A
Project Report

Entitled

Robotic Spider

Submitted to the Department of Electronics Engineering in Partial Fulfilment for the Requirements for the Degree of

Bachelor of Technology
(Electronics and Communication)

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B. TECH. IV(EC), 7$^{\text{th}}$ Semester

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(Year: 2024-25)

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CERTIFICATE

This is to certify that the Project Report entitled "**Robotic Spider**" is presented & submitted by Dip, Ashish, Om, Piyush, bearing Roll No. U21EC003, U21EC056, U21EC057, U21EC066 of B.Tech. IV, 7^{th} Semester in the partial fulfillment of the requirement for the award of B.Tech. Degree in Electronics & Communication Engineering for academic year 2024-25.

They have successfully and satisfactorily completed their **Project Exam** in all respects. We certify that the work is comprehensive, complete and fit for evaluation.

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Acknowledgements

We would like to express our profound gratitude and deep regards to our guide and Head of the Electronics Engineering Department Prof. J. N. Sarvaiya for his guidance. We are heartily thankful for suggestion and the clarity of the concepts of the topic that helped us a lot for this work. We would also like to thank all the faculties of DoECE for their co-operation and suggestions.

Special thanks to Rinkesh Sir and Aksh Sir for their Continuos Support.

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Abstract

This project presents the design and development of a four-legged robotic spider, capable of basic autonomous movements and obstacle detection using Bluetooth control and an ultrasonic sensor. With a focus on creating an adaptable and efficient robotic platform, the spider robot demonstrates the integration of sensor-based obstacle avoidance and remote control functionalities, which are critical for autonomous mobile robots.

The robotic spider is built with a lightweight yet sturdy structure, incorporating a microcontroller to handle the coordination of the legs' movements and sensor data processing. The Bluetooth module enables wireless control via a smartphone, allowing users to direct the robot's movements in real time. Additionally, the ultrasonic sensor enables the robot to detect and avoid obstacles, enhancing its autonomy in dynamic environments.

Through various design iterations, mechanical testing, and software calibration, the robotic spider achieved reliable motion and obstacle avoidance capabilities. This project has applications in surveillance, search and rescue, and environmental exploration. The report discusses the detailed design, assembly, coding, and testing processes, along with the challenges encountered and future enhancements that could further expand the robot's functionalities.

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Chapter 1
Introduction

The field of robotics has seen rapid advancements in recent years, with robots increasingly being designed to mimic the movement and functionality of living organisms. Among these, robotic spiders have garnered significant attention due to their ability to navigate challenging terrains with agility and stability. Inspired by the versatile locomotion of arachnids, this project focuses on developing a four-legged robotic spider capable of performing basic movements and avoiding obstacles autonomously. By integrating Bluetooth control for remote operation and an ultrasonic sensor for environmental awareness, the robot offers a foundation for exploring applications in areas such as surveillance, exploration, and disaster management.

Arduino nano board, Nano IO Expansion Shield, and twelve SG 90 servo motors are used for the spider robot. Two 18650 li-ion batteries are used to provide power. An ultrasonic sensor is used to set Obstacle Avoiding and a Bluetooth module is used to control Bluetooth. An Android app is used to control the spider robot using Bluetooth. This Spider robot can be made into three types by changing the Arduino codes and modules.

Robotic spiders offer unique advantages in mobility and control, especially in environments that are inaccessible to wheeled or tracked robots. Their compact size and multi-legged structure allow for enhanced stability and precise maneuverability. This project is inspired by the potential applications of robotic spiders in areas such as surveillance in hazardous environments, search and rescue operations in disaster-stricken areas, and environmental exploration in rugged terrains. By incorporating obstacle detection and remote control functionalities, the project seeks to demonstrate the capabilities of a cost-effective and efficient robotic platform.

1.1 Objectives of the Project

The primary objective of this project is to design and implement a four-legged robotic spider capable of performing basic locomotion and obstacle avoidance. Specific goals include:

- Developing a mechanical structure that mimics the movement of a spider's legs.
- Integrating an ultrasonic sensor to detect and respond to obstacles in real-time.
- Implementing Bluetooth-based remote control for user interaction.

- Optimizing the robot's performance for stability, responsiveness, and power efficiency

The last few decades have witnessed a significant surge in the interest and development of mobile robots, largely owing to their remarkable ability to function autonomously in diverse environments, including critical applications such as search and rescue missions. These mobile robots span a range of categories, including wheeled robots, tracked robots, and legged robots, each tailored to specific operational demands and environmental challenges.

This report presents a fundamental implementation of a spider-inspired robot, serving as a foundational model for the integration of more advanced functionalities. The robot's design centers around a robust main frame, featuring four articulated legs, the motion of which is meticulously orchestrated by a total of 12 servo motors. Within the core of the main frame, we have integrated an Arduino Nano Microcontroller and extension, alongside necessary voltage regulators, complemented by the utilization of two rechargeable lithium batteries to sustain extended operation.

The advantages of legged locomotion extend beyond the more number of legs; they encompass posture diversity and leg functionality as well . While wheeled and tracked robots excel in flat terrains, they often falter in cluttered, complex, or hazardous environments. Legged robots, on the other hand, exhibit the potential to traverse a wide spectrum of terrains, from rugged landscapes to intricate and challenging settings. To harness this potential, various walking algorithms have been meticulously designed and rigorously tested to evaluate their performance

1.2 Comparison of the Legged robot Over Wheeled robot

Each system possesses its unique set of advantages and disadvantages. In Table 1.1 we present a comprehensive comparative analysis between the legged robot and the wheeled robot, outlining their respective strengths and limitations.

The Quadruped Robot is a four-legged walking robot that closely resembles spiders, utilizing its legs for locomotion and demonstrating the capability to perform a variety of tasks, both through human interaction and autonomously.

In the subsequent sections, we delve into the intricate design and control aspects of this spider robot, emphasizing its adaptability across various terrains and its potential for diverse applications, including entertainment and humanrobot interaction. Additionally, we provide insights into the meticulous testing procedures that validate its performance, showcasing its capacity to navigate challenging environments with precision and efficiency. [10]

Technical Criteria	Wheeled Robot	Legged Robot
Maneuverability	no	yes
Navigation over obstacles	no	yes
Transvers ability	no	yes
Controllability	yes	no
Terrain Land	no	yes
Efficiency	no	yes
Stability	yes	no
Cost Effective	yes	no

Table 1.1: The comparison of the Legged robot over Wheeled robot [10]

1.3 Components Needed

- 3D-printed spider robot parts (chassis, legs, connectors)
- 12 X SG90 Servo Motor (180 degrees)
- Arduino Nano board
- Nano IO Expansion Shield
- 18650 Battery Holder – 2 Cell
- Two 18650 Lithium-ion battery 3.7v
- Switch
- LM2596 DC-DC Buck Converter Step-Down Power Module
- HC-SR04 4Pin Ultrasonic Sensor
- HC-05 or HC-06 Bluetooth Module
- Female to Female jumper wire
- 4 X M3 30mm Screws and nuts
- Glue gun
- Soldering Iron

1.3.1 3D Print the Robot Parts

To 3D print the essential components for the Spider Robot, allocate approximately seven to eight hours of printing time. Configure 3D printer with a layer height of 0.2mm, infill set at 15 persentage and a printing speed of 65 for optimal results. Following these parameters and utilizing the recommended settings ensures the production of durable and accurately detailed parts for assembling the Spider Robot.

Print parts list:

- 1x body d.stl
- 1x body u.stl
- 2x coxa l.stl
- 2x coxa r.stl
- 2x tibia l.stl
- 2x tibia r.stl
- 4x femur 1.stl
- 8x s hold.stl

1.4 Scope of the Project

This project focuses on the development of a prototype robotic spider with the following features:

- A four-legged mechanical structure driven by servo motors for movement.
- A microcontroller to process commands and sensor data.
- Bluetooth communication for remote control via a smartphone or external device.
- An ultrasonic sensor for real-time obstacle detection and avoidance.
- The project emphasizes both the hardware design and software integration necessary to achieve a functional and responsive robotic system.

1.5 Organization of Report

The document begins with an **Introduction**, which provides a comprehensive overview of the project. This section sets the stage by outlining the objectives of the robotic spider, highlighting the key advantages of legged robots over wheeled robots, and presenting the components required for the project. It delves into the need for 3D-printed parts and concludes with a discussion on the scope of the project.

The **Literature Review** explores the historical development and evolution of quadruped robotics. It highlights recent advancements in areas such as obstacle avoidance, repetitive movements in robotic systems, and Bluetooth-controlled robotics. This section also touches on future directions and ongoing research in the field, providing a foundation for understanding the project's context and relevance.

The **Electronic System Design for the Robotic Spider** outlines the proposed design in detail. Key components such as the LM2596 DC-DC buck converter, Arduino Nano, and Nano I/O expansion shield are thoroughly described, with explanations of their functionalities and pin configurations. Additional components like the HC-SR04 ultrasonic sensor, HC-05 Bluetooth module, and servo motors are also discussed, focusing on their roles in the project, working principles, and interfacing with the microcontroller. The section concludes by detailing the system integration process.

The **Mechanical Design** emphasizes the critical aspects of robotic locomotion. It draws inspiration from biological systems, specifically spiders, and compares their movement patterns and leg structures with those of the robot. This section also addresses material selection, the process of designing and 3D printing robot parts, and post-processing of these parts. Calculations related to mechanical parameters, including torque and the center of gravity (COG), are derived to ensure stable and efficient movement.

The **Algorithm for the Robotic Spider** describes the software development environment and the core algorithms implemented in the project. The walking algorithm, obstacle avoidance algorithm, and Bluetooth control algorithm are discussed in detail, explaining how they enable the robot to perform its intended tasks. Results obtained from testing these algorithms are also presented.

Finally, the **Conclusion and Future Scope** summarizes the outcomes of the project and proposes potential future enhancements. This section reflects on the project's contributions to the field and explores possibilities for extending its functionality and applications.

Chapter 2
Literature Review

Quadruped robotics, designed to mimic the legged locomotion of animals, has been an active area of research for decades, aimed at improving mobile robots' ability to navigate various terrains autonomously. From early mechanical designs to advanced AI-driven systems, the field has progressed significantly, with developments in sensors, actuators, algorithms, and control systems. This chapter explores the historical background, recent advancements, and ongoing research in quadruped robotics, focusing on obstacle avoidance, repetitive movement, and wireless control systems that have directly influenced the development of the 3-in-1 spider robot project.

2.1 Historical Background of Quadruped Robotics

The concept of legged robots can be traced back to the early 20th century when engineers began attempting to replicate animal locomotion. The first notable mechanical legged machine was the **walking truck** developed by General Electric in the 1960s. Though it was mechanically impressive for its time, it was cumbersome, lacked versatility, and had limited autonomous functionality [12].The 1980s marked a turning point in quadruped robotics with the introduction of the **Raibert Hopper**, developed by Marc Raibert at MIT. This system was one of the first to incorporate dynamic balance into legged locomotion, which was a critical development for legged robots. Raibert's work demonstrated that robots could balance dynamically while moving, laying the foundation for more complex designs in the future [12].

In the 1990s and early 2000s, robots such as **BigDog** (Boston Dynamics) and **Cheetah** (MIT) demonstrated the potential for legged robots to handle dynamic and rough terrains. These robots were powered by advanced computing systems and sensors, including accelerometers, gyroscopes, and sophisticated algorithms to maintain balance and stability [13].

2.2 Recent Developments and Research

2.2.1 Obstacle Avoidance

One of the primary challenges in quadruped robotics is enabling robots to navigate dynamic environments without human intervention. Obstacle avoidance is a key functionality that allows robots to detect and circumvent barriers in their path. Early systems relied on simple bump sensors or basic IR sensors, but the development of ultrasonic sensors such as the **HC-SR04** has revolutionized this aspect of robotic design.

Ultrasonic sensors measure the time taken for sound waves to bounce back after being emitted, which allows the robot to detect objects within its range. According to **Tao et al. (2019)**, the use of these low-cost ultrasonic sensors combined with Arduino-based systems has become widely popular in educational robots due to their simplicity, affordability, and reliability. These sensors can be used for real-time navigation, allowing robots to autonomously avoid obstacles in various environments [14].

Moreover, more advanced methods for obstacle avoidance, such as machine learning algorithms, have been explored. **Chowdhary et al. (2021)** propose a hybrid approach that combines ultrasonic sensors with a machine learning framework to enhance obstacle detection and avoidance in mobile robots. This approach allows the robot to ”learn” its environment and improve navigation over time, offering a significant improvement over purely sensor-based methods [15].

2.2.2 Repetitive Movements in Robotic Systems

The ability to perform repetitive movements is crucial for robots, especially in tasks that require stability, precision, and energy efficiency. Quadruped robots achieve this through the synchronization of multiple servos that control each leg's motion. **Servo motors** such as the **SG90**, used in the 3-in-1 spider robot, are popular in educational and hobbyist quadruped robots due to their affordability and ease of use.

Shin et al. (2020) conducted a study on energy-efficient gait optimization in quadruped robots. Their research emphasized the importance of designing energy-efficient gaits to extend the operational lifetime of robots, particularly in autonomous systems that need to perform continuous movements over long periods. They concluded that the optimization of repetitive leg movements, including adjusting the timing and sequence of the steps, could significantly reduce energy consumption while maintaining balance and speed [16].

Additionally, **Waldron et al. (2018)** explored biologically inspired gaits for quadruped robots, drawing from the walking patterns of animals such as dogs and cats. Their research focused on mimicking natural movements to improve the efficiency and agility of robots in dynamic environments. This work has been highly influential in the development of more advanced legged robots, such as Boston Dynamics' **Spot**, which employs dynamic gaits to navigate obstacles and perform tasks in complex settings [17].

2.2.3 Bluetooth-Controlled Robotics

The integration of wireless control into robotic systems has opened up new possibilities for remote operation and user interaction. The **HC-05 Bluetooth module**, which is commonly used in hobbyist and educational robots, allows for simple, wireless communication between a robot and a smartphone or computer. The ease of use and cost-effectiveness of Bluetooth systems have made them a popular choice for various robotic applications, including the 3-in-1 spider robot project.

Sharma et al. (2020) explored the use of Bluetooth-controlled robots and discussed the advantages of wireless control in robotics education. Their study demonstrated that Bluetooth technology allows for intuitive user interfaces and real-time interaction, which is crucial for beginners in robotics to learn programming, sensors, and control systems. Bluetooth modules, such as **HC-05** and **HC-06**, enable robots to execute complex commands remotely, providing a flexible platform for both novice and experienced users [18].

Moreover, **Singh et al. (2019)** delved into the security and robustness of Bluetooth communication, emphasizing the need for secure communication channels to prevent unauthorized access in sensitive applications. Their research also highlighted the development of encryption techniques to ensure the integrity and privacy of control signals, which is critical for applications in remote-controlled robotics [19].

2.3 Future Directions and Ongoing Research

The future of quadruped robotics lies in the integration of artificial intelligence (AI), soft robotics, and energy-efficient systems. AI has the potential to revolutionize quadruped robots by enabling them to learn and adapt to their environments autonomously. **Li et al. (2022)** discussed the integration of deep learning algorithms with quadruped robots for autonomous navigation, which allows robots to recognize obstacles, plan paths, and make real-time decisions. This research aims to improve the adaptability of robots in dynamic and unpredictable environments, making them more suitable for applications like search-and-rescue missions or exploration of hazardous areas [20].

Soft robotics is another rapidly growing field that aims to develop robots with flexible, elastic components. These robots can interact more safely with humans and navigate unstructured environments more naturally. Researchers like **Rus et al. (2020)** have demonstrated that soft quadruped robots, using materials such as elastomers, can exhibit more fluid and adaptable movements compared to traditional rigid robots. The flexibility of these robots allows them to overcome obstacles more effectively and adapt to different terrain types [21].

In terms of energy efficiency, the development of lightweight materials and energy-harvesting systems is expected to enhance the performance and sustainability of quadruped robots. Ongoing research in **gait optimization** and **battery management** will continue to play a key role in improving the operational lifetime and autonomy of robots. **Bhat et al. (2021)** discussed various energy-saving techniques and low-power electronics that can help reduce the energy consumption of legged robots [22].

2.4 Summary

Quadruped robotics has progressed from early mechanical systems to advanced, AI-driven, and energy-efficient robots capable of performing complex tasks. The integration of obstacle avoidance, repetitive movement, and Bluetooth control in modern robots reflects the advancements in sensor technology, control algorithms, and wireless communication. The 3-in-1 spider robot project builds upon these advances, offering a versatile, cost-effective solution for educational and research purposes. The project leverages ultrasonic sensors for obstacle avoidance, servo motors for repetitive movements, and Bluetooth for remote control, drawing inspiration from the innovations discussed in the literature.

Chapter 3
Electronic System Design for Robotic Spider

This chapter introduces the 3-in-1 robotic spider's electronic system design and integration. The suggested design, which outlines the general architecture and essential parts needed to execute the robotic system, opens the chapter. Each functional block is then thoroughly explained, including the functions of the power supply system, servo motor setup, sensor integration, and core control unit. The final section covers the integration of all electronic components, emphasising how the system is wired, tested, and validated to provide the desired functionality of Bluetooth control, obstacle avoidance, and repetitive movements. The chapter offers a thorough rundown of the electrical design and execution procedure, guaranteeing a methodical approach to the robotic spider's realisation.

3.1 Proposed Design for Robotic Spider

This section introduces the suggested design for the robotic spider, which combines a number of electronic components to allow for mobility, obstacle avoidance, and Bluetooth-controlled operation. A power supply system, core control unit, servo motors, Bluetooth module, and ultrasonic sensor are among the pieces that make up the system's architecture.

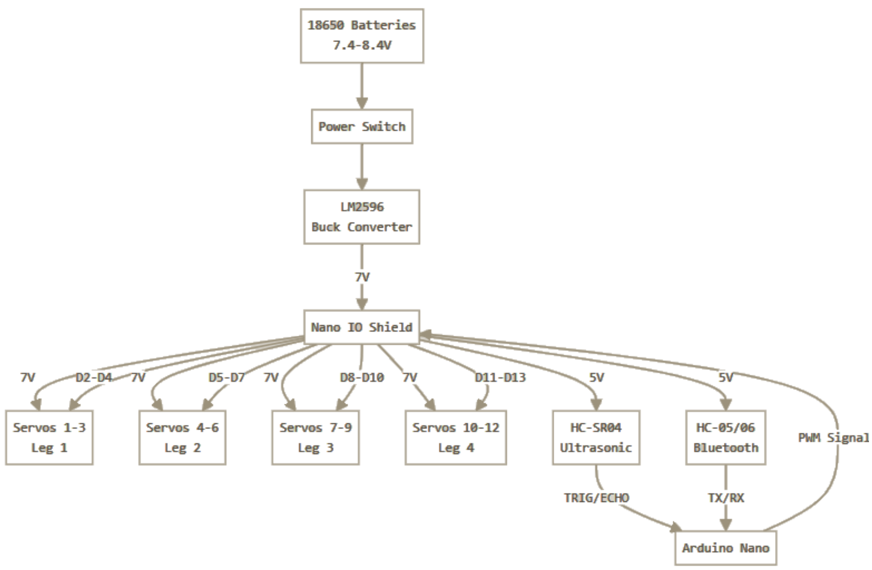

Figure 3.1: Proposed Block Diagram of Robotic Spider

The Block Diagram in Figure 3.1 Provide all over connection of proposed design. Two 18650 lithium-ion batteries connected in series make up the Power Supply System, which supplies the system with the voltage it needs. The Arduino Nano and the servo motors are powered by a steady 7V output that is controlled by an LM2596 DC-DC Buck Converter.

The Arduino Nano and an IO Expansion Shield serve as the Core Control Unit. The robotic spider's legs are moved by this unit, which receives inputs from the Bluetooth module and ultrasonic sensor and transmits control signals to the 12 servo motors. A leg of the spider is controlled by each of the four sets of servo motors.

The robot can be controlled wirelessly with a smartphone or other external device thanks to the Bluetooth Module (HC-05), which enables remote commands. By identifying obstructions in the robot's route, the Ultrasonic Sensor (HC-SR04) allows autonomous navigation by providing the Arduino Nano with the necessary information for decision-making.

Next, we will examine each block of the suggested design.

3.2 LM2596 DC-DC Buck Converter Step-Down Power Module

The LM2596 is a compact, efficient DC-DC buck converter that reduces input voltage to a lower, stable output, enabling precise power management in electronic and robotic projects.

3.2.1 Why LM2596

We are using the LM2596 DC-DC buck converter instead of other voltage level transfer methods like an op-amp because it offers high efficiency, stable output voltage, and the ability to handle higher currents (up to 2-3A), which is crucial for powering multiple components such as servos, the Arduino, and sensors in the spider robot. Unlike op-amps, which may struggle with load regulation and provide less efficient power conversion, the LM2596 ensures a reliable and consistent power supply while minimizing energy loss, making it an ideal and cost-effective solution for this project.

3.2.2 LM2596 Overview

The LM2596 DC-DC Buck Converter is shown in figure 3.2 is a sophisticated power management integrated circuit (IC) designed to efficiently reduce a higher input voltage to a lower, regulated output voltage. At its core, the buck converter operates on a fundamental principle of switching technology that allows precise voltage regulation with minimal energy loss.

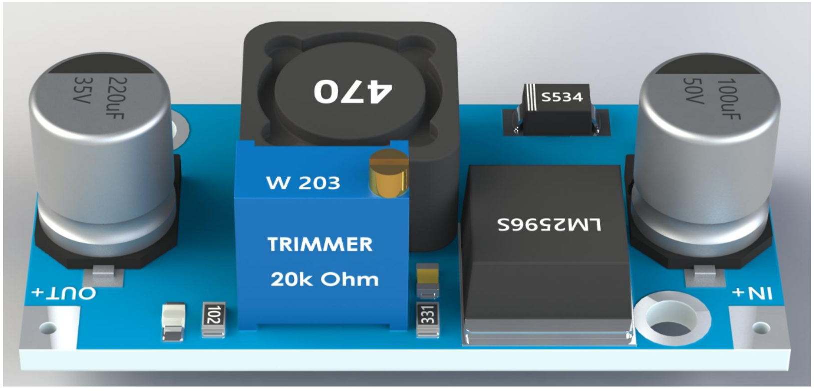

Figure 3.2: LM2596 [1]

The fundamental working mechanism of the buck converter involves a rapid switching process that occurs at a fixed frequency of 150 kHz. The primary components responsible for this process are a high-frequency switch (typically a MOSFET), a diode, an inductor, and a capacitor. When the switch is closed, current flows through the inductor, storing energy in its magnetic field. When the switch opens, the inductor prevents sudden current drops by maintaining a continuous current flow through the diode. This switching action effectively ”chops” the input voltage, creating a pulsed waveform that is then smoothed by the output capacitor to produce a stable, lower DC voltage [23].

3.2.3 LM2596 Pinout

Here shown in figure 3.3 how the LM2596 DC to DC Converter Module looks like. You can notice that the LM2596 is an IC, and the module is a circuit build around the IC to make it work as an adjustable converter.

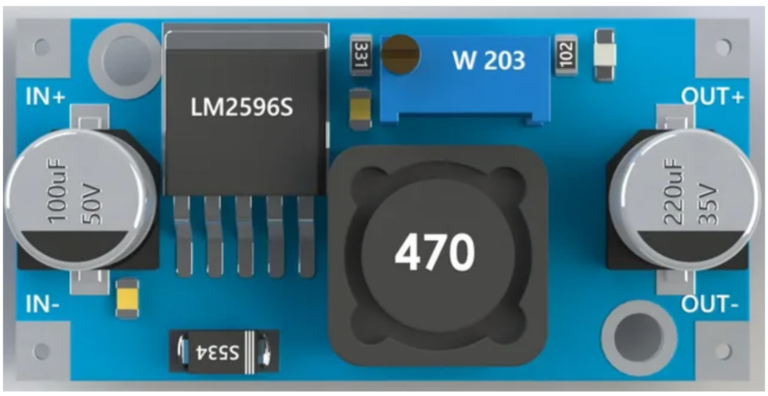

Figure 3.3: LM2596 Pinout Overview [1]

Pinout for LM2596 module is very simple:

- **IN+** Here we connect the red wire from the battery (or the power source), this is VCC or VIN (4.5V - 40V)
- **IN-** Here we connect the black wire from the battery (or the power source), this is ground, GND or V–
- **OUT+** Here we connect the positive voltage of the power distribution circuit or a component powered
- **OUT-** Here we connect the ground of the power distribution circuit or a component powered [23]

3.3 Arduino Nano

Arduino Nano is a compact, breadboard-friendly microcontroller board that provides a powerful, miniature version of the standard Arduino, ideal for space-constrained projects requiring full Arduino functionality in a smaller package.

3.3.1 What is an Arduino Nano Board?

Arduino Nano is shown in figure 3.4 is one type of microcontroller board, and it is designed by Arduino.cc. It can be built with a microcontroller like Atmega328. This microcontroller is also used in Arduino UNO. It is a small size board and also flexible with a wide variety of applications. Other Arduino boards mainly include Arduino Mega, Arduino Pro Mini, Arduino UNO, Arduino YUN, Arduino Lilypad, Arduino Leonardo, and Arduino Due. And other development boards are AVR Development Board, PIC Development Board, Raspberry Pi, Intel Edison, MSP430 Launchpad, and ESP32 board [2].

This board has many functions and features like an Arduino Duemilanove board. However, this Nano board is different in packaging. It doesn't have any DC jack so that the power supply can be given using a small USB port otherwise straightly connected to the pins like VCC and GND. This board can be supplied with 6 to 20volts using a mini USB port on the board.

Integrating 12 servo motors, a Bluetooth module, and an ultrasonic sensor with an Arduino Nano creates a sophisticated robotic control system. By strategically utilizing the Nano's PWM and digital pins, we can precisely manage multiple servo motors

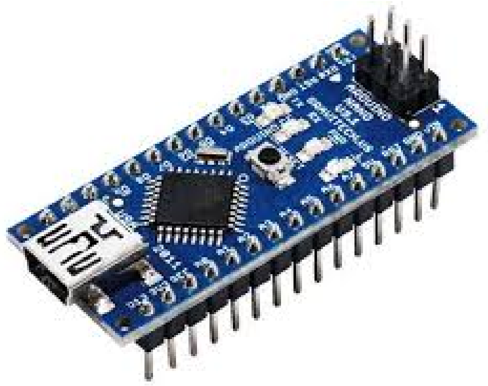

Figure 3.4: Arduino Nano [2]

for complex movements, while the HC-05 Bluetooth module enables wireless communication and control. The HC-SR04 ultrasonic sensor adds environmental awareness, allowing the system to detect obstacles and navigate autonomously. Careful pin allocation and power management are crucial, leveraging the Nano's 5V logic and external power supplies to ensure reliable performance across all components. This combination transforms the Arduino Nano into a powerful, versatile platform for advanced robotic applications, bridging precise mechanical control, wireless connectivity, and intelligent sensing [24].

Table 3.1: Arduino Nano Specifications [3]

Specification	**Details**
Microprocessor	ATmega328P (8-bit AVR family)
Operating Voltage	5V
Input Voltage (Vin)	7V to 12V
Total I/O Pins	22
Analog Input Pins	6 (A0 to A5)
Digital Pins	14
Power Consumption	19 mA
I/O Pins DC Current	40 mA
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz
Weight	7g
PCB Size	18 x 45 mm
Communication Interfaces	SPI, IIC, USART

3.3.2 Arduino Nano Pinout

Now that we have seen a little bit about Arduino Nano and its important features and specifications, let us dive into the Arduino Nano Pinout. Figure 3.5 shows the complete pinout of Arduino Nano Board.

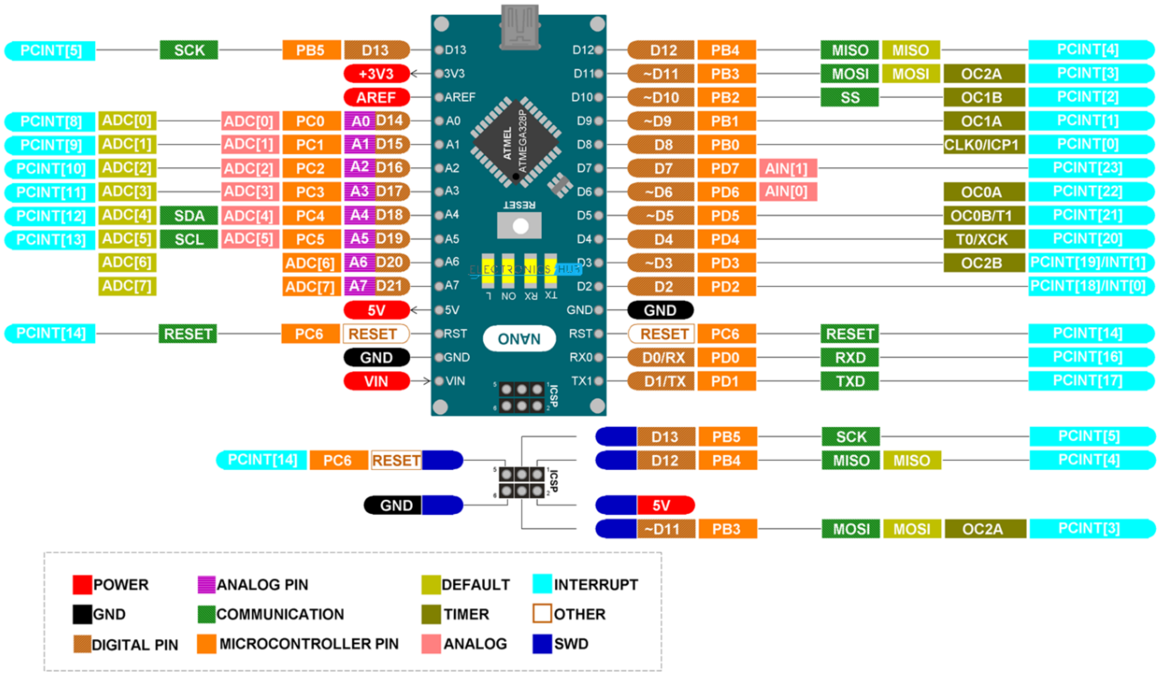

Figure 3.5: Arduino Nano Pinouts [3]

Table 3.2: ICSP Connector Pin Details [3]

Pin	Description
MISO	Master In Slave Out (Input or Output)
5V	Supply
SCK	Clock (from Master to Slave)
MOSI	Master Out Slave In (Input or Output)
RESET	Reset (Active LOW)
GND	Ground

Table 3.3: Arduino Nano Pin Detailed Configuration [3]

Pin Number	Pin Name	Description/Alternative Functions
1	TX / D1	Digital IO Pin 1, Serial TX Pin, Generally used as TX
2	RX / D0	Digital IO Pin 0, Serial RX Pin, Generally used as RX
3	RST	Reset (Active LOW)
4	GND	Ground
5	D2	Digital IO Pin 2
6	D3	Digital IO Pin 3, Timer (OC2B)
7	D4	Digital IO Pin 4, Timer (T0/XCK)
8	D5	Digital IO Pin 5, Timer (OC0B/T1)
9	D6	Digital IO Pin 6
10	D7	Digital IO Pin 7
11	D8	Digital IO Pin 8, Timer (CLK0/ICP1)
12	D9	Digital IO Pin 9, Timer (OC1A)
13	D10	Digital IO Pin 10, Timer (OC1B)
14	D11	Digital IO Pin 11, SPI (MOSI), Timer (OC2A)
15	D12	Digital IO Pin 12, SPI (MISO)
16	D13	Digital IO Pin 13, SPI (SCK)
17	3V3	Power
18	AREF	Analog Reference
19	A0	Analog Input 0
20	A1	Analog Input 1
21	A2	Analog Input 2
22	A3	Analog Input 3
23	A4	Analog Input 4, I2C (SDA)
24	A5	Analog Input 5, I2C (SCL)
25	A6	Analog Input 6
26	A7	Analog Input 7
27	5V	+5V Output from regulator or +5V regulated Input
28	RST	Reset (Active LOW)
29	GND	Ground
30	VIN	Unregulated Supply

3.4 Nano I/O Expansion Shield

The Arduino Nano IO Expansion Shield shown in figure 3.6 is a multipurpose board made to improve the Arduino Nano's capability and make networking easier. This shield separates all of the Nano's pins—digital, analogue, power, and communication—into conveniently accessible headers that are conveniently labelled. It has several power options, such as the ability to accept external power sources through a terminal block or DC jack. It also has integrated voltage regulators that can supply 3.3V and 5V outputs for components that are connected [25].

Sensors, monitors, and other peripherals can be seamlessly integrated with the shield thanks to its dedicated I2C and UART communication ports. It is the perfect option for robotics applications because it has several servo motor headers with the right power pins. Additional connectors are included for wireless communication modules that allow plug-and-play capabilities for wireless projects and the Internet of Things, including Bluetooth (HC-05/HC-06), nRF24L01, and XBee. A reset button, power and com-

Figure 3.6: Nano IO Expansion Shield [4]

munication status LEDs, and, in certain models, a little prototyping space for custom circuit creation are all features that make the shield easy to use. Its design makes it easy to incorporate parts like sensors, actuators, and communication modules straight into the project. [4]

All things considered, the Arduino Nano IO Expansion Shield is a strong add-on that improves the Nano's usability in robotics, Internet of Things, and prototype projects by streamlining intricate connections and offering structured, intuitive access to the board's capabilities. [4]

3.5 Ultrasonic Sensor (HC-SR04)

The HC-SR04 is an affordable and easy to use distance measuring sensor which has a range from 2cm to 400cm (about an inch to 13 feet).

The sensor is composed of two ultrasonic transducers. One is transmitter which outputs ultrasonic sound pulses and the other is receiver which listens for reflected waves. It's basically a SONAR which is used in submarines for detecting underwater objects. [5]

Here are its main specifications:

Table 3.4: HC-SR04 Specifications [5]

Operating Voltage	5V DC
Operating Current	15mA
Operating Frequency	40KHz
Min Range	2cm / 1 inch
Max Range	400cm / 13 feet
Accuracy	3mm
Measuring Angle	$< 15°$
Dimension	45 x 20 x 15mm

3.5.1 Ultrasonic Sensor(HC-SR04) Pinout

Figure 3.7 Shows the pinout of the sensor:

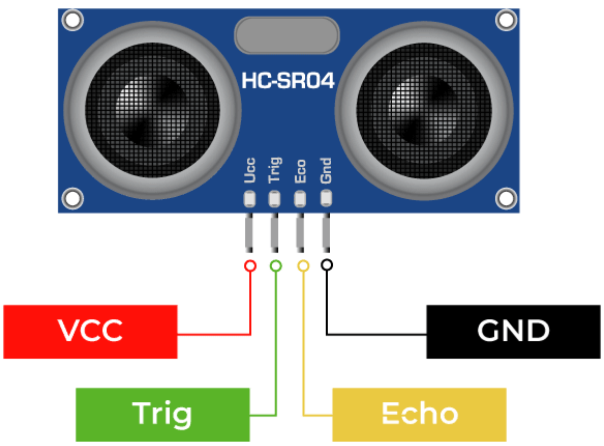

Figure 3.7: Ultrasonic Sensor(HC-SR04) Pinout [5]

The sensor has 4 pins. VCC and GND go to 5V and GND pins on the Arduino, and the Trig and Echo go to any digital Arduino pin. Using the Trig pin we send the ultrasound wave from the transmitter, and with the Echo pin we listen for the reflected signal. [5]

3.5.2 How the HC-SR04 Ultrasonic Distance Sensor Works?

Figure 3.8 provides working of ultrasonic sensor, It emits an ultrasound at 40 000 Hz which travels through the air and if there is an object or obstacle on its path It will bounce back to the module. Considering the travel time and the speed of the sound you can calculate the distance. In order to generate the ultrasound we need to set the

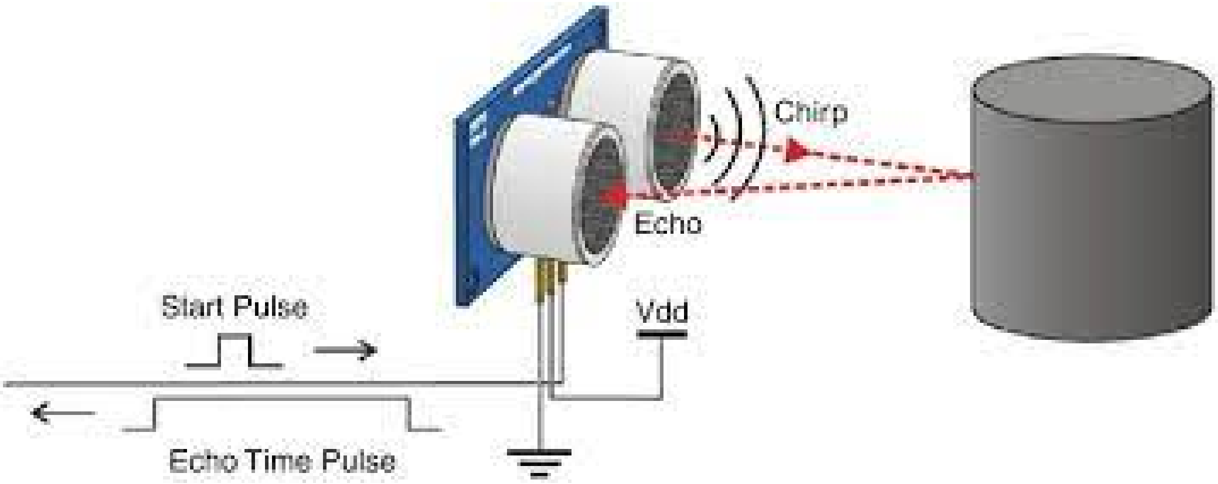

Figure 3.8: Ultrasonic Sensor with Object [6]

Trig pin on a High State for 10 µs. That will send out an 8 cycle ultrasonic burst which will travel at the speed of sound. The Echo pins goes high right away after that 8 cycle ultrasonic burst is sent, and it starts listening or waiting for that wave to be reflected from an object.

If there is no object or reflected pulse, the Echo pin will time-out after 38ms and get back to low state. [9] If we receive a reflected pulse, the Echo pin will go down sooner than those 38ms. According to the amount of time the Echo pin was HIGH, we can determine the distance the sound wave traveled, thus the distance from the sensor to the object.

For that purpose we are using the following basic formula for calculating distance:
Distance = Speed x Time

We actually know both the speed and the time values. The time is the amount of time the Echo pin was HIGH, and the speed is the speed of sound which is 340m/s.

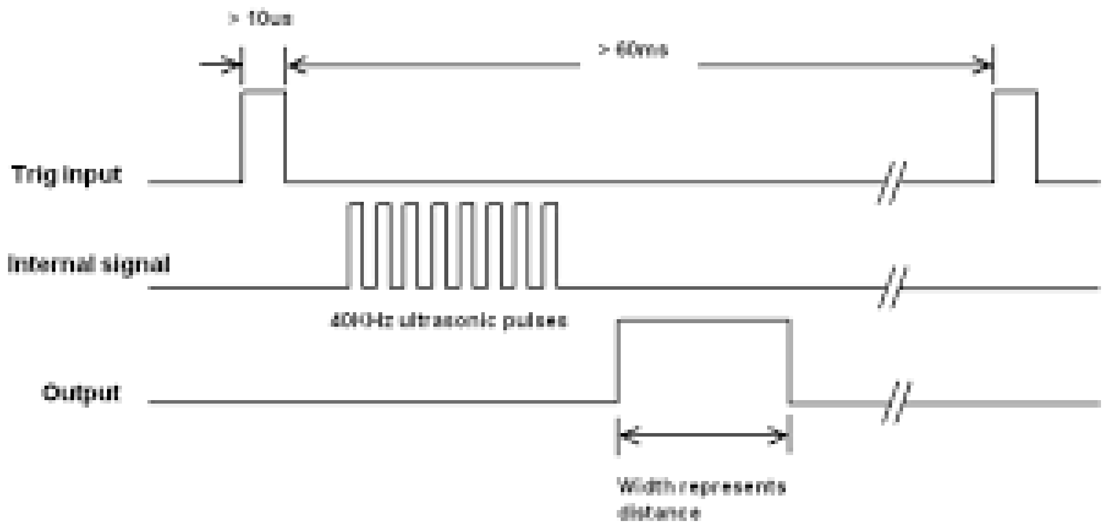

Figure 3.9: Timing Diagram [6]

There's one additional step we need to do, and that's divide the end result by 2. and that's because we are measuring the duration the sound wave needs to travel to the object and bounce back. [9]

$$\text{Distance} = \frac{\text{Speed of Sound} \times \text{Time}}{2}$$

where:

- **Speed of Sound**: The speed of sound in air
- **Time**: The total time for the sound wave to travel to the object and back.
- Division by 2 accounts for the round trip of the sound wave.

3.5.3 Testing of Ultrasonic Sensor

We tested the HC-SR04 ultrasonic sensor using the Arduino Nano. The sensor was connected to the Nano's trigger and echo pins, and the setup was powered through the Arduino. The sensor's ability to detect distances was verified by positioning an object at various distances and observing the sensor's response. Figure 3.10 shows the testing setup with the Arduino Nano and ultrasonic sensor.

The sensor's output was displayed on the Arduino IDE serial monitor, showing the distance readings in centimeters. The results were consistent as the object moved closer or farther from the sensor. Figure 3.11 illustrates the distance measurements in the serial monitor, confirming the sensor's accuracy and functionality for our project.

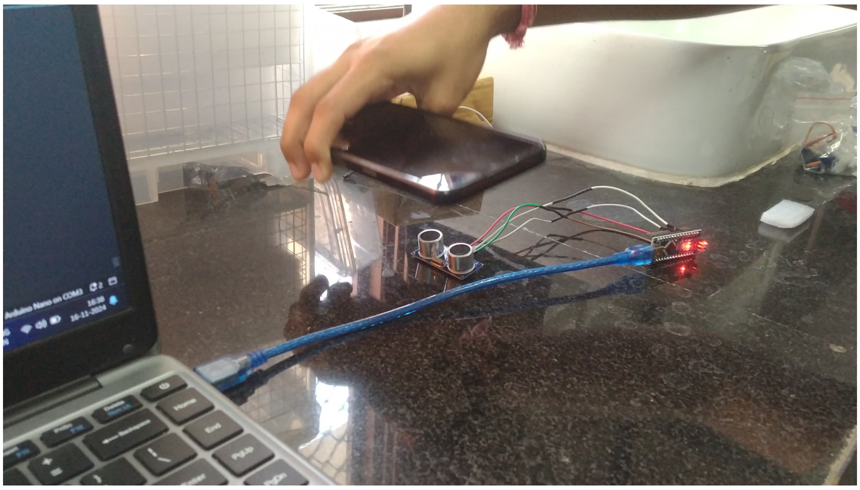

Figure 3.10: Testing setup for Ultrasonic sensor

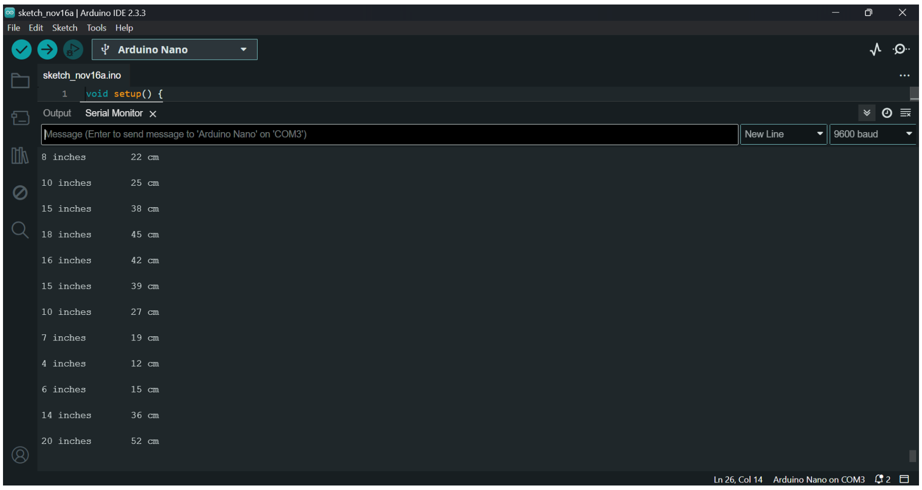

Figure 3.11: Results of Ultrasonic Testing

3.6 HC-05 Bluetooth Module

The HC-05 Bluetooth module enables wireless communication for our robotic spider, allowing seamless control and data transmission between the robot and external devices like smartphones or computers. This compact module provides a simple, low-cost way to add wireless connectivity to our robotic project, transforming how we interact with and control our spider robot.

3.6.1 HC-05 Hardware Overview

The HC-05 which is shown in figure 3.12 is a Bluetooth-to-Serial-Bridge module that allows wireless communications between two microcontrollers or between a microcontroller and a smartphone, laptop, or desktop PC with Bluetooth capability. It's perfect for directly replacing a wired asynchronous serial interface!

Figure 3.12: HC-05 Bluetooth Module [7]

Each of these modules contains a Bluetooth transceiver, meaning they're capable of both sending and receiving data.

As a Class 2 Bluetooth device, the HC-05 has a nominal range of 10 m. Of course, that is out in the open. Its range gets a little weaker inside the house, especially because of the walls. [26]

3.6.2 Modes of Operation

Controlling the HC-05 module and sending data through it are two different operations, but they are both accomplished through the serial interface. To distinguish between these two types of data, the HC-05 employs two distinct communication modes: AT mode and Data mode.

In AT Mode, you can configure various settings of the HC-05 module, such as its name, baud rate, PIN code, and data rate.

In Data Mode, the HC-05 module acts as a transparent data gateway. When the HC-05 receives data, it removes the Bluetooth headers and trailers and sends it to the UART port. When data is written to the UART port, the HC-05 constructs a Bluetooth packet and sends it over the Bluetooth wireless connection. [26]

3.6.3 Connection Roles

The HC-05 Bluetooth module can function in two main roles: Master and Slave.

In Slave Role, the HC-05 module waits for other devices to initiate a connection. This is the module's default role and is commonly used in projects where you want to control things using a smartphone. In Master Role, the HC-05 actively searches for other Bluetooth devices and tries to initiate a connection. This mode is used in projects where two microcontrollers need to communicate wirelessly. To switch between roles, you need to configure the HC-05 module by putting it into AT mode and sending AT commands over the UART port. [11]

3.6.4 Power

The maximum operating voltage of the bare HC-05 chip is 3.3V. Therefore, the module includes a linear 3.3V regulator which is shown in figure 3.13, which allows a voltage from 3.6V to 6V to be used to supply power to the module.

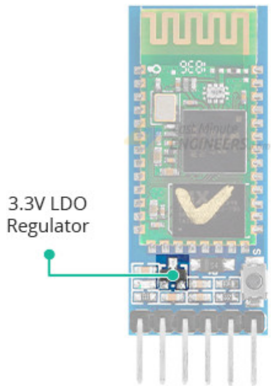

Figure 3.13: HC-05 3V3 Regulator [7]

It is important to note that the HC-05 module has a 3.3V logic level, so we cannot connect the HC-05 module's Rx pin directly to a digital pin on a 5V microcontroller like an Arduino UNO. In other words, the Rx pin on the HC-05 module is not 5V-tolerant. Therefore, before connecting to the HC-05 module, the microcontroller's Tx signal must be stepped down to 3.3V. [11]

The current consumption of the HC-05 module depends on what state it is in. This table from the datasheet provides some good estimates:

Table 3.5: Current Consumption Of HC-05 [11]

Mode	Current Consumption
Connected with data transfer	45 mA
Connected Idle	8 mA

3.6.5 Status LED

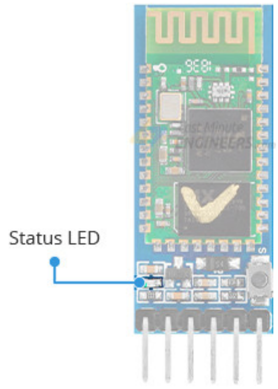

Figure 3.14: HC-05 Status LED [7]

LED Shown in figure 3.14,it blinks at various rates to indicate the status:

- When powered up, the module enters Bluetooth pairing mode, with the LED flashing rapidly at about 2 Hz.
- When the module is paired with a device, the LED flash pattern changes to two quick flashes, followed by a pause, and then repeats.
- When the module is put into AT mode, the LED blinks at a slow and steady rate. [11]

3.6.6 AT Mode

AT Mode shown in figure 3.15 is the configuration mode where you can send Hayes AT-style commands to the HC-05 module to change its settings like name, baud rate, password, etc.

Normally, the HC-05 module is in data mode. To put it into AT mode, you need to press-and-hold the onboard button while powering up the module. The LED will then start blinking at a slow and steady rate, indicating that the module is in AT mode.

Once in AT mode, you can send AT commands to the module over the UART port. The module will respond to the commands, either by acknowledging the command, providing the requested data, or signaling an error. The commands usually start with "AT+" followed by the specific command, e.g., "AT+NAME?" queries the name of the module or "AT+NAME=QUADRAPED" changes the name to "QUADRAPED" which is shown in figure 3.16. [27]

AT commands should be sent at the baud rate specified for the AT mode, which is often different from the baud rate used for data transmission. The default baud rate for AT mode is 38400 bps, but it can be changed if necessary.

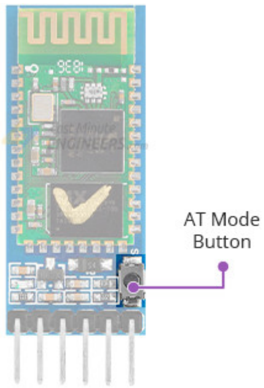

Figure 3.15: AT Mode Button [7]

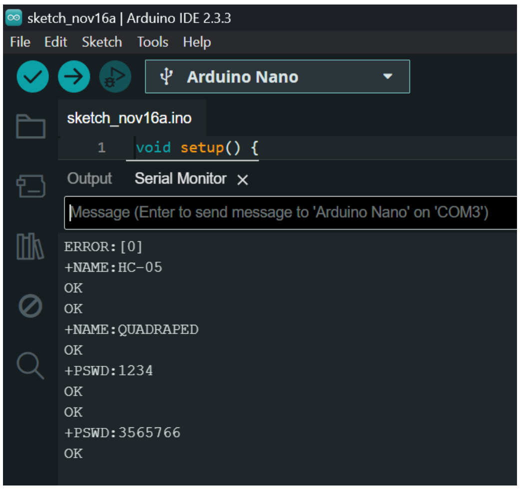

Figure 3.16: Serial monitor of Arduino IDE for AT commands

3.6.7 HC-05 Pinout

Figure 3.17 shows the pinouts of HC-05 Bluetooth module

1. **STATE** pin can be used to determine the current status of the HC-05 module. The State pin is LOW when the module is not paired and HIGH when it is.

2. **RXD** pin receives serial data from the microcontroller. It should be connected to the TX of the microcontroller. Please note that this pin is not 5V-tolerant. Therefore, before connecting the module to a 5V microcontroller, the microcontroller's Tx signal must be stepped down to 3.3V.

3. **TXD** pin sends serial data to the microcontroller. It should be connected to the RX of the microcontroller.

4. **GND** is the ground pin, common to any other device connected to the module.

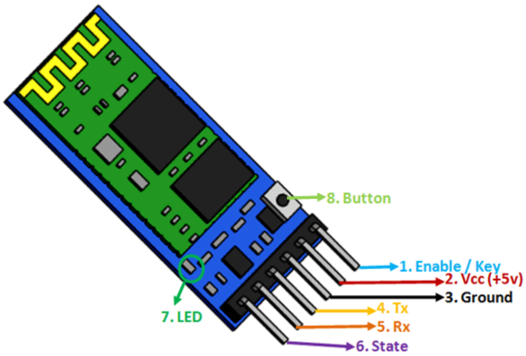

Figure 3.17: HC-05 Pinout [8]

5. **VCC** is where you connect the positive supply voltage. This voltage supply signal is routed to the HC-05 chip via a 3.3V regulator. It should range from 3.6V to 6V.

6. **EN** is connected to the on-board regulator enable pin and is pulled high by a 220k resistor. Pulling this pin low disables the regulator, which consequently turns off the HC-05. [26]

3.6.8 Controlling the HC-05 Module

A serial interface is all that is required to control the HC-05 Bluetooth module and send data through it. It acts, essentially, like a data pipeline: serial data that goes into the module (from the RXD pin), is passed out the Bluetooth connection. Data coming in from the Bluetooth side is passed out the serial side (out the TXD pin).

To set up this data pipeline, we follow a two-step process:

1. Connect the HC-05 module to a device capable of sending and receiving serial data, like an Arduino or any microcontroller with UART.

2. On the Bluetooth side, we establish a wireless connection between the HC-05 module and another Bluetooth-enabled device, such as an Android phone. This connection involves a pairing process similar to connecting any other Bluetooth devices together. You will also need a terminal program installed on your phone that can communicate via Bluetooth. For this purpose, we recommend using the "Serial Bluetooth Terminal," which is available in the Play Store. However, there are also many other free options that you can explore. [28]

In summary, we just need to set up the serial interface between the HC-05 and our microcontroller and then pair the HC-05 with the other Bluetooth device, and we're good to go!

3.7 Servo Motor

Servo motors are precision-driven devices that enable accurate rotational control in various applications, from robotics to remote-controlled vehicles. These sophisticated motors can rotate to specific angles with remarkable precision, making them essential in fields requiring detailed mechanical movement.

3.7.1 What is a Servo Motor?

A servo motor is a type of motor that can rotate with great precision, Figure 3.18 provide inner view of servo motor Normally this type of motor consists of a control circuit that provides feedback on the current position of the motor shaft, this feedback allows the servo motors to rotate with great precision. If you want to rotate an object at some specific angles or distance, then you use a servo motor. It is just made up of a simple motor which runs through a servo mechanism. If motor is powered by a DC power supply then it is called DC servo motor, and if it is AC-powered motor then it is called AC servo motor.In this section, we will be discussing only about the DC servo motor working. Apart from these major classifications, there are many other types of servo motors based on the type of gear arrangement and operating characteristics. A servo motor usually comes with a gear arrangement that allows us to get a very high torque servo motor in small and lightweight packages. Due to these features, they are being used in many applications like toy car, RC helicopters and planes, Robotics, etc. [29]

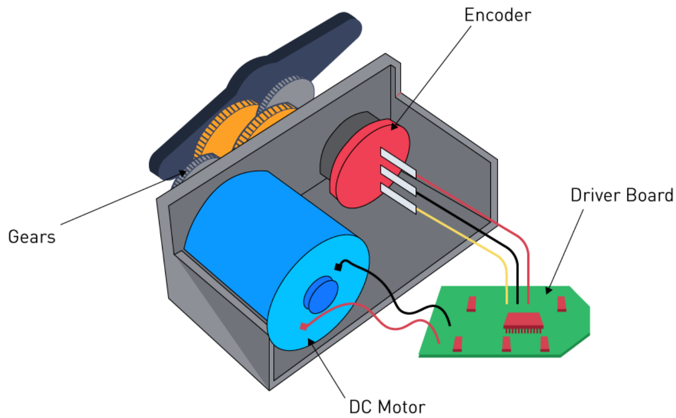

Figure 3.18: Servo Motor Inner View [5]

Servo motors are rated in kg/cm (kilogram per centimeter) most hobby servo motors are rated at 3kg/cm or 6kg/cm or 12kg/cm. This kg/cm tells you how much weight your servo motor can lift at a particular distance. For example: A 6kg/cm Servo motor should be able to lift 6kg if the load is suspended 1cm away from the motors shaft, the greater the distance the lesser the weight carrying capacity. The position of a servo motor is decided by electrical pulse and its circuitry is placed beside the motor. [29]

3.7.2 Servo Motor Working Mechanism

It consists of three parts:

- Controlled device
- Output sensor
- Feedback system

It is a closed-loop system where it uses a positive feedback system to control motion and the final position of the shaft. Here Figure 3.19 provide the feedback system of servo motor, the device is controlled by a feedback signal generated by comparing output signal and reference input signal.

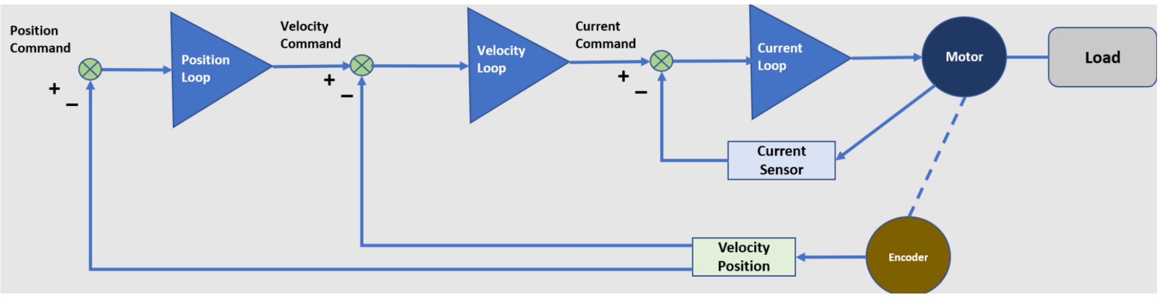

Figure 3.19: Servo Motor Block Diagram [9]

Here reference input signal is compared to the reference output signal and the third signal is produced by the feedback system. And this third signal acts as an input signal to the control the device. This signal is present as long as the feedback signal is generated or there is a difference between the reference input signal and reference output signal. So the main task of servomechanism is to maintain the output of a system at the desired value at presence of noises. [30]

3.7.3 Servo Motor Working Principle

A servo consists of a Motor (DC or AC), a potentiometer, gear assembly, and a controlling circuit. First of all, we use gear assembly to reduce RPM and to increase torque of the motor. Say at initial position of servo motor shaft, the position of the potentiometer knob is such that there is no electrical signal generated at the output port of the potentiometer. Now an electrical signal is given to another input terminal of the error detector amplifier. Now the difference between these two signals, one comes from the potentiometer and another comes from other sources, will be processed in a feedback mechanism and output will be provided in terms of error signal. This error signal acts as the input for motor and motor starts rotating. Now motor shaft is connected with the potentiometer and as the motor rotates so the potentiometer and it will generate a signal. So as the potentiometer's angular position changes, its output feedback signal changes. After sometime the position of potentiometer reaches at a position that the output of potentiometer is same as external signal provided. At this condition, there will be no output signal from the amplifier to the motor input as there is no difference between external applied signal and the signal generated at potentiometer, and in this situation motor stops rotating. [29]

3.7.4 Interfacing Servo Motors with Microcontrollers

Interfacing hobby Servo motors like s90 servo motor with MCU is very easy. Servos have three wires coming out of them. Out of which two will be used for Supply (positive and negative) and one will be used for the signal that is to be sent from the MCU.

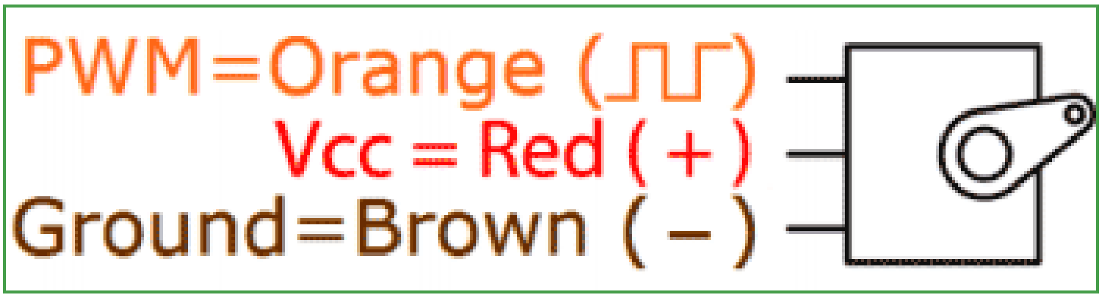

Figure 3.20: Servo Motor Pin Diagram [5]

3.7.5 Controlling Servo Motor

Figure 3.21 provides pin Diagram of servo motor,Servo motor is controlled by PWM (Pulse with Modulation) which is provided by the control wires. There is a minimum pulse, a maximum pulse and a repetition rate. Servo motor can turn 90 degree from either direction form its neutral position. The servo motor expects to see a pulse every 20 milliseconds (ms) and the length of the pulse will determine how far the motor turns. For example Shown in figure 3.5, a 1.5ms pulse will make the motor turn to the 90° position, such as if pulse is shorter than 1.5ms shaft moves to 0° and if it is longer than 1.5ms than it will turn the servo to 180°. [31]

Servo motor works on PWM (Pulse width modulation) principle, means its angle of rotation is controlled by the duration of applied pulse to its Control PIN. Basically servo

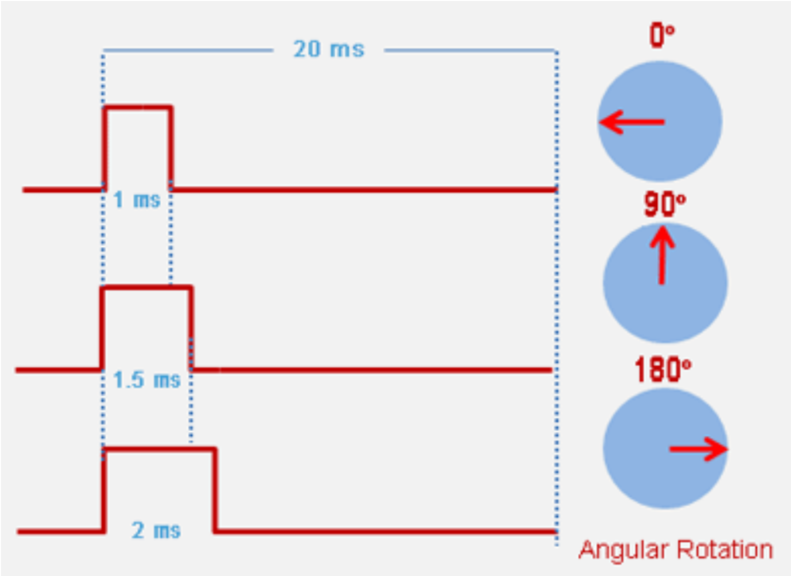

Figure 3.21: Servo Motor Rotation According to Signal [5]

motor is made up of DC motor which is controlled by a variable resistor (potentiometer) and some gears. High speed force of DC motor is converted into torque by Gears. We know that WORK= FORCE X DISTANCE, in DC motor Force is less and distance (speed) is high and in Servo, force is High and distance is less. The potentiometer is connected to the output shaft of the Servo, to calculate the angle and stop the DC motor on the required angle. [31]

3.7.6 Testing of servo motor

In our project, we tested all 12 SG90 servo motors using an Arduino Nano board. The motors were individually controlled using the standard ”Sweep” code, which is a simple script to make a servo motor rotate back and forth between its minimum and maximum angles (0° and 180°). This test allowed us to ensure that all motors were functioning properly, providing smooth and consistent movements. The Arduino Nano, known for its compact size and versatility, was used to program and send control signals to each servo, verifying that each motor responded correctly to the commands. The sweep test also helped in fine-tuning the wiring and power distribution to the motors, ensuring the system’s overall reliability. With all 12 servo motors tested successfully, we could proceed to integrate them into the spider robot’s movements for repetitive tasks, obstacle avoidance, and Bluetooth control functionalities.

3.8 System Integration

The spider robot's electronic architecture combines a number of parts to provide three unique features: Bluetooth-controlled operation, obstacle avoidance, and basic movement control. The Arduino Nano microprocessor, at the heart of the system, processes sensor inputs and wireless signals to operate 12 servo motors for leg movements. Figure 3.22 illustrates how all the electronic components are connected to each other.

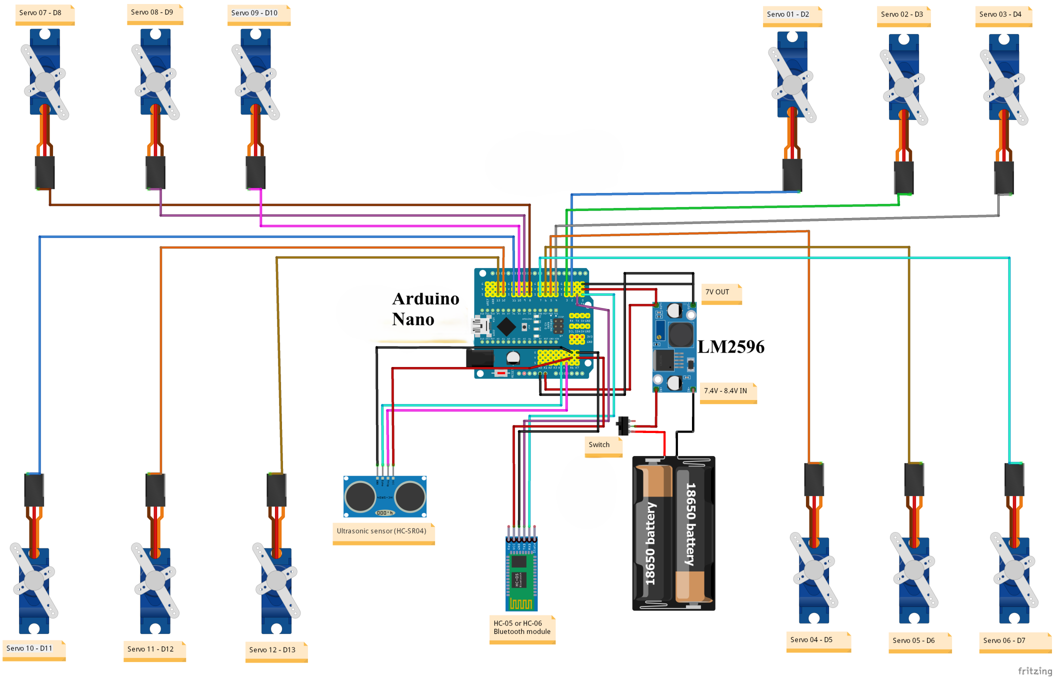

Figure 3.22: Overall Robotic Spider Electronic System Connections

Power Supply System:

- The system is powered by two 18650 lithium-ion batteries (3.7V each) connected in series to provide 7.4V-8.4V input
- A power switch is integrated for system control
- The LM2596 DC-DC buck converter steps down the battery voltage to a stable 7V output suitable for the Arduino and servos

Core Control Unit:

- Arduino Nano serves as the main controller
- The Nano IO Expansion Shield is mounted on top of the Arduino Nano for easier connections and pin management

- The expansion shield provides organized power distribution and signal routing

Servo Motor Configuration:

- Total of 12 SG90 servo motors (labeled Servo 01-D2 through Servo 12-D13)
- Servos are arranged in four groups of three for each leg Connection details for each servo:
  - Red wire: Power (7V)
  - Black/Brown wire: Ground (GND)
  - Yellow/Orange wire: PWM signal from Arduino

Sensor Integration:

1. **Ultrasonic Sensor (HC-SR04):**
   - VCC: Connected to 5V from Arduino
   - GND: Connected to ground
   - ECHO: Connected to digital pin on Arduino
   - ECHO: Connected to digital pin on Arduino
   - Used for obstacle detection in obstacle avoidance mode
2. **Bluetooth Module (HC-05):**
   - VCC: Connected to 5V
   - GND: Connected to ground
   - TX: Connected to Arduino RX pin
   - RX: Connected to Arduino TX pin
   - Enables wireless control via smartphone

Signal Routing:

- PWM signals from Arduino digital pins (D2-D13) control individual servos
- Color-coded wiring scheme for easy identification:
  - Power lines: Red
  - Ground lines: Black
  - Signal lines: Various colors for different servos

Power Distribution:

- The 7V regulated output from the buck converter powers:
  - All 12 servo motors
  - Arduino Nano (via VIN)
- 5V from Arduino powers:
  - Ultrasonic sensor
  - Bluetooth module

Chapter 4
Mechanical Design

Mechanical design is the foundation of any robotic system, as it significantly determines the robot's ability to perform tasks effectively, adapt to various environments, and maintain structural integrity under different conditions. In robots focused on locomotion, especially quadrupeds, the mechanical design becomes even more critical as it governs how the robot interacts with its surroundings, how efficiently it moves, and how well it can handle dynamic challenges. A robust and thoughtful mechanical design ensures a balance between functionality, efficiency, and adaptability, making the robot not just operational but also optimized for its intended tasks [32].

4.1 Key Aspects of Mechanical Design in Robotic Locomotion

Stability and Balance

Stability and balance are fundamental to ensuring a robot's ability to maintain equilibrium during both static and dynamic activities. Stability minimizes the risk of tipping over, particularly when traversing uneven terrains or carrying loads. To achieve this, a well-balanced design is critical. Uniform weight distribution across the robot's body ensures no single leg or joint is overburdened, which is especially crucial in quadrupeds where each leg must support an equal share of the load. Symmetrical placement of legs, typically arranged in a rectangular or square footprint, enhances the base of support and provides stability. Moreover, a low center of gravity, achieved by compact body design and strategic placement of heavy components like batteries near the base, significantly reduces the likelihood of tipping. Quadruped robots inherently offer better stability compared to bipedal robots due to their wider support base and ability to maintain balance even when one leg loses traction [33].

Efficiency in Movement

Efficiency in movement plays a critical role in robotic locomotion, minimizing the energy required for movement and enabling longer operational times. This efficiency stems from precise mechanical design and optimization of motion. Rotary joints and multi-segmented limbs, mimicking biological systems, allow for a natural range of motion while ensuring smooth transitions between steps, which reduces unnecessary energy expenditure. Gait optimization is another key consideration, with common patterns like the wave gait, which sequentially moves legs for maximum stability, and the tripod gait, which alternates groups of three legs for higher speeds. Lightweight materials such as aluminum and carbon fiber further enhance efficiency by reducing the overall weight of the robot. These design choices not only improve energy utilization but also reduce wear and tear on actuators and joints, ultimately increasing the robot's lifespan [34].

Durability and Adaptability

Durability and adaptability are vital for robotic systems operating in challenging environments. Mechanical designs must account for exposure to rough terrains, moisture, and temperature fluctuations. Using durable materials such as aluminum, which is lightweight and corrosion-resistant, or carbon fiber, which offers both strength and flexibility, ensures the robot's longevity. Adaptability is achieved through bio-inspired designs that mimic natural movements, enabling robots to handle complex terrains with ease. Quadruped robots, for example, can dynamically adjust their gait or posture based on real-time data, such as climbing inclines or navigating obstacles. These features make the robot resilient and capable of functioning effectively in diverse scenarios [33].

Ease of Maintenance and Modularity

Ease of maintenance and modularity enhance the robot's practicality and usability. A modular design allows individual components to be easily replaced or upgraded, significantly reducing downtime during repairs. For instance, leg assemblies can be swapped out independently, and additional sensors or tools can be attached to a standardized frame. Using 3D-printed parts and standardized fasteners further simplifies repair and customization, enabling users to adapt the robot for different tasks or environments by changing configurations or tools [34].

Integration of Mechanical Design with Other Systems

Integration of mechanical design with other systems ensures seamless performance by aligning the mechanical components with the robot's electronics, control algorithms, and software. Sensors, such as IMUs for balance and ultrasonic devices for obstacle detection, rely on stable and precise mechanical structures for accurate operation. Actuators like servo motors depend on well-designed linkages to translate electrical signals into precise movements. The software plays a crucial role in this integration, utilizing real-time data from sensors to adjust gait or posture dynamically. Feedback loops enable the robot to correct its stance or movement, making the mechanical design more adaptable and responsive. Together, these aspects form a cohesive system that combines strength, efficiency, and intelligence to achieve advanced robotic locomotion [32].

4.2 Bio-Inspired Locomotion in Quadruped Robots: A Comparison with Spiders

Bio-inspired robotics leverages the biological principles of animals to create efficient and adaptable robotic systems. The concept of bio-inspired locomotion, especially in quadruped robots, is heavily influenced by the movement mechanics of animals like spiders. These animals exhibit a high degree of mobility, stability, and adaptability, making them ideal models for robotic design. In this section, we will compare the locomotion of quadruped robots with the natural locomotion of spiders in detail, focusing on key aspects such as leg structure, movement patterns, stability, and adaptability to various terrains [32].

4.2.1 Leg Structure: Spider vs. Robot

Spider Leg Anatomy A spider's leg is a marvel of natural engineering, consisting of several segments as given in figure 4.1 that work together to allow complex and adaptive movements. The basic structure of a spider's leg includes the following parts:

- **Coxa**: The base segment that connects the leg to the body.
- **Femur**: The first long segment after the coxa.
- **Tibia**: The next segment, often longer and more flexible.
- **Metatarsus and Tarsus**: The final segments involved in movement and interaction with surfaces.

Each segment in a spider's leg can move independently, providing flexibility and enabling a wide range of motions, including precise adjustments for walking, climbing, and jumping. The spider's leg is controlled by multiple muscles that allow it to perform complex movements through a combination of flexion and extension.

Quadruped Robot Leg Design In quadruped spider robots, the design of the legs as given in the figure 4.2 often mimics the structure of a spider's leg, but with mechanical components replacing biological tissue. A quadruped robot typically has a **multi-segmented leg system**:

- **Coxa (Hip joint)**: The part of the leg that attaches to the robot's body.
- **Femur**: The segment that connects the coxa to the tibia.
- **Tibia**: The segment that links the femur to the foot or end part of the leg.

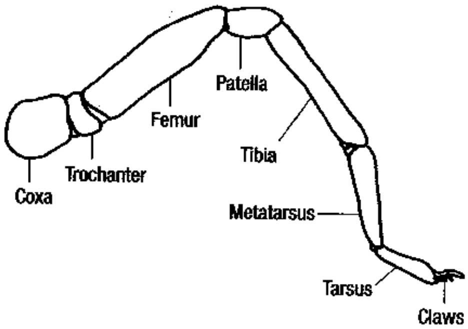

Figure 4.1: spider leg

Figure 4.2: Robot Leg

Just like a spider's leg, the robot's leg is designed with multiple degrees of freedom (DOF) at each joint, allowing for flexible movement. However, unlike biological legs, robot legs are typically powered by **servo motors** or **actuators**, which allow the leg segments to move in precise, programmed ways.

4.2.2 Movement Patterns: Spider vs. Robot

Spider Locomotion Spiders exhibit several types of locomotion patterns based on their needs and the terrain they are navigating. Their movements are highly adaptable and efficient, designed for maintaining stability across uneven surfaces or even vertical climbs.

- **Tripod Gait**: One of the most common walking patterns for spiders is the **tripod gait**, where three legs (one on the left and two on the right, or vice versa) move at a time. This provides a stable foundation for the spider to move forward while maintaining balance. **Stability**: The tripod gait ensures that the spider has at least three legs in contact with the ground at all times, preventing it from tipping over.

- **Wave Gait**: This is another movement pattern in which legs move in a sequential wave-like fashion. This gait is useful for precise or controlled movement over smooth surfaces or when climbing.
- **Specialized Movements**: Spiders also exhibit specialized movements like **jumping** or **climbing**. These movements rely on their leg flexibility, strong exoskeleton, and finely-tuned muscle control.

Quadruped Robot Locomotion Quadruped spider robots mimic the spider's natural gaits and motions by using multiple leg segments with independent control over each joint. Their actuators and control systems are designed to replicate these gaits with precision.

- **Tripod Gait in Robots**: Similar to spiders, quadruped robots use the tripod gait for stability. The advantage of a robotic tripod gait is that it can be precisely controlled, ensuring the robot can handle uneven terrains and obstacles without losing balance. **Controlled Movement**: In robots, the tripod gait is often synchronized through software algorithms that calculate the optimal speed and movement path for the robot. Robots can dynamically adjust leg movements depending on terrain feedback, making the gait efficient and adaptive.
- **Wave Gait in Robots**: Robots also employ wave gaits, especially when traversing smoother surfaces or for slower, more controlled movements. A wave gait is particularly useful in climbing or precision tasks, as the sequential leg movements provide balance and reduced risk of missteps.
- **Specialized Movements in Robots**: Many advanced quadruped robots are designed with climbing abilities. However, the robot's ability to jump or adapt to sudden movements is typically limited compared to spiders, as robots rely on servo motors, which have limitations in flexibility and speed compared to biological muscles.

4.2.3 Summary: Comparing Spider and Robot Locomotion

The comparison between spider and robot locomotion given in Table 4.1 highlights key similarities and differences in their movement strategies. Spiders use multi-segmented, muscle-powered legs and natural gaits like tripod and wave, excelling in climbing and adaptability to rough terrains. In contrast, robots employ motor-powered legs, guided by sensors and algorithms, with similar gaits but limited efficiency on steep climbs. Spiders rely on biological systems for energy efficiency and dynamic stability, whereas robots achieve balance using stabilization algorithms and low centers of gravity. While robots mimic spider-like movements, their functionality is constrained by mechanical and energy limitations [33].

Feature	Spider Locomotion	Robot Locomotion
Leg Structure	Multi-segmented, flexible, muscle-powered	Multi-segmented, motor-powered
Gait Patterns	Tripod, wave, climbing, jumping	Tripod, wave, climbing (limited)
Stability	Dynamic and static, low center of gravity	Stabilization algorithms, low center of gravity
Terrain Adaptability	High adaptability, climbs easily, rough terrain	Good adaptability, but less efficient on steep climbs
Movement Control	Natural, biological control through muscles	Controlled via servos, sensors, algorithms
Energy Efficiency	Highly efficient, biological systems	Energy-efficient design but limited by actuators

Table 4.1: Comparison of Spider and Robot Locomotion Features

4.3 Material Selection for Spider Robot

Selecting the right material for a spider robot is critical to achieving the ideal balance between weight, durability, cost, and performance. The material should be lightweight to facilitate efficient locomotion, durable enough to withstand mechanical stress and environmental conditions, and cost-effective to suit the robot's purpose. Different materials bring specific advantages and are chosen based on the robot's design requirements and intended applications. Below is a detailed discussion of commonly used materials, including the choice of PLA+ (Polylactic Acid Plus) for this specific robot design.

PLA+ (Polylactic Acid Plus) is a thermoplastic material derived from renewable resources such as cornstarch or sugarcane [35]. It is an enhanced version of standard PLA, offering improved properties like toughness, flexibility, and durability. The material is biodegradable, making it an environmentally friendly option for robotic projects [35]. Its lightweight nature makes it ideal for minimizing energy consumption during motion, which is especially important for robots relying on battery-powered actuators. PLA+ is also highly printable, allowing for precise and intricate designs using 3D printing technology, with minimal warping or errors. Its affordability makes it accessible for hobbyist projects, educational robots, and lightweight applications where cost efficiency is critical. Moreover, As given in Table 4.2 it provides adequate strength, with improved impact resistance compared to standard PLA, making it suitable for small to medium-sized robots.

Property	**Value**
Material Type	PLA+ (Polylactic Acid Plus)
Density	1.24 g/cm^3
Tensile Strength	60–70 MPa
Elongation at Break	10–20%
Flexural Strength	90–100 MPa
Heat Resistance	Higher than standard PLA (approx. 75°C)
Printing Temperature	200–230°C
Bed Temperature	50–70°C
Biodegradability	Partially biodegradable
Impact Resistance	Better than standard PLA
Dimensional Stability	High
Ease of Printing	Excellent, low warping
Post-Processing Compatibility	Sanding, painting, and gluing
Applications	Prototypes, functional parts, decorations

Table 4.2: Properties of PLA+ Filament

Aluminum 6061 is a lightweight and corrosion-resistant material widely used in robotics due to its excellent machinability and moderate strength-to-weight ratio [36].This material is highly durable, resisting deformation under mechanical stress and ensuring structural integrity even in demanding applications. Additionally, aluminum has the natural ability to dissipate heat, which is advantageous for robots incorporating heat-generating components such as servos or processors. Its polished and sleek finish adds aesthetic appeal to the design. Aluminum is commonly used in research robots or outdoor applications that require a moderate payload capacity, typically in the range of 1 to 5 kilograms.

Carbon Fiber stands out for its exceptional strength-to-weight ratio, making it one of the most sought-after materials for high-performance robotics [37].It is extremely lightweight yet incredibly strong, providing the ability to handle dynamic loads and impacts without deformation. Carbon fiber's resistance to chemical and environmental degradation makes it suitable for challenging environments, such as exploration or reconnaissance missions. Its lightweight properties reduce energy consumption, which is crucial for robots designed for agile or extended operations. Furthermore, its high-tech, premium look enhances the overall design aesthetics, making it a preferred choice for professional-grade robots.

Acrylonitrile Butadiene Styrene (ABS) Plastic is another commonly used material in robotics, especially for prototyping or small-scale production [38].This thermoplastic offers moderate strength and flexibility, with excellent resistance to impact and heat. ABS is lightweight, which reduces actuator strain and ensures ease of movement for robots. Its cost-effectiveness makes it an appealing option for DIY projects, educational prototypes, and smaller robotic systems. Moreover, it is easily molded or 3D printed, allowing for rapid design iterations and testing.

4.4 Basics of 3D Printing

4.4.1 Designing Spider Robot Parts

The design phase is the foundation of any 3D printing project, especially for a spider robot, where precision, functionality, and adaptability are critical. To create the 3D model, CAD (Computer-Aided Design) software such as Fusion 360, TinkerCAD, or SolidWorks is typically used. Fusion 360 is ideal for detailed, parametric designs and offers simulation capabilities, making it a top choice for intricate projects [39]. TinkerCAD, on the other hand, is beginner-friendly and suitable for simpler components, while SolidWorks excels in industrial-grade designs requiring precise mechanical features. When designing, structural integrity is paramount. Parts must have adequate thickness and support to handle mechanical loads, with reinforcements added to stress-prone areas like leg joints and motor mounts. Holes and slots should be included for fasteners, ensuring they are slightly oversized (e.g., 0.2 mm larger) to account for printer tolerances [40].

Compartment spaces should be allocated for microcontrollers, sensors, and batteries, with channels or slots for wires to reduce clutter and ensure smooth operation. Modularity is also essential; breaking the design into smaller parts simplifies printing and assembly. Components should be designed to snap together or attach securely using screws or adhesives. Before proceeding to printing, CAD simulation tools can be used to analyze the mechanical strength of critical parts and check for potential collisions between moving components, such as leg segments. Figure 4.3 illustrates the 3D-printed left coxa component, showcasing its lightweight and robust design optimized for efficient load distribution and precise motion in robotic legs.

4.4.2 3D Printing Process

After completing the design, the next step is preparing for 3D printing, where calibration and proper planning are crucial to achieving high-quality parts. Calibrating the printer begins with leveling the print bed to ensure even layers and prevent print failures. A simple method, such as using a piece of paper to check the nozzle's distance

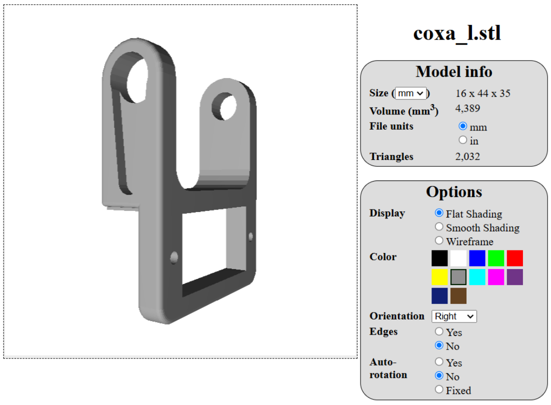

Figure 4.3: Left Coxa

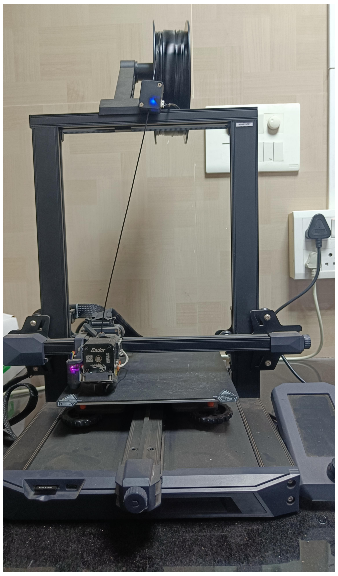

Figure 4.4: 3D Printer

from the bed, can be highly effective. Material settings must also be adjusted based on the filament being used; for instance, PLA requires a nozzle temperature of 200–210°C and a bed temperature of 50–60°C, while ABS requires 220–240°C and 90–110°C, respectively. Print speed should be set slower (30–50 mm/s) for detailed components like leg joints to enhance precision [41]. Figure 4.4 depicts a state-of-the-art 3D printing machine, highlighting its ability to fabricate intricate robotic components with high precision and customizable material properties, ensuring durability and efficiency in design.

The slicing process is the next critical step. This involves loading the 3D model into slicing software such as Cura or PrusaSlicer, which translates the model into machine-readable instructions. Settings such as layer height and infill must be carefully configured. A layer height of 0.1–0.2 mm is ideal for achieving fine details in small parts like joint connectors. For load-bearing components such as legs and motor mounts, an infill density of 50–70 percentage is recommended, while non-structural parts can suffice with 10–20 percent. Overhanging features, like leg joint hinges, require support structures to ensure successful printing. Additionally, parts should be oriented to minimize the need for supports and maximize strength along stress axes. Before printing large or critical parts, it is wise to print smaller components first. This allows you to test the printer's accuracy, material behavior, and the fitment of features such as holes and joints [42].

4.4.3 Post-Processing of 3D Printed Parts

Once printing is complete, post-processing steps are necessary to refine the parts and prepare them for assembly. The first step involves removing support structures carefully using tools such as pliers or a utility knife. It is important to avoid applying excessive force, especially on delicate features like hinges or thin walls, to prevent damage. After removing supports, sanding the edges ensures a smooth finish and precise movement. Begin with coarse-grit sandpaper (100–150) to eliminate large bumps or uneven layers, followed by fine-grit sandpaper (400–800) to achieve a polished surface. Sand critical contact areas, such as joints and slots, for improved fit and functionality [43].

Assembly is where individual components come together to form a fully functioning spider robot. For joining parts, screws or bolts are the most reliable fasteners. Ensure that holes are cleaned and threaded properly, and use washers or spacers to improve joint stability where necessary. For non-moving parts, adhesives like superglue or epoxy can provide a permanent bond. When using adhesives, apply them sparingly to prevent interference with adjacent components. If the design includes snap-fit connections, test the fit carefully and sand the edges for smoother assembly, if needed.

Once assembled, final adjustments should be made to ensure optimal performance. Check the alignment of all moving parts, such as leg joints and actuators, and secure electronic components, including sensors and motors. Properly route wires to prevent tangling or interference with the robot's movements. Finally, perform a functional test of the robot to identify and fix any issues related to movement, stability, or electrical connections. Through careful attention to these steps, you can create a robust and functional spider robot that fully leverages the benefits of 3D printing technology.

4.5 Derivation of Mechanical Parameter

4.5.1 Calculation of Torque

The weight and force analysis of the robotic spider starts by calculating its total weight based on the masses of its components. Weight is a measure of the force exerted by gravity on the robot's total mass and is determined using the equation:

$$W = m \times g$$

where m is the total mass of the robot, and g is the acceleration due to gravity, which is $9.81\,\text{m/s}^2$. Breaking it down into the individual contributions from the components: the base frame weighs $200\,\text{g}$ (converted to $0.2\,\text{kg}$), the servos collectively weigh $600\,\text{g}$ as there are 12 servos each weighing $50\,\text{g}$, the electronics add $150\,\text{g}$ ($0.15\,\text{kg}$), and the battery contributes $300\,\text{g}$ ($0.3\,\text{kg}$). Adding these gives the total mass:

$$m_{\text{total}} = 0.2 + 0.6 + 0.15 + 0.3 = 1.25\,\text{kg}$$

The total weight is then calculated by multiplying this mass by g:

$$W = 1.25 \times 9.81 = 12.26\,\text{N}$$

This value of W represents the total gravitational force acting on the robot.

For the servo motors, it is essential to determine the torque they must generate to lift and move the robot's legs. Torque is the rotational equivalent of linear force and is calculated as:

$$T = F \times r$$

where F is the force acting on the servo arm, and r is the length of the servo arm (distance from the axis of rotation to the point where the force is applied). Since the weight is distributed across the four legs of the robot, each leg bears a quarter of the total weight. The force on each leg is:

$$F_{\text{leg}} = \frac{W}{4} = \frac{12.26}{4} = 3.065\,\text{N}$$

If the servo arm has a length of $3\,\text{cm}$ (which is equivalent to $0.03\,\text{m}$), the torque required for one servo is:

$$T = 3.065 \times 0.03 = 0.09195\,\text{Nm}$$

To ensure the chosen servos are capable of handling this requirement, we compare this value with the maximum torque of the MG90S servo, which is rated at $2.2\,\text{kg} \cdot \text{cm}$. Converting this to Newton-meters gives:

$$2.2\,\text{kg} \cdot \text{cm} = 0.2156\,\text{Nm}$$

The difference between the servo's maximum torque and the required torque gives the torque margin:

$$\text{Torque Margin} = 0.2156 - 0.09195 = 0.12365\,\text{Nm}$$

This margin shows that the MG90S servos provide more than enough torque to meet the demands of the robotic spider's operation, ensuring stable and reliable movements of its legs during walking or other maneuvers.

4.5.2 Calculation of COG

The center of gravity (COG) is the average position of the robot's mass, crucial for maintaining stability. The COG is calculated as the weighted average of the positions of all components.

General Formula

$$COG_x = \frac{\sum(m_i \times x_i)}{\sum m_i}, \quad COG_y = \frac{\sum(m_i \times y_i)}{\sum m_i}, \quad COG_z = \frac{\sum(m_i \times z_i)}{\sum m_i}$$

Where:

- m_i: Mass of the i-th component
- x_i, y_i, z_i: Position coordinates of the i-th component relative to a reference point
- $\sum m_i$: Total mass of the robot

Example COG Calculation

Assume the following component layout:

Component	Mass (kg)	Position (x, y, z) (m)
Base Frame	0.2	$(0, 0, 0)$
Battery Pack	0.3	$(0, 0.05, -0.02)$
Arduino Nano	0.15	$(0.02, -0.03, 0.01)$
12 Servo Motors	0.6	Distributed on legs

For simplicity, divide servo mass equally among legs:

$$\text{Mass per leg} = \frac{0.6}{4} = 0.15\,\text{kg}$$

Assume legs are positioned symmetrically:

- Front-left leg: (-0.1, 0.1, -0.05)
- Front-right leg: (0.1, 0.1, -0.05)
- Rear-left leg: (-0.1, -0.1, -0.05)
- Rear-right leg: (0.1, -0.1, -0.05)

Calculation Steps

Total Mass:

$$\sum m_i = 0.2 + 0.3 + 0.15 + (0.15 \times 4) = 1.25\,\mathrm{kg}$$

COG in x-direction:

$$COG_x = \frac{1}{1.25}\,(0.003 - 0.015 + 0.015 - 0.015 + 0.015) = 0.0008\,\mathrm{m}$$

COG in y-direction:

$$COG_y = \frac{1}{1.25}\,(0.015 - 0.0045 + 0.015 + 0.015 - 0.015 - 0.015) = 0.008\,\mathrm{m}$$

COG in z-direction:

$$COG_z = \frac{1}{1.25}\,(-0.006 + 0.0015 - 0.0075 - 0.0075 - 0.0075 - 0.0075) = -0.028\,\mathrm{m}$$

Final COG Position:

$$COG = (0.0008, 0.008, -0.028)\,\mathrm{m}$$

This position indicates the robot's COG relative to the base frame, which must stay within the support polygon for stability.

Chapter 5
Algorithm for Robotic Spider

The Software Development chapter provides a detailed explanation of the programming and logic implementation for the 3-in-1 Spider Robot based on the Arduino Nano. The software layer is pivotal in ensuring the robot's multifunctionality, including walking, obstacle avoidance, and Bluetooth control. This chapter covers the development environment, core algorithms, debugging processes, flowcharts, and sample codes, making it a comprehensive guide to the software architecture.

5.1 Development Environment

The software for the Spider Robot was built using:

1. **Arduino IDE:**

   The Arduino Integrated Development Environment (IDE) is a software platform designed for writing, compiling, and uploading code to Arduino boards, such as the Arduino Nano used in this spider robot project. It provides an easy-to-use interface and supports the C/C++ programming language with built-in libraries tailored to Arduino development. The simplicity of the IDE makes it an ideal choice for beginners and experts alike.

   In the context of the spider robot, the Arduino IDE serves as the backbone for software development and debugging. The primary purpose of the IDE is to bridge the gap between the developer's algorithms and the hardware components of the robot. It allows the code to interact seamlessly with the servos, ultrasonic sensors, and Bluetooth modules. [44]

   Advantages of Using Arduino IDE for This Project

   The Arduino IDE streamlines the entire development process for the spider robot. Its user-friendly interface and extensive library support eliminate the complexities of low-level programming. The modularity encouraged by the IDE enables developers to build each component (walking, obstacle avoidance, Bluetooth control) as separate functions, which are then combined into a cohesive program.

   Furthermore, the IDE's debugging tools, such as the serial monitor, significantly reduce development time. Developers can simulate conditions like obstacles or Bluetooth commands and observe the robot's behavior in real time. This iterative testing process ensures that the robot functions as expected under various scenarios.

Overall, the Arduino IDE is an indispensable tool for this project, providing a robust platform to turn theoretical algorithms into practical implementations that bring the spider robot to life. [44]

2. **Programming Language:**

   The programming language used in this spider robot project is primarily C/C++, which is the standard language for Arduino-based development. It provides the necessary balance of simplicity and power, making it suitable for embedded systems like the Arduino Nano. The language's structured approach and extensive library support enable developers to translate the project's algorithms into precise instructions for the robot's hardware components.

   In this project, the programming language is the medium through which the robot's various functionalities—such as walking, obstacle avoidance, and Bluetooth communication—are implemented. It allows the developer to define the robot's behavior by interacting with servos, sensors, and communication modules in a controlled and systematic manner. [45]

   Characteristics of C/C++ for Arduino Projects

   (a) Low-Level Hardware Interaction C/C++ is well-suited for embedded systems because it allows direct interaction with hardware components. For instance, in this spider robot, controlling the servo motors involves setting specific angles through Pulse Width Modulation (PWM) signals, a task that C/C++ handles efficiently through libraries like `Servo.h`.

   (b) Modular and Structured Approach The language supports a modular programming paradigm, which is crucial for complex projects like this one. Each functionality, such as walking or obstacle avoidance, can be encapsulated into separate functions or modules. This approach not only organizes the code but also makes it easier to debug and extend. [45]

   (c) Library Support Arduino's ecosystem is built around C/C++, and it includes numerous pre-written libraries that simplify complex tasks. For example:

   - The `Servo.h` library abstracts the complexities of generating precise PWM signals to control servo motors.
   - The `SoftwareSerial.h` library enables serial communication with the Bluetooth module, facilitating user control of the robot.

   (d) Real-Time Execution C/C++ is ideal for real-time applications like robotics, where precise timing is critical. The language allows developers to use functions like `delay()` and `millis()` to control the timing of movements and sensor readings, ensuring synchronized operations.

3. **Libraries:**

   Libraries play a critical role in the development of the spider robot by simplifying the interaction with hardware components and abstracting complex functionalities. In Arduino-based projects like this one, libraries provide pre-written, optimized code that allows developers to focus on the logic and algorithms rather than the underlying low-level details. Below is an in-depth explanation of the key libraries used in this spider robot project:

   1. Servo.h Library: The Servo.h library is one of the most important components of this project as it manages the control of servo motors, which are the actuators for the robot's legs. Servo motors require precise control of angles to execute the walking motion, turning, and other leg movements.
   2. SoftwareSerial.h Library: The SoftwareSerial.h library enables serial communication on additional pins of the Arduino Nano. Since the hardware UART is typically occupied for uploading code, this library is crucial for establishing communication with external modules like Bluetooth.
   3. NewPing.h: Although not always explicitly mentioned, projects involving ultrasonic sensors often use the NewPing.h library. This library simplifies the interaction with the HC-SR04 ultrasonic sensor used for obstacle detection.
   4. AdafruitMotorShield.h: In some advanced implementations, developers may use a motor shield to control multiple servos or motors. The AdafruitMotorShield.h library provides an interface for such shields, enabling high-level control of motor speed, direction, and position. [44]

5.2 Core Algorithms

5.2.1 Walking Algorithm

The Walking Algorithm is fundamental to the spider robot's motion. Its design and implementation rely heavily on simulating biological leg movements, providing a stable yet flexible gait for the robot. The algorithm begins with the initialization of servos controlling the robot's legs. Each servo is assigned a neutral position, typically 90 degrees, to ensure the legs are balanced before motion starts. This step is crucial as it prevents abrupt or erratic movements, which could destabilize the robot. The initialization ensures that all servos are synchronized, creating a consistent starting point for walking.

Once initialized, the walking process involves lifting one leg at a time. The "lift" action is achieved by sending a signal to the servo to reduce its angle, effectively raising the leg above the ground. This mimics how animals lift their legs to step forward. The

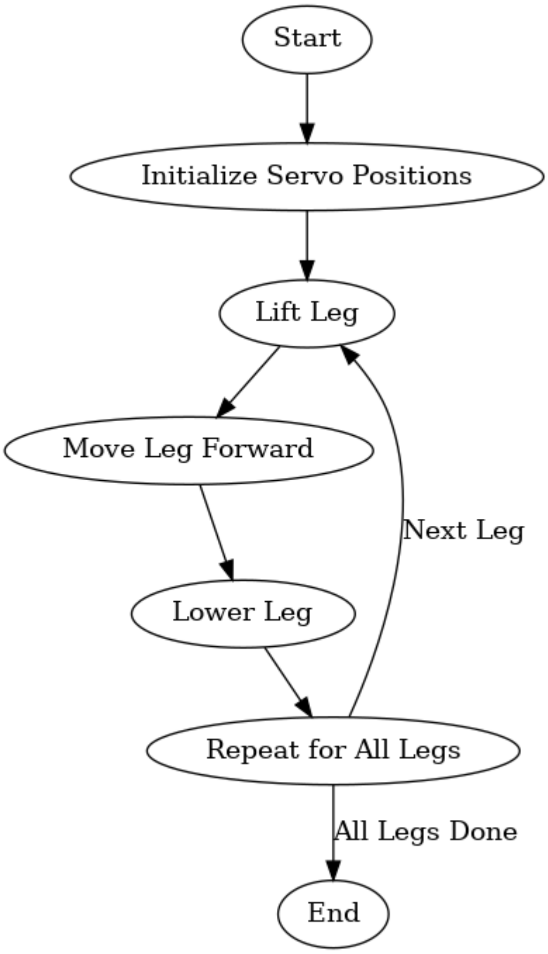

Figure 5.1: Walking Algorithm

lifted leg is then moved forward by rotating the servo to a specified angle, creating the forward stride. This forward motion requires precise timing and control to maintain the robot's balance. After moving forward, the leg is lowered back to its neutral position, completing one step. This cycle is repeated sequentially for each leg based on a predefined gait pattern. The pattern ensures that no two legs on the same side move simultaneously, preserving the robot's stability. For instance, the robot might follow an alternating leg movement strategy, such as lifting and moving one leg from the front left side and another from the rear right. The algorithm loops through these steps until the walking process is halted, either by an external signal or upon completion of its task. [46]

1. **Start:**

   The execution begins by powering up the robot and initializing the Arduino Nano. The microcontroller ensures all connected hardware components (e.g., servos, sensors) are ready for operation.

Example:

```
void setup()
for (int i = 0; i ¡ 8; i++)  // Assuming 8 servos
servo[i].attach(pin[i]); // Attach each servo to its pin
```

2. **Initialize Servo Positions:**

   Before any movement, the servos controlling the legs are reset to their neutral positions (90°). This establishes a balanced base for smooth operation.

   Example:

   ```
   void initializeServoPositions()
   for (int i = 0; i ¡ 8; i++)
   servo[i].write(90); // Neutral position
   delay(1000); // Wait for stabilization
   ```

3. **Lift Leg:**

   The servo associated with a specific leg is commanded to increase its angle, lifting the leg off the ground. This isolates the leg for forward movement.

   Example:

   ```
   void liftLeg(int leg)
   servo[leg].write(120); // Adjust to lift
   delay(200); // Allow time for movement
   ```

4. **Move Leg Forward:**

   After lifting, the leg moves forward to simulate a walking stride. The servo rotates to extend the leg to its forward-most position.

   Example:

   ```
   void moveLegForward(int leg)
   servo[leg].write(60); // Move leg forward
   delay(200);
   ```

5. **Lower Leg:**

   The servo then repositions the leg to its initial level, completing the forward motion cycle for that leg.

   Example:

   ```
   void lowerLeg(int leg)
   servo[leg].write(90); // Reset to neutral
   delay(200);
   ```

6. **Repeat for All Legs:**

   The same cycle is executed for each leg based on a predefined gait pattern. This ensures the robot maintains balance while walking.

   Example of Sequential Execution:

   ```
   for (int leg = 0; leg ¡ 4; leg++) // For quadruped
   liftLeg(leg);
   moveLegForward(leg);
   lowerLeg(leg);
   ```

7. **End:**

- The process halts either upon receiving a stop signal or after completing a specific walking distance.

5.2.2 Obstacle Avoidance Algorithm

The Obstacle Avoidance Algorithm adds an autonomous navigation capability to the robot, making it capable of reacting to its surroundings. The process begins with the initialization of an ultrasonic sensor, typically HC-SR04, which is used to measure distances. The sensor emits ultrasonic waves, which bounce off obstacles and return to the sensor. The time taken for the echo to return is processed to calculate the distance to the obstacle. This real-time distance measurement is pivotal for the robot's ability to navigate independently. If the measured distance is less than a preset threshold, say 20 cm, the robot identifies the presence of an obstacle and triggers the avoidance sequence.

In the avoidance sequence, the robot stops its forward motion to assess the obstacle's location further. It then executes a preprogrammed rotation, often by pivoting one side of the legs while keeping the other stationary, effectively rotating the robot. This rotational movement allows the robot to scan for a clearer path. Once the robot detects an open path beyond the threshold distance, it resumes the walking algorithm, navigating around the obstacle. This entire process of obstacle detection, avoidance, and resumption of motion is looped continuously, enabling the robot to adapt dynamically to its environment. For instance, if the robot encounters a narrow corridor with multiple obstacles, it will execute several rotation and forward movement cycles until it finds a navigable route. [47]

1. **Start:**

   The obstacle avoidance routine initializes by powering the ultrasonic sensor and setting communication with the Arduino Nano.

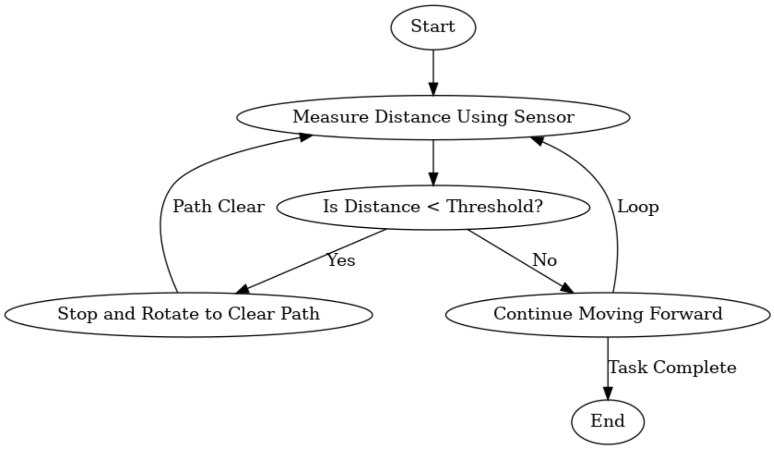

Figure 5.2: Obstacle Avoidance

2. **Measure Distance Using Sensor:**

   The ultrasonic sensor calculates distance by emitting sound waves and measuring the time taken for the echo. This data is converted into a measurable range in centimeters.

   Example:

   ```
   long measureDistance()
   digitalWrite(trigPin, LOW);
   delayMicroseconds(2);
   digitalWrite(trigPin, HIGH);
   delayMicroseconds(10);
   digitalWrite(trigPin, LOW);
   long duration = pulseIn(echoPin, HIGH);
   return duration * 0.034 / 2; // Convert to cm
   ```

3. **Is Distance ¡ Threshold?**

   If the measured distance is less than the threshold (e.g., 20 cm), the robot identifies an obstacle and plans avoidance.

   Example:

   ```
   if (measureDistance() ¡ 20)
   avoidObstacle();
   ```

4. **Stop and Rotate to Clear Path:**

   The robot stops and executes a rotation sequence to find an obstacle-free path. This is done using differential movements in the legs or rotation motors.

Example:
void avoidObstacle()
// Rotate 45 degrees
rotateLeft();

delay(500); // Test for clear path

5. **Continue Moving Forward:**

   Once the path is cleared, the robot resumes the walking algorithm.

   Example:
   void loop()
   if (measureDistance() ¿= 20)
   walkForward();

6. **End:**

The obstacle avoidance routine terminates once the robot completes its journey or receives a stop signal.

5.2.3 Bluetooth Control Algorithm

The Bluetooth Control Algorithm is a crucial component that enables user interaction and remote control of the robot. This algorithm starts by initializing a Bluetooth module, such as HC-05 or HC-06, and establishing a serial connection between the robot and a controlling device, typically a smartphone or PC. The Bluetooth module is set to a standard baud rate (e.g., 9600), ensuring reliable communication. Once connected, the robot listens for incoming commands via the serial port. These commands are usually sent in the form of characters representing actions like moving forward ('F'), turning left ('L'), turning right ('R'), or stopping ('S').

When a command is received, the robot parses it to determine the corresponding action. For example, if the command is 'F,' the robot triggers the walking algorithm to move forward. Similarly, if the command is 'L,' it initiates a subroutine that turns the robot left by adjusting the servos to rotate the robot in place. The command execution is immediate, allowing for real-time control. After executing a command, the robot loops back to monitoring the serial input, ensuring it remains responsive to further instructions. This continuous monitoring creates an interactive experience, where the user has full control over the robot's movements. Additionally, the system can handle commands for stopping or altering its task, providing flexibility for various applications.

In combination, these algorithms allow the robot to perform complex tasks autonomously and respond dynamically to user inputs. The walking algorithm forms the

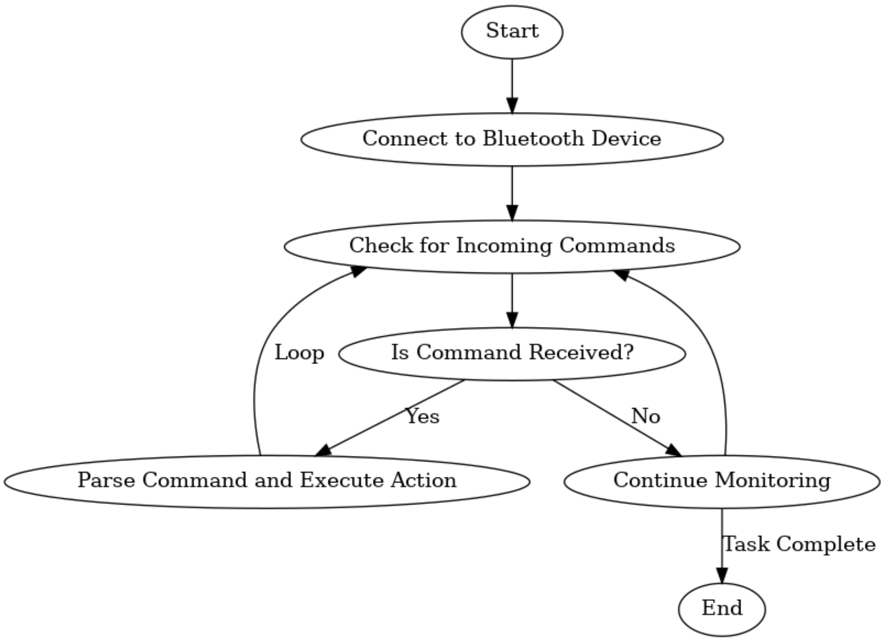

Figure 5.3: Bluetooth Control Flowchart

foundation of the robot's movement, while the obstacle avoidance algorithm ensures safety and adaptability in changing environments. The Bluetooth control algorithm adds an interactive layer, making the robot versatile for both autonomous and manual operations. The modular design of these algorithms ensures that they can be integrated seamlessly, with each component contributing to the robot's overall functionality. This structured approach to software development ensures that the robot is both robust and versatile, ready for real-world applications such as exploration, surveillance, or educational purposes. [48]

Bluetooth Control Flowchart: Describes decision-making in obstacle navigation:

The software development process for the 3-in-1 Spider Robot involved careful planning and execution. By integrating servo control, obstacle detection, and Bluetooth communication, the robot achieved functionality in all three modes. Future improvements could include integrating machine learning for advanced obstacle avoidance and gait optimization.

1. Start:

The system initializes the Bluetooth module, such as HC-05, and sets the baud rate for communication.

Example:

void setup()

Serial.begin(9600); // Initialize Bluetooth

2. Connect to Bluetooth Device:

The robot pairs with the user's smartphone or PC using Bluetooth and establishes a stable connection. Check for Incoming Commands:

The robot continuously monitors the serial input for control commands.

Example:

if (Serial.available() ¿ 0)
char command = Serial.read();
executeCommand(command);

3. Is Command Received?

If no command is received, the system continues monitoring. If a command is received, the robot proceeds to execute it. Parse Command and Execute Action: Each command is matched with a specific action (e.g., 'F' for forward, 'L' for left). The corresponding subroutine is triggered.
Example
void executeCommand(char command)
if (command == 'F')
walkForward();
else if (command == 'L')
turnLeft();

4. Continue Monitoring:

After executing the action, the robot loops back to monitoring, enabling real-time user control. The Bluetooth control routine ends when the user disconnects or issues a termination command.

The integration of the Walking Algorithm, Obstacle Avoidance Algorithm, and Bluetooth Control Algorithm collectively forms a robust and intelligent system that allows the spider robot to perform versatile and dynamic tasks. Together, these algorithms enable the robot to exhibit seamless motion, adapt to its environment, and respond to real-time user commands, making it highly functional for a range of applications.

The Walking Algorithm provides the robot with a stable and coordinated movement mechanism, simulating natural gait patterns that ensure balance and precision. This foundational capability is enhanced by the Obstacle Avoidance Algorithm, which introduces autonomy and adaptability. By utilizing real-time distance measurements, the robot can navigate complex environments, avoid collisions, and determine safe paths without requiring constant human intervention. Meanwhile, the Bluetooth Control Algorithm bridges the gap between autonomous operation and user interaction, allowing remote control and customization of the robot's behavior through a simple, intuitive interface.

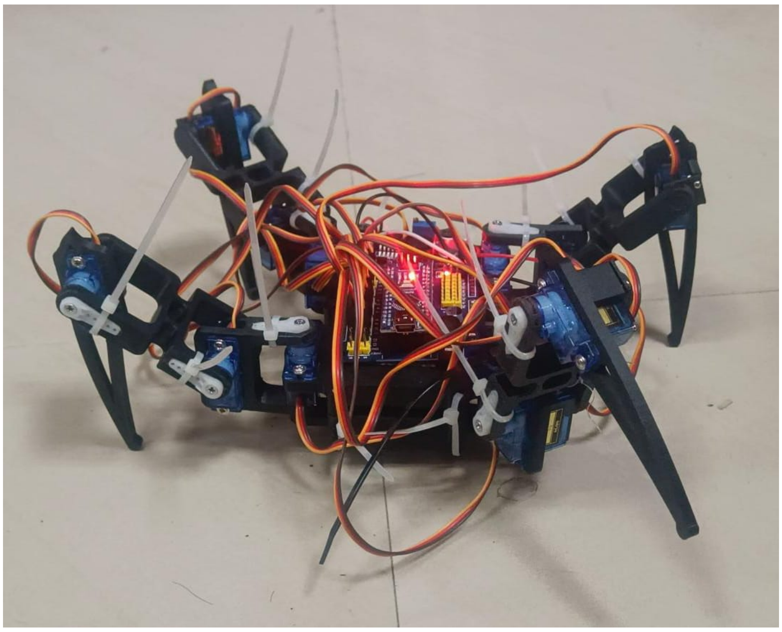

Figure 5.4: Hand Wave Robot

5.3 Result

Basic repetitive movements:

1. stand up, wait 2 sec
2. step forward 5 steps, wait 2 sec
3. backward 5 steps, wait 2 sec
4. turn right, wait 2 sec
5. turn left, wait 2 sec
6. wave the hand,, wait 2 sec
7. shake the hand, wait 2 sec
8. body dancing
9. sit down, wait 2 sec
10. back to 1

Obstacle Avoiding

1. Stand up, wait 5 sec

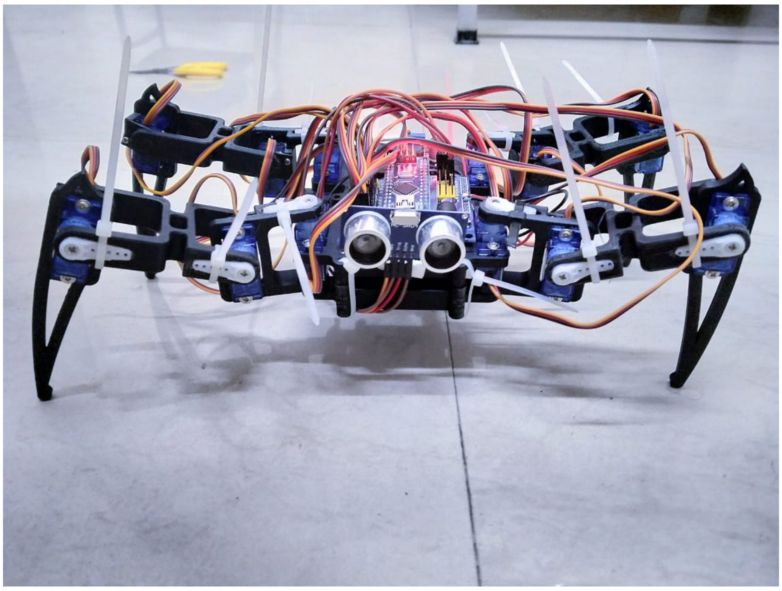

Figure 5.5: Robotic Spider with Ultrasonic sensor

2. Wave hand, wait 2 sec
3. Step forward, until object detection
4. When object detected, backward 3 step
5. Rotate 90 degree
6. Back to 3

Bluetooth-controlling

1. Stand up, when bluetooth connected
2. Press button for
3. forward
4. backward
5. left
6. right
7. hand wave
8. hand shake
9. dancing

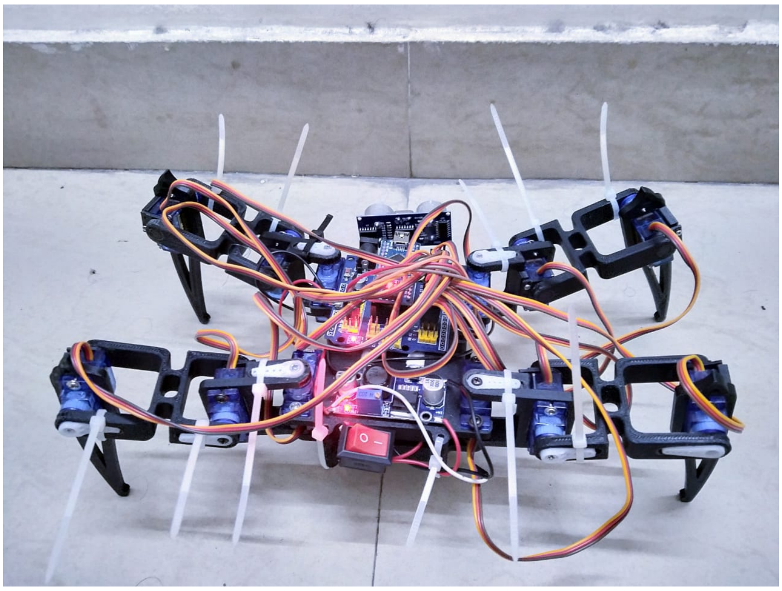

Figure 5.6: Robotic Spider obstacle detection

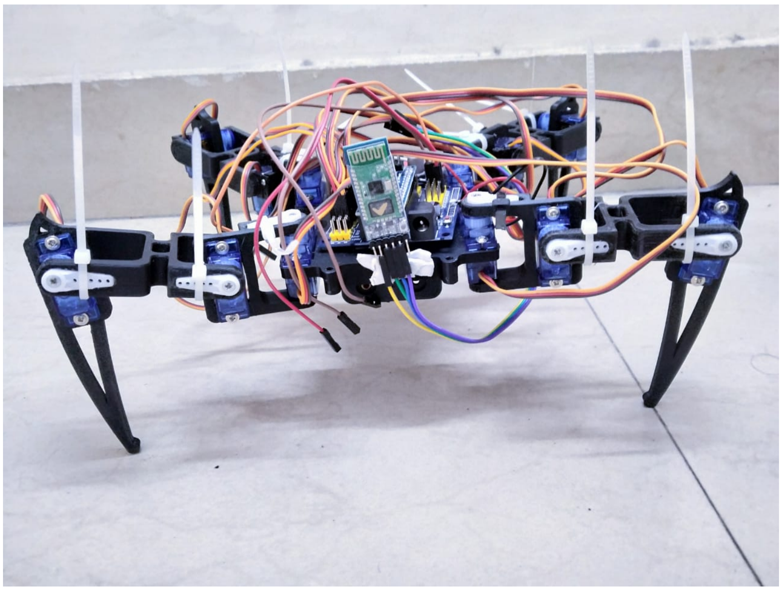

Figure 5.7: Robotic Spider with Bluetooth

Chapter 6
Conclusion & Future Scope

The development of the four-legged robotic spider has been a significant step toward understanding and implementing bio-inspired robotic systems. This project successfully demonstrated the integration of mechanical design, electronics, and software to achieve a robot capable of controlled movement and obstacle detection. While the current design meets its objectives of basic functionality and Bluetooth-based control, it also highlights opportunities for further enhancements. Exploring advanced features such as improved autonomy, enhanced mobility, and smarter control systems can expand the robot's applications in real-world scenarios like surveillance, exploration, and search and rescue. This chapter summarizes the project's outcomes and outlines potential directions for future improvements and innovations.

The mechanical structure, designed to mimic a spider's legs, provided stability and mobility, making the robot suitable for navigation in moderately uneven terrains. The ultrasonic sensor proved effective in detecting obstacles within the predefined range, enabling responsive movement adjustments. Bluetooth-based control allowed seamless user interaction, making the robot easy to operate remotely.

Throughout the project, challenges such as calibrating servo motors, optimizing obstacle detection algorithms, and ensuring smooth communication between components were addressed. The robot's performance in real-time control and obstacle navigation validates the feasibility of using simple, cost-effective components to build functional robotic systems.

This project serves as a stepping stone for further advancements in mobile robotics, demonstrating how basic systems can lay the groundwork for more complex autonomous robots. The knowledge and experience gained from this endeavor have contributed significantly to the understanding of robotics, electronics, and programming.

6.1 Future Scope

The robotic spider, while functional, has potential for significant improvements and enhancements. Future work could focus on the following areas: **Improved Autonomy**

- Advanced Obstacle Avoidance: Integrating additional sensors such as infrared or LiDAR for more accurate obstacle detection and navigation in complex environments.

- Path Planning Algorithms: Developing algorithms for autonomous pathfinding to allow the robot to navigate predetermined routes or explore unknown areas independently.

Enhanced Mobility

- Six or Eight Legs: Expanding the robot's design to include six or eight legs to improve stability and mimic real spider movements more accurately.

- Dynamic Gait Control: Implementing adaptive gait patterns for smoother and faster movement across various terrains.

Smart Control Systems

- AI Integration: Using machine learning to improve obstacle detection, adapt movements based on terrain, and enhance decision-making capabilities.

- Voice Commands: Adding a voice-recognition module to allow users to control the robot through verbal instructions.

Camera Integration

- Adding a camera module to enable video streaming for real-time surveillance or exploration.

- Utilizing computer vision for object recognition and advanced environmental interaction.

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