, the leg joints are gradually moved to predefined angles until the robot reaches the correct standing height. Once the desired height is reached, the system automatically switches to the Stand state.

In the Stand state, the robot maintains a stable upright posture and waits for further commands. If a walk command is received, the robot transitions to the Walk state, where predefined gait patterns are executed to generate forward movement. While walking, the robot continuously monitors its posture and balance to ensure stable motion.

When a stand command is issued during walking, the robot exits the Walk state and returns to the Stand state. If an idle command is received while standing, the robot moves to the Transition to Idle state. In this transition, the robot slowly lowers its body until a safe idle height is reached. Once this height is achieved, the system automatically switches back to the idle state.

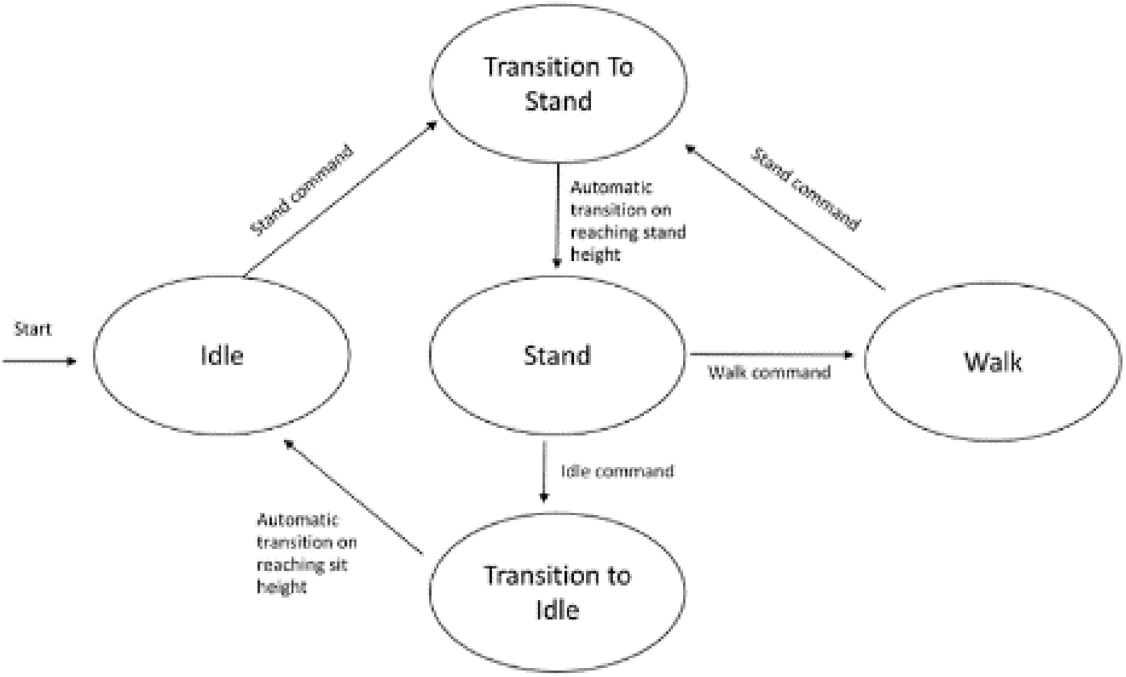

Figure 21

Chapter 4

Problems and Challenges

During the development of this project, several technical and practical challenges were encountered. These challenges occurred at different stages of the design, implementation, and testing phases, and addressing them required multiple iterations, troubleshooting, and design adjustments.

One of the major challenges was power management, especially related to the servomotors used in the robot’s legs. Each servo required a significant amount of current, particularly under load during walking and standing motions. Determining how much current each servo could draw and selecting a suitable power supply was not straightforward. Improper power distribution initially caused voltage drops and unstable behavior, and in one case, a servo was damaged during testing due to excessive current draw and overheating. This highlighted the importance of proper current calculations, protection, and power regulation in robotic systems.

Another challenge was the availability and cost of components. Some parts, including sensors and mechanical components, were either expensive locally or not readily available. As a result, components had to be ordered from outside sources, leading to long waiting times and delays in project progress. These delays affected the project timeline and required adjustments to the development schedule.

The 3D design of the robot body and legs was also a significant challenge. Designing a structure that could securely hold the servos, support the robot’s weight, and allow smooth movement required multiple design iterations. Some early designs did not provide sufficient strength or proper alignment, leading to mechanical stress and limited range of motion. Several modifications were needed to improve balance, stability, and durability.

Calibration of the robot’s movement was another major difficulty. The walking behavior of the robot required precise calibration of servo angles and timing. The calibration process was repeated multiple times approximately five full calibration attempts before achieving stable and smooth walking. Small errors in calibration caused imbalance, incorrect posture, or inefficient movement, making this a time-consuming and sensitive process.

Integrating the LiDAR sensor with the walking system presented additional challenges. Synchronizing obstacle detection with leg movement required careful timing and logic to ensure that the robot could react to obstacles without losing balance. Proper placement of the LiDAR and filtering its data to avoid false detections were also challenging and required multiple tests and adjustments.

Other challenges included software debugging, sensor communication issues, and ensuring reliable data transfer between different system components. In addition, testing the robot safely while protecting both the hardware and the user required extra precautions, especially during early movement tests.

Overall, these challenges provided valuable learning experiences and contributed significantly to improving the final system design. Overcoming these difficulties enhanced the reliability, performance, and robustness of the robot and deepened the team's understanding of real-world robotic system development.

Chapter 5

Results and Discussion

This chapter presents the results obtained from building and testing the robot dog prototype and discusses its overall performance. After several calibration attempts, the robot achieved a stable standing position and a basic walking pattern. Proper calibration improved balance and reduced mechanical stress on the servomotors compared to earlier tests.

Sensor integration produced positive results. LiDAR was used not only for obstacle detection but also to support mapping and localization of the surrounding environment. During testing, the robot was able to generate a basic map, estimate its position, and plan safe movement paths based on detected obstacles. As a result, the robot could adjust its movement and navigate short distances autonomously, demonstrating the feasibility of sensor-based navigation and path planning. Audio output through the speaker provided guidance and alert messages, which is important for both guide and guard modes.

Despite these results, some limitations were observed. Power consumption remained a major issue due to the high current required by multiple servos, which reduced operating time. Navigation accuracy was also affected by GPS signal limitations, making sensor fusion necessary. Additionally, repeated testing revealed mechanical stress on some 3D-printed parts.

Overall, the results confirm that the robot dog prototype successfully demonstrates the main objectives of the project. While improvements are needed, the system shows strong potential as a combined assistive and security robotic platform.

Chapter 6

Conclusion and Future Work

Conclusion

In this project, a multifunctional robot dog prototype was designed and developed to operate as both a guide and a guard robot. The system successfully demonstrated basic walking, navigation, obstacle detection, and audio interaction using integrated sensors such as GPS, LiDAR, a camera, and audio devices. Although challenges related to power management, calibration, and mechanical design were encountered, the final prototype met the main project objectives. This work demonstrates the feasibility of combining assistive and security features in a single robotic platform and provides a strong foundation for future improvements and development.

Future Work

- Enhancing power management by using more efficient servomotors, better battery technology, and improved power distribution to increase operating time and system stability.

- improving walking performance to make the robot’s movement more natural and smooth.

- Increasing interaction with the owner through improved feedback systems and smarter behavior, allowing the robot to respond more intuitively to user commands and situations.

- Adding voice command functionality to enable hands-free control

- Expanding outdoor capabilities

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