An-Najah National University

Faculty of Engineering & Information Technology

Design, Implementation & Control of Autonomous Hexapod Robot for Search and Rescue

by

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Under the supervision of

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Disclaimer

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Abstract

The hexapod robot is an autonomous robotic platform that walks on six legs. The robot is able to provide a great deal of flexibility and stability thanks to the gait algorithms that can be implemented to drive the actuators on each leg. The legs of the hexapod gives it a significant advantage over the wheeled robot, allowing it to traverse through rough terrain without becoming stuck.

The goal of this bachelor's project is to research, construct, and program a hexapod robot, the robot non-electronic components can be 3D printed from plastic or cut with a laser from sheet metal.

This project will demonstrate the issues encountered as well as the programming necessary to make it walk will .

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1 Introduction

1.1 Problem

The development of hexapod robots was motivated by several challenges and problems in robotics that researchers sought to address. Some of the key factors that led to the invention of hexapod robots include:

- Locomotion in complex environments:
  Traditional wheeled or tracked robots often face difficulties when navigating through rough or uneven terrains, especially in natural or disaster-stricken environments. Hexapod robots, inspired by the versatile locomotion of insects and spiders, offer a solution to this problem by using multiple legs to maintain stability and traverse various surfaces effectively.

- Stability and adaptability:
  Hexapod robots are designed to have a high degree of stability. The multiple legs and joints allow them to distribute their weight and adjust their posture, enabling them to remain balanced even on uneven ground or in the presence of external disturbances. This stability makes them suitable for applications such as exploration, where maintaining balance is crucial.

- Obstacle negotiation:
  Obstacles pose a significant challenge for many robots. Hexapod robots, with their leg configurations and flexibility, excel at traversing obstacles such as steps, gaps, or rough terrain. Their ability to step over or around obstacles provides an advantage over robots with fewer legs or less adaptable locomotion mechanisms.

- Biomechanics and locomotion research:
  Hexapod robots have been developed as a means to study the biomechanics and locomotion principles of insects and other legged creatures. By replicating the leg structures and movement patterns found in nature, researchers can gain insights into the mechanics of locomotion and apply those principles to improve robot design and performance.

- Versatile applications:
  The versatility of hexapod robots enables their deployment in a wide range of applications. They can be used for tasks such as search and rescue operations in disaster scenarios, surveillance and inspection in hazardous environments, agricultural monitoring, entertainment and performance, and even scientific research in fields like biology and robotics.

In summary, the invention of hexapod robots was driven by the need for robots that could navigate complex terrains, negotiate obstacles, maintain stability, and provide a platform for studying locomotion principles. These robots offer a solution to the challenges faced by traditional wheeled or tracked robots and have found applications in various fields.

1.2 Objectives

The aim of this project is to build a hexapod robot using available computing power, sensors and actuators and provide it with certain amount of autonomy. More specifically the robot should be given the fundamental building blocks to roam around certain predefined environments on its own without putting itself into harm's way.

In other words, this project objectives include the following:

- Obtain a fully operational hexapod robot.
- Get acquainted with embedded programming.
- Study six-legged locomotion.
- Add sensor evaluation to the mix.

1.3 Importance of the work

Researching hexapod robots in the field of search and rescue holds immense importance due to their unique capabilities and potential impact. Firstly, hexapod robots' versatile locomotion allows them to navigate complex and hazardous terrains, including rubble, debris, and rough surfaces, where traditional wheeled or tracked robots struggle. This ability is crucial in search and rescue operations, enabling these robots to access hard-to-reach areas, locate survivors, and provide vital assistance during emergencies.

Secondly, hexapod robots' stability and adaptability enhance their effectiveness in search and rescue scenarios. With their multiple legs and balanced weight distribution, they can traverse unstable or uneven surfaces without compromising their stability, making them more resilient in challenging environments. Additionally, their maneuverability enables them to negotiate obstacles, such as debris piles or collapsed structures, providing greater access to potential victims.

By researching hexapod robots for search and rescue applications, scientists and engineers can further improve their capabilities, optimize their control systems, enhance their sensory perception, and develop more efficient and robust designs. This research contributes to the advancement of robotic technologies in disaster response, potentially saving lives, reducing risks for human rescuers, and increasing the overall efficiency and effectiveness of search and rescue operations.

1.4 Organization of the report

The following chapter (Constraints and prior work) will concentrate on the primary issues that we ran into while working on this project and will highlight earlier work that assisted in the development of this project.

The (Literature Review) chapter follows, introducing and Describes some of the related work and demonstrates how it varies from this work.

Then, in the fourth chapter (Methodology), we will go into more depth about how we built this project. The methods utilized to gather the required data, the technology we employed, the process of building this robot, software tools, and hardware equipment.

The chapter that follows is (Future work), which includes the ideas that we aspire to add to our project in future.

The next chapter is (Conclusion and Recommendations) which will summarise the ideas of projects and will also contain some recommendations related to our work.
The last chapter is (References).

2 Constraints and earlier work

2.1 Constraints

- Limited time:
  This project was finished under the strain of exams, course projects, and work.

- 3D-printed parts issues:
  Handling 3D printed parts can be challenging, especially when dealing with poor print quality. It often requires extra effort and time-consuming post-processing work like sanding, smoothing, and filling to address rough surfaces and imperfections caused by the limitations of the printer. As someone who has experienced these difficulties firsthand, We know the frustration and labor-intensive nature of manually refining the printed parts to achieve the desired level of finish and aesthetics, making the overall production process more complex.

- The constrains of occupation:
  Traveling between cities in Palestine can be challenging due to various factors. The presence of Israeli military checkpoints, roadblocks, and restrictions on movement imposed by the Israeli government can significantly impede the freedom of movement for Palestinians. These checkpoints often lead to delays, long queues, and unpredictable travel times, impacting daily life, and as students who had to travel between two cities to get to the collage that affected us negatively.[1]

  Regarding online shopping, there was difficulties in purchasing the needed parts for our project, particularly electronics.

  Palestinians encounter obstacles such as high import taxes, customs fees, and lengthy clearance processes. Additionally, limited access to international markets and shipping restrictions can further complicate online shopping experiences for Palestinians, and because of that we had to keep looking for other electronic parts for this project that we could not buy online which caused a lot of delay and difficulties.[2]

2.2 Earlier Work

2.2.1 Micro-Controllers

helped with the micro-controller component and how to use it to control the physical components.

2.2.2 Micro-Processor

gave a background on the current and voltage handling of ICs and modules.

2.2.3 CPU & Micro-Controllers Laps

helped to the wiring, welding, and debugging of the hardware components.

2.2.4 Networks and Wireless

used the knowledge gained during theses courses to establish the connection between the mobile application and the raspberry pi wirelessly.

2.2.5 Critical Thinking and Research Skills

One of the few non-technical classes that taught us how to conduct research and prepare a report.

2.2.6 self learning

e also went through a considerable amount of self- learning, picking up new languages like python and Kotlin that we needed.

3 Literature review

3.1 Design of a Hexapod Robot

A six-legged walking robot is referred to as a hexapod by definition. Although there are many distinct types of hexapod robots, most of them are biologically inspired by hexapod insects in terms of their mechanics and movements.

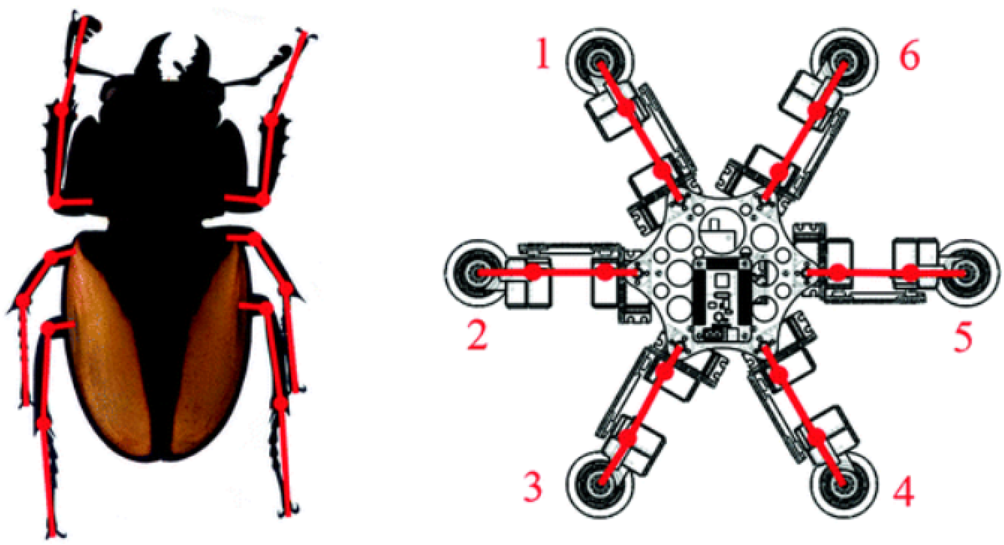

Figure 1: hexapod robot vs insect

We struggled to construct our own design from scratch, and were drawn to the interesting hexapod designs we found online, so we decided to take a different approach. We decided to find publicly downloadable hexapod designs since we appreciate the resources at our disposal such as [3]. With a fresh outlook, we welcomed the chance to take inspiration from the work of others and modify their designs to suit our requirements.

After thorough consideration and assessment, we discovered a design that fit our objective. This decision allowed us to concentrate on the technical details of using 3D printing and post-processing methods to bring the hexapod to life. In the end, this experience demonstrated the value of adaptability and flexibility, enabling us to change the existing concept into a concrete and satisfying reality.

One of the 6 identical legs of our chosen design:

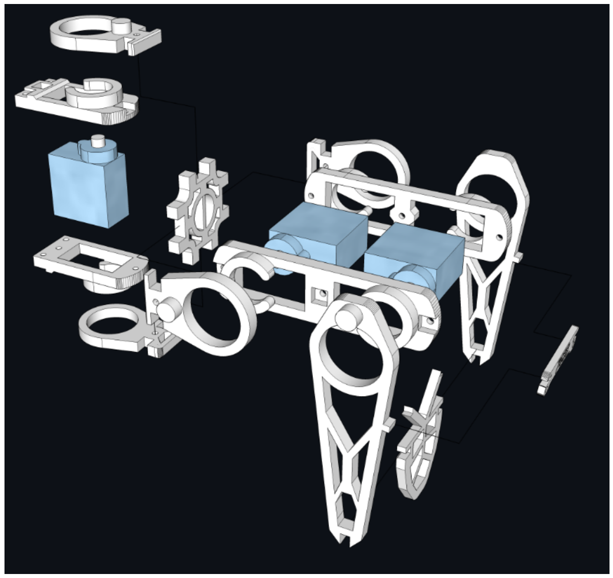

Figure 2: one leg structure

the full mechanical structure after assembly:

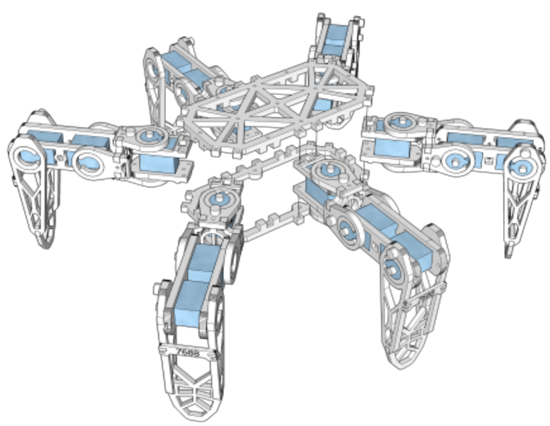

Figure 3: full 3d structure

3.2 Robot kinematics

3.2.1 The tripod gait principle of hexapod robots

Hexapod insects, such as cockroaches, ants, and others, do not walk with their feet moving simultaneously. Most of the time, three pairs of legs form two groups. Insects advance using two alternate tripods as a result. One group is made up of the right front leg, right rear leg, and left middle leg. The other group is made up of the right front leg, right rear leg, and right middle leg. The other tripod remains on the ground to support the body while the feet of one tripod synchronously raise.

Additionally, the middle foot serves as a point of support, the muscles in the front leg's tibia produce pulling force, and the muscles in the back leg's tibia produce pushing force. The center of gravity is therefore on the supporting tripod's three legs, which causes the body to slightly spin around the middle foot. The opposite group then does the identical procedures, and two tripods each move in turn. Because the center of gravity is constantly on the tripod when an insect walks in the tripod gait, it can stop and start at any time. The path taken when walking follows a curve rather than a straight line.

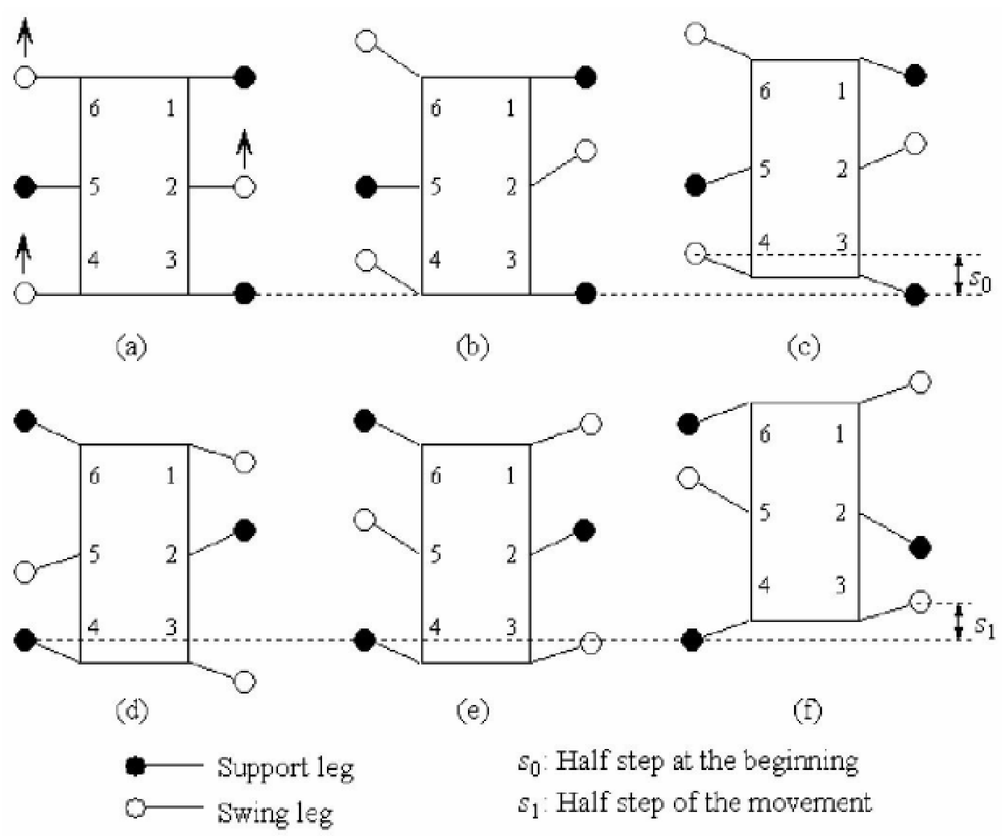

Figure 4: Tripod gait of hexapod robot

In Figure 2, legs 2 on the right, 4 on the left, and 6 on the left all rise together at the start of a walk to get ready to move. The remaining three legs, namely legs 1, 3, and 5, continue to be in a supportive position. They support the body so that its center of gravity is on the tripod-like structure made up of the three legs. In order for the robot to stand on the ground steadily, see Fig. 2(a). The hexapod robot's body is supported by the supporting legs 1, 3, and 5 as they move forward (see Fig. 2(b)), and the robot body is propelled by a DC servo-actuator to walk a half step at the same time (see Fig. 2(c)).

Swing legs 2, 4, and 6 immediately put down and switch to the supporting state when the robot moves into the proper position. As a result, the tripod's center of gravity is where Legs 2, 4, and 6 meet. In order to move forward, the old supporting legs 1, 3, and 5 have been lifted (see Fig. 2(d)).

The supporting legs 2, 4, and 6 support the body when the swing legs are in motion (see Fig. 1(e)), while the robot continues to move by taking a half-step (see Fig. 1(f)). A step is made up entirely of s0 and s1. If the robot walks at a constant speed, s0 is created in the beginning, s1 appears during the movement, and so equals s. The hexapod robot moves forward continuously while undergoing a continuous cycle of tripod gait alteration.[4]

3.3 Legged vs wheeled robots

Extreme terrain restricts wheeled robots' ability to move. Legged robots, on the other hand, may be able to get around this by changing their gaits. Hexapods have one benefit over bipeds or quadrupeds: static stability when moving. The more legs you have, the more stable you are and the more gait patterns you can choose from. The biggest change is going from four to six legs. The improvement becomes noticeably smaller and the hardware cost rises for robots with more than six legs[5].

4 Methodology

4.1 Hardware Components

This section discusses the design, tools, and basis of the hexapod robot in order to illustrate the full development process.

1. Raspberry Pi:

   We chose the Raspberry Pi Zero W as the control system for our hexapod project due to its ability to effectively manage the 16 actuators with the assistance of two PCA9685 motor drivers. The Raspberry Pi Zero W offers a compact and affordable solution, providing sufficient processing power for the intricate coordination and control tasks involved in the hexapod's movements. Through its GPIO (General Purpose Input/Output) pins and compatibility with PCA9685 motor drivers, the Raspberry Pi Zero W can accurately transmit control signals to the motor drivers, enabling precise manipulation of the actuators' position, speed, and synchronization. Furthermore, the Raspberry Pi Zero W's built-in wireless connectivity facilitates convenient remote control and communication, enhancing the overall versatility and user-friendliness of our hexapod project[6].

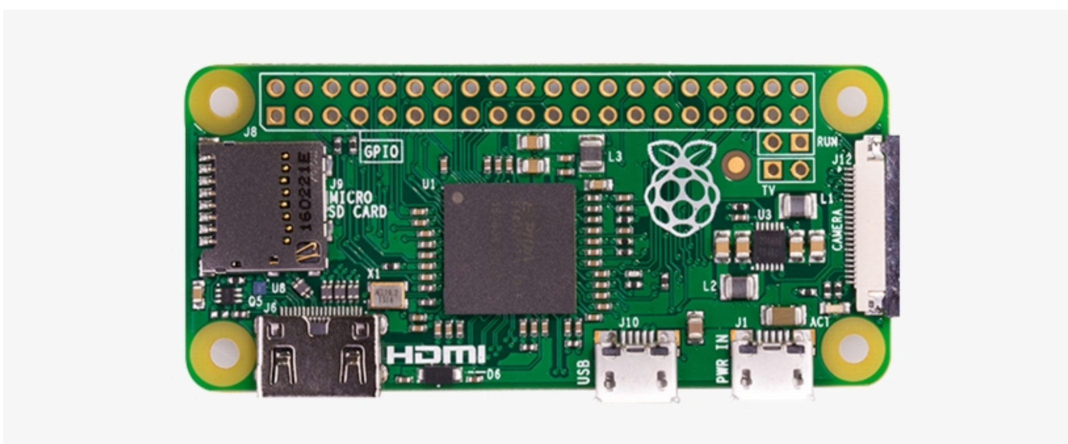

Figure 5: raspberry zero w

2. Stepper Motors:

   We chose to use 16 SG90 stepper motors as actuators for our hexapod robot, primarily due to their remarkable precision and synchronization capabilities. The SG90 stepper motors afford us the ability to achieve accurate control over the position and motion of each leg, resulting in smooth and coordinated movements. With their step-wise rotation, these motors enable us to achieve the desired level of leg positioning accuracy, making them an ideal choice for ensuring the stability and precision required for the hexapod's locomotion[7].

   For this project the servo motors have range of 180 degrees.

Figure 6: sg90 Stepper Motor

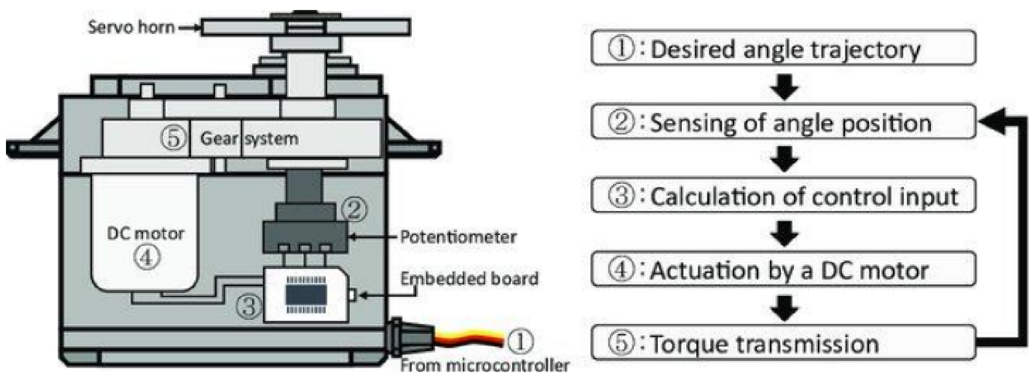

Figure 7: Stepper Motor inside structure

3. PCA9685:

We incorporated two PCA9685 motor drivers to establish a connection with the Raspberry Pi for several reasons. Firstly, employing two PCA9685 motor drivers allows us to conveniently and efficiently control all 16 actuators in our hexapod robot simultaneously. Each motor driver has the capacity to handle up to 16 servo or stepper motors, enabling us to manage the entire set of actuators effectively.

Secondly, by utilizing the PCA9685 motor drivers, we relieve the Raspberry Pi of the task of generating precise control signals. These motor drivers possess built-in PWM (Pulse Width Modulation) functionality, streamlining the control of servo and stepper motors. By offloading this responsibility, the Raspberry Pi can focus on other critical processing tasks while ensuring accurate and stable actuator control.

Furthermore, the PCA9685 motor drivers offer the advantage of individual channel control, empowering us to independently adjust the speed, position, and synchronization of each actuator. This level of control is crucial for achieving the desired leg movements and coordination in our hexapod robot.

Through the integration of two PCA9685 motor drivers with the Raspberry Pi, we achieve efficient management and precise control over all 16 actuators, facilitating smooth and synchronized motion in our hexapod robot design[8].

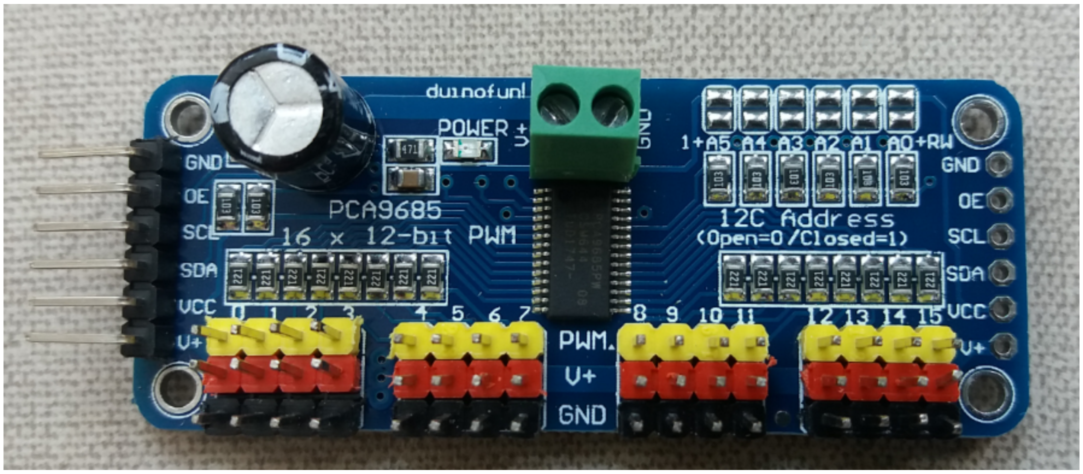

Figure 8: PCA9685

4. Lithium Batteries:

   We decided to utilize rechargeable Lithium batteries as the power source for our hexapod robot, which incorporates 16 servos. There are several reasons behind this choice. Firstly, Lithium batteries offer a high energy density, enabling extended operational periods without the need for frequent recharging. This is particularly important to sustain the hexapod's power requirements during prolonged usage without frequent battery replacements.

   Secondly, rechargeable Lithium batteries provide a consistent and reliable power supply. They maintain stable voltage levels throughout their discharge cycle, ensuring a reliable and steady performance from the servos. This stability is crucial for maintaining precise and synchronized movements of the hexapod's legs.

   Moreover, Lithium batteries are compact and lightweight, making them an ideal choice for mobile robotic applications like our hexapod[9].

Figure 9: Lithium Batteries

5. XL4015 Buck converter:

   We integrated the XL4015 voltage regulator into our hexapod robot to decrease the voltage from the Lithium batteries while increasing the current. By utilizing the XL4015, we achieve efficient and precise voltage regulation, resulting in a stable power supply. The regulator allows us to flexibly adjust the output voltage to meet the specific requirements of different components. Furthermore, its high efficiency minimizes power loss and extends the battery life of our hexapod[10].

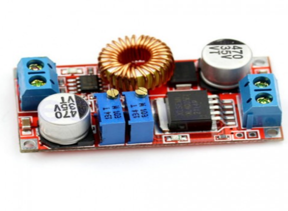

Figure 10: XL4015 Buck converter

6. MP2315:

   We chose to incorporate the MP2315 step-down converter between the power source and the Raspberry Pi for several reasons. Firstly, the MP2315 efficiently converts the higher voltage from the power source to a suitable level for the Raspberry Pi, ensuring a stable and regulated voltage supply. This protects the Raspberry Pi from potential damage caused by voltage fluctuations.

   Secondly, the MP2315 offers built-in protection features, including over-current and over-temperature protection, safeguarding the Raspberry Pi from power-related issues. This enhances the reliability and lifespan of the Raspberry Pi within our hexapod robot.

   Furthermore, the MP2315 step-down converter is compact and lightweight, making it easy to integrate into the limited space of our robot's design. Its high efficiency minimizes power loss during voltage conversion, maximizing energy efficiency[11].

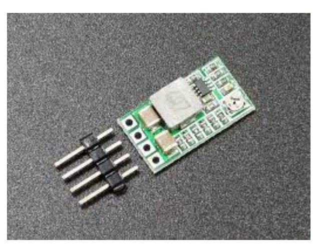

Figure 11: MP2315

4.2 Software

4.2.1 Raspberry Pi programming

First, we installed the operating system on the Raspberry Pi, following the instructions provided by the Raspberry Pi Foundation. Once that was done, we set up the programming environment by installing the necessary software and libraries, for Python.

To control the hexapod's movements, we researched different algorithms. We looked into ways to make it walk, plan its motions, and use sensors. With that knowledge, we wrote the code for the hexapod's controller using Python[12].

We tested the controller thoroughly to make sure it worked well. If needed, we made adjustments and improvements to get the hexapod moving just the way we wanted. Then, we connected the controller to the hexapod's hardware, like the motors and sensors, to make it all work together.

4.2.2 Mobile Application

We utilized Kotlin[13], a user-friendly programming language for Android development, to create an Android application for controlling the hexapod robot. Kotlin's simplicity and concise syntax made it an excellent choice for our project.

Using Kotlin, we developed an intuitive Android application that enabled users to control the hexapod via Wi-Fi and Bluetooth connections, while also establishing a connection with the Raspberry Pi. For Wi-Fi control, we implemented the necessary code to establish a connection between the Android device and the Raspberry Pi, allowing users to remotely send commands and control the hexapod's movements.

Additionally, we integrated Bluetooth functionality into the Android application, enabling users to pair their Android devices with the hexapod via Bluetooth. This provided an alternative control option for localized connections, while maintaining the communication between the Android device and the Raspberry Pi.

By leveraging Kotlin and incorporating both Wi-Fi and Bluetooth capabilities in the Android application, we provided users with a versatile control solution for the hexapod robot. They could choose between Wi-Fi and Bluetooth connectivity options, while ensuring seamless communication with the Raspberry Pi for efficient control of the hexapod's actions.

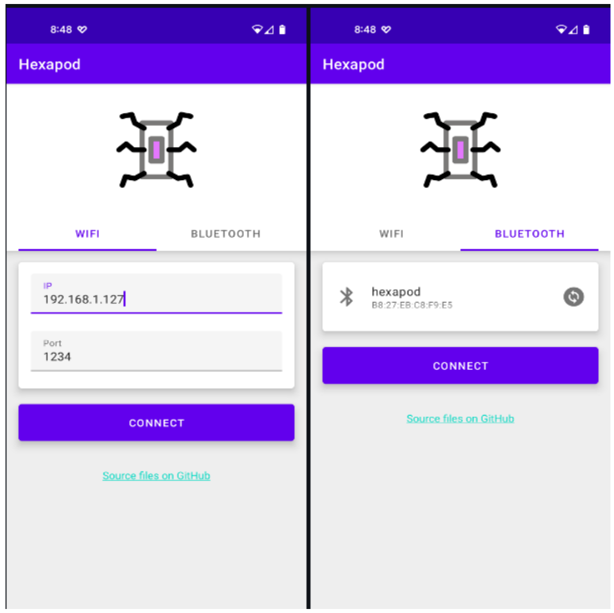

Figure 12: mobile application 1

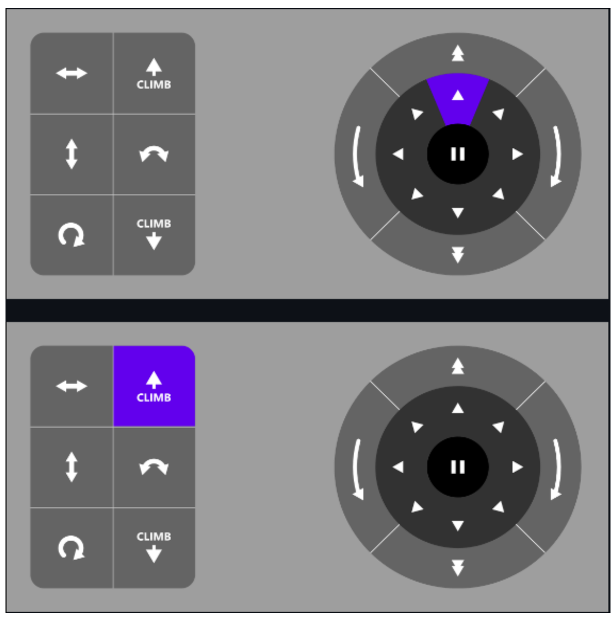

Figure 13: mobile application 2

4.3 Robot Assembly

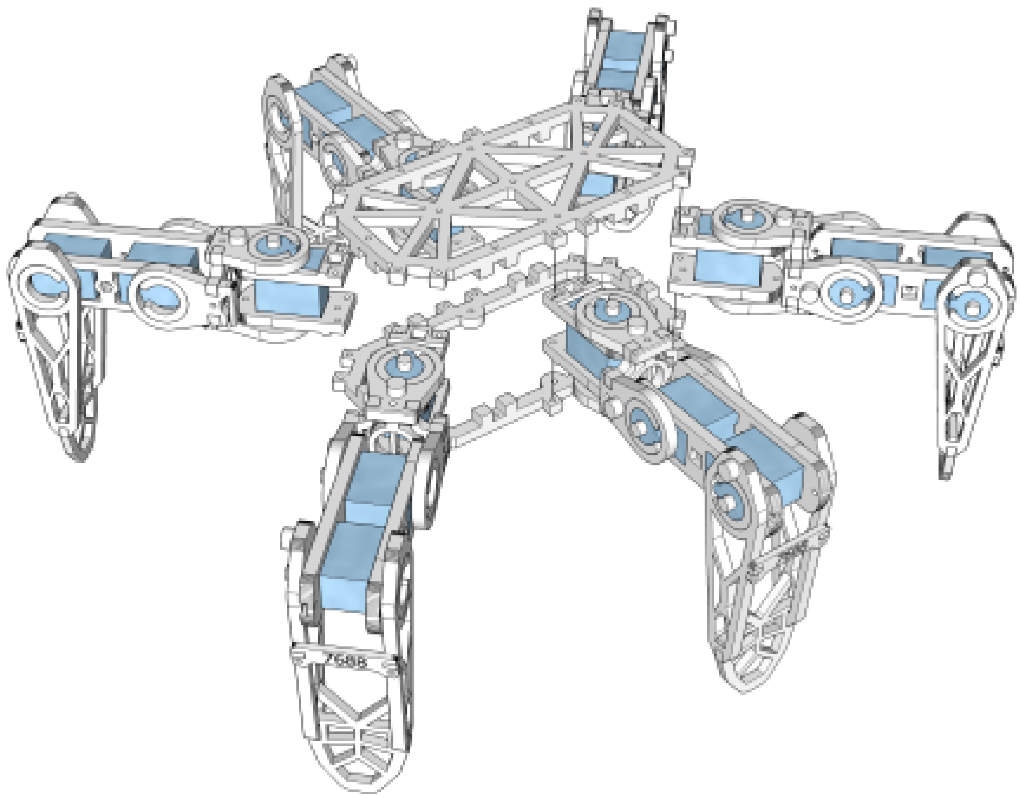

Figure 14: 3D parts view

5 Results & Discussion

5.1 Introduction

This chapter presents the results and discusses the process of building and programming a hexapod robot. The goal of the project was to create a useful hexapod robot with autonomous movement and obstacle avoidance capabilities. The important conclusions and difficulties encountered during the study are outlined in the following sections.

5.2 Results Presentation

5.2.1 Construction Results

The hexapod robot was successfully built using 3D-printed components. The mechanical assembly of the robot's body, legs, and joints was completed according to the design specifications, but this step took so mush effort and hard work because the 3D-printed parts came out not as intended, so that as mentioned in the constraints chapter before we had to file every single piece (82) pieces in order to make the assembled robot move smoothly. we also used a special lubricating substance for the joints. Additionally, the integration of servo motors and motor drivers allowed for controlled leg movements and coordination.

5.2.2 Programming Results

The hexapod robot's programming required the creation of algorithms for autonomous navigation and locomotion. Through extensive testing and iterations, the robot proved its capacity to walk with a tripod gait pattern and avoid obstacles while being remotely controlled by an android app through WiFi. This was made possible by the raspberry pi's built-in WiFi module (ESP32).

5.3 Discussion of Results

5.3.1 Successful Construction

The construction phase yielded positive results, as the hexapod robot was built according to the design plan. The use of quality materials ensured stability and durability, allowing for effective leg movements and overall functionality. However, challenges were encountered during the 3D printing process, including the need for additional work due to poor printer quality. These challenges were overcome through careful post-processing techniques, such as sanding and adjustments to ensure proper fit and functionality.

5.3.2 Programming Challenges

The programming phase presented several challenges, particularly in the implementation of complex locomotion algorithms and obstacle avoidance behaviors. Debugging and fine-tuning the code was a time-consuming process, requiring extensive troubleshooting to address unexpected behavior and optimize the robot's movements. Additionally, limitations in computational power and memory on the micro controller posed constraints on the complexity of the implemented algorithms.

5.4 Comparison with Previous Studies

The results of this study align with previous research on hexapod robots, demonstrating successful construction and programming of a functional robot. However, the encountered challenges in 3D printing and programming highlight the importance of careful design considerations and the need for strong error-handling mechanisms.

6 Future Work

In terms of future developments for our hexapod robot, we have outlined the following areas for improvement:

1. Sensor Integration: We intend to integrate various sensors to improve the robot's perception and interaction with its surroundings. These sensors may include proximity sensors for detecting and avoiding obstacles, gyroscopes for improved stability, and accelerometers for measuring motion and orientation. By incorporating sensors, we aim to enhance the robot's awareness and responsiveness.

2. Camera Integration: The addition of a camera to the hexapod robot presents opportunities for vision-based applications. By equipping the robot with a camera, we can enable functions such as capturing images, streaming live video, and implementing computer vision algorithms for tasks like object recognition or visual inspection.

3. Algorithm Expansion: Our plan is to enhance the robot's capabilities by incorporating more algorithms. For instance, we aim to integrate artificial intelligence techniques to enable the robot to follow lines autonomously. This will allow it to navigate designated paths with precision and efficiency.

7 Conclusions and Recommendation

7.1 Conclusion

In conclusion, the focus of our graduation project was to design and develop a hexapod controlled by a mobile application using Raspberry Pi and WiFi connectivity. Through our endeavor, we achieved significant milestones and notable outcomes.

One of the key features of our project was the integration of 18 servo motors into the hexapod's design. These motors played a crucial role in enabling precise and coordinated movements, allowing the hexapod to navigate and perform various tasks with agility and stability.

Additionally, we successfully established a wireless connection between the hexapod and a mobile application. Leveraging the capabilities of Raspberry Pi and WiFi technology, we created an intuitive interface that provided users with convenient control over the hexapod's movements. This allowed for real-time interaction and remote operation, enhancing the overall user experience and expanding the potential applications of the hexapod.

Throughout the development process, we encountered and overcame several challenges, including designing an efficient servo motor control system, ensuring seamless communication between the Raspberry Pi and the mobile application, and optimizing the overall performance and stability of the hexapod.

By overcoming these challenges, we were able to achieve impressive outcomes. Our hexapod demonstrated smooth and precise locomotion, capable of walking, turning, and even performing complex maneuvers. The mobile application provided a user-friendly interface with intuitive controls, enabling users to easily command the hexapod's actions.

In conclusion, our graduation project successfully showcased the development of a hexapod controlled by a mobile application using Raspberry Pi and WiFi connectivity. Through our efforts, we achieved a functional and versatile hexapod with impressive locomotion capabilities. This project not only demonstrates our technical skills and problem-solving abilities but also holds great potential for further innovation in the field of robotics.

7.2 Recommendation

Research and Planning: Begin by researching different hexapod designs, mechanisms, and control methods. Understand the components required, such as servo motors, microcontrollers, and power systems. Plan out your project and set achievable goals.

Component Selection and Assembly: Select high-quality components based on your budget and project requirements. Assemble the hexapod's mechanical structure, ensuring precise alignment and robust construction. Take your time to ensure a solid foundation for your project.

Electronics and Wiring: Connect the servo motors to the microcontroller, ensuring proper wiring and signal connections. Utilize a power supply that can adequately drive all the servos. Double-check the connections to avoid any electrical issues.

Programming and Control: Develop the control logic and algorithms to command the hexapod's movements. Utilize a programming language compatible with your chosen microcontroller. Implement control features such as walking gaits, turning, and other desired actions.
Testing and Iteration: Gradually test each component and functionality of your hexapod. Identify and address any issues or errors that arise during testing. Refine your design and programming as necessary to improve performance and stability.

Documentation and Sharing: Document your entire build process, including the design, code, and any modifications made along the way. Share your progress and experiences with the robotics community through online forums, social media, or a personal blog. By sharing your journey, you contribute to the collective knowledge and inspire others.

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