A Project Report

On

"**Miniature Hexapod for Surveillance Applications**"

In the partial fulfilment for the reward of

B.Tech. Mechatronics Engineering

for

Symbiosis Skills and Professional University

submitted by

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SEM: VIII

under the guidance of

Prof. Jahida Subedar

School of Mechatronics Engineering

B.Tech. in Mechatronics Engineering

A.Y. 2022-23

This is to certify that the project entitled

“Miniature Hexapod for Surveillance Applications”

submitted by

Ms. Pradnya Sushil Shinde (1900601005)
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Mr. Pradnesh Suresh Hagawane (1900601011)

Is a bonafede work carried out by students under the supervision of Prof. Jahida Subedar and it is submitted towards partial fulfilment of requirement of Bachelor of Technology in Mechatronics Engineering from the Symbiosis Skills and Professional University, Pune during the academic year 2022-2023.

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Acceptance Certificate

The project entitled "**Miniature Hexapod for Surveillance Applications**" submitted by **Ms. Pradnya Sushil Shinde (1900601005)**, **Mr. Om Prakash Deshmukh (1900601008), Mr. Pradnesh Suresh Hagawane (1900601011)** may be accepted for evaluation.

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Date: 29.05.23

Student Declaration

I hereby declare that the project work entitled "**Miniature Hexapod for Surveillance Applications**" submitted to Symbiosis Skills and Professional University, Pune is a record of an original work done by me under the guidance of **Prof. Jahida Subedar**, School of Mechatronics Engineering and this work is submitted in the partial fulfilment of requirement for the award of Bachelor of Technology in Mechatronics Engineering. The results embodied in this report have not been submitted to any other university or institute for the award of any degree or diploma.

Date: 29-05-2023

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Acknowledgement

I would like to express my deep and sincere gratitude to my guide, **Prof. Jahida Subedar** of Mechatronics Engineering for her unflagging support andcontinuous encouragement throughout the seminar work. Without Her guidance and persistent help in this report would not have been possible. I must acknowledge the faculties and staff of the School of Mechatronics Engineering.

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Abstract

A miniature hexapod is a small, six-legged robot that could move in various directions and navigate through challenging terrains. This type of robot has become increasingly popular in recent years due to its versatility and potential applications in areas such as surveillance, exploration, and search and rescue. In this project, we present the design and development of a miniature hexapod that utilizes a combination of mechanical and electronic components to achieve its locomotion. The robot is capable of walking in multiple gaits, including tripod, ripple, and wave, and can be controlled through a wireless interface. We describe the design process, the selection of materials, and the fabrication techniques used to construct the robot. We also present the results of experiments conducted to evaluate the robot's performance, including its speed, stability, and agility. The previous versions of this robot had certain improvements needed related to size, performance and aesthetics. The robot has therefor been constructed to overcome issues concerned with the aforementioned improvements. The miniature hexapod represents a significant achievement in the development of small-scale robotics and has the potential to be used in a variety of applications in the future.

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I. Introduction

a) Hexapod: A Robotic Inspiration from Insects

Robotics is a field of engineering and computer science that deals with the design, construction, operation, and use of robots. A robot is a machine that can carry out complex actions automatically or under the control of a computer program. Robotics is an overlap of mechanical engineering, electrical engineering, and computer science to create intelligent machines that can perform a wide range of tasks, from manufacturing and assembly to space exploration and military operations.

Combination of various processes and fields such as robot design, control, sensing, perception, and artificial intelligence allow development of innumerable variety of robots. Robot design involves the creation of mechanical structures and systems that can move and interact with the environment. Control refers to the algorithms and software that enable a robot to perform a specific task. Sensing involves the use of sensors to detect and measure physical and environmental parameters, while perception involves the interpretation of sensor data to create a model of the robot's environment. Finally, artificial intelligence enables robots to make decisions and adapt to changing conditions.

Several famous robots by companies such as Amazon Robotics, Boston Dynamics have been deployed for various applications:

Figure 1: Warehouse Robot by Amazon Global Robotics [1]

Robotics has applications in many fields, including manufacturing, medicine, agriculture, transportation, and space exploration.

Figure 2: Spot by Boston Dynamics for Field Operations [2]

The ease with which Robotics has transformed our lives and industries, is what allows it to extends its application further.

One of the key parts in Robotics is: Inspiration from Animals.

As technology advances, it is becoming easier to replicate animal behavior. Characteristics such as vision, locomotion, decision making have been implemented in Robots. Biomimicry, the practice of imitating nature's designs and processes to solve human problems, has played a significant role in the development of robotic systems.

Animals have evolved over millions of years to be highly adapted to their environments, and their unique features and behaviors have inspired engineers and scientists to create robots with similar capabilities. For example, researchers have studied the flight of birds and the swimming of fish to design more efficient drones and underwater robots. By drawing inspiration from nature, robotics engineers and researchers hope to create more efficient, adaptable, and resilient robots that can tackle a wide range of tasks and environments.

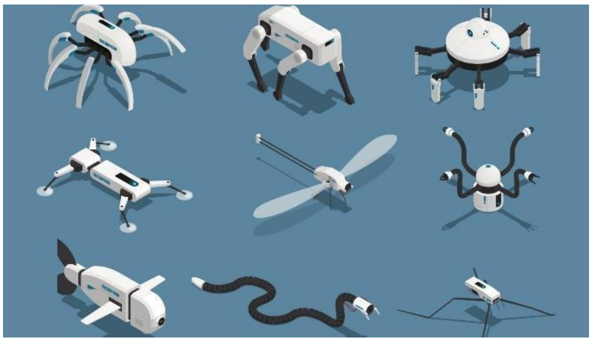


Figure 3: Several of Animal-Inspired Robots [3]

A hexapod is a type of robot that has six legs. Hexapods are often designed to mimic the movement of insects, such as spiders, ants, and beetles, which have six legs and are highly maneuverable and adaptable to different environments.

Hexapods are popular in robotics research and development due to their ability to navigate challenging terrain, including uneven surfaces, stairs, and rough terrain. They are also capable of performing tasks that require high stability, such as carrying payloads or cameras. They are typically controlled by a central computer or microcontroller, which coordinates the movement of the legs to achieve locomotion. Each leg of a hexapod is often composed of several segments, with joints that can be actuated by motors or other mechanisms. By controlling the movement of each leg independently, a hexapod can achieve a wide range of motions, including walking, running, crawling, and climbing.

Hexapods are used in a variety of applications, including search and rescue, military operations, exploration, and entertainment. They are also commonly used in education and research as a platform for studying biomechanics, control systems, and robotics algorithms.

Figure 4: PhantomX Hexapod MK-IV by Trossen Robotics [4]

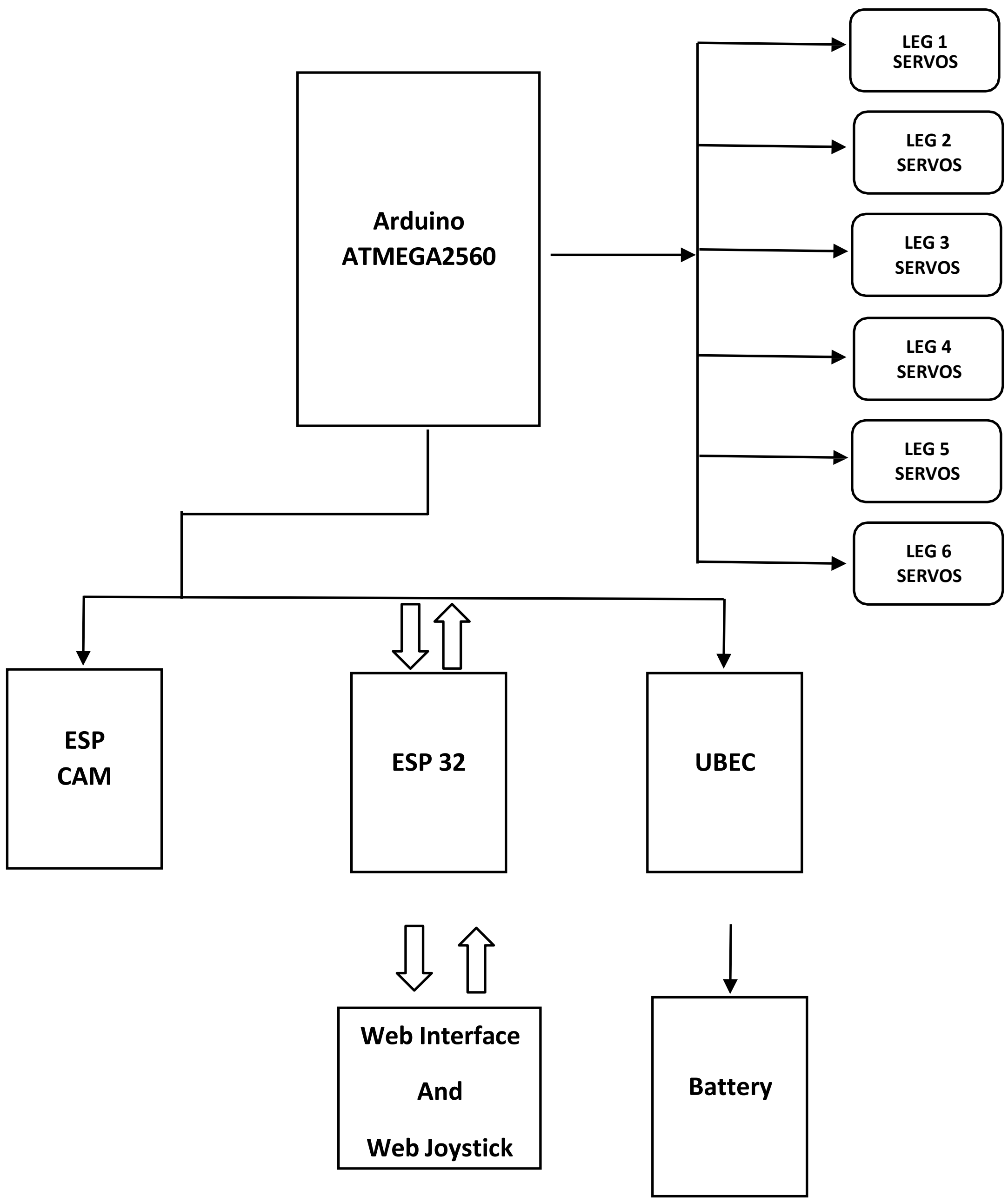
In the above figure, we can see Trossen Robotics' ROS based six-legged PhantomX robot. The PhantomX MK-IV Hexapod is a ROS research platform featuring the Raspberry PI 4b and the DYNAMIXEL XL Series Smart Servos from Robotis. The platform offers Wi-Fi, tethered connection and wireless via Bluetooth / PlayStation 4 Control options. The MK-IV Hexapod has a payload capacity of roughly 1lb, walking speed of roughly 129mm/s (default gait) and an estimated run time on battery of 45 minutes.

b) Project Inspiration

Hextorq – A Six-Legged Robot by Pune's Startup, Technodune Pvt. Ltd. is designed for surveillance and defence-related applications. The company was looking to scale down the robot to fit in the small-scale applications like duct cleaning, swarm robotics, inspection of sites etc. Their requirement was that of a generic design that could be used in the above applications. Following are the improvements made in the presented project:

- Issue: Hexapod is bulky thereby provides a slower mobility.
- Solution implemented:
    - Designed a miniature hexapod with about 30% size reduction.
    - Scaled down with modular leg deign and removable battery ports, without having to disassemble the entire robot.
- The previous versions used FPV camera which cannot be connected over the internet and therefore cannot be accessed by multiple users.
- Solution:
    - Integrated ESP32 CAM feed on a Web Interface which can be accessible by anyone.
- The previous versions were controlled using PS2 Controller which is expensive.
    - The controller is a web Joystick on that can be used on any given mobile phone.

c) Architecture



II. Literature Review

The paper *titled "A modular hexapod robot for versatile locomotion" by Chen and Chen (2018)*[5] presents a design approach for a modular hexapod robot that offers versatility inlocomotion. The authors address the need for adaptable robots capable of navigating various terrains by proposing a modular design with integrated actuators and sensors.

The researchers highlight the significance of modularity in robotic systems as it allows for reconfiguration and adaptation to different environments. By employing modular segments, each equipped with its own actuators and sensors, the hexapod robot can achieve versatile locomotion patterns and adaptability.

The authors provide a detailed description of the modular design, discussing the construction and arrangement of the robot's components. They emphasize the importance of the mechanical structure and the selection of suitable actuators to ensure efficient and reliable locomotion. Furthermore, the paper describes the control system of the hexapod robot. The authors present a control architecture that coordinates the movements of the individual segmentsand enables the robot to perform a variety of locomotion tasks. The control system incorporates sensor feedback to adjust the gait parameters and ensure stability and adaptability in different terrains.

To evaluate the performance of the modular hexapod robot, the authors conducted experiments on different surfaces, including flat ground, inclined planes, and uneven terrains. The experimental results demonstrate the robot's ability to adapt its locomotion patterns and successfully traverse various environments. In conclusion, Chen and Chen (2018) propose a modular hexapod robot design that provides versatile locomotion capabilities. The research highlights the importance of adaptability in robotic systems, particularly in the context of navigating diverse terrains.The presented modular design and control system offer promising possibilities for futuredevelopments in hexapod robot design and applications.

The paper titled *"Bio-inspired hexapod robot design for improved stability and maneuverability" by Kim et al. (2019)*[6] explores a bio-inspired approach to enhance the stability and maneuverability of hexapod robots. The authors aim to mimic the structure and leg morphology of insects to improve the robot's overall performance. The researchers emphasize that insect locomotion is highly efficient and adaptable to different environments, making it an excellent source of inspiration for designing robotic systems. By replicating the leg morphology and movement patterns of insects, they believe that the hexapod robot can achieve similar levels of stability and maneuverability.

The paper provides a detailed description of the bio-inspired design of the hexapod robot. The authors discuss the mechanical structure, including the leg design and the integration of actuators, sensors, and joints. They highlight the importance of replicating the multi-DOF (Degrees of Freedom) leg movements observed in insects to enhance the robot's mobility.

Furthermore, the control system of the bio-inspired hexapod robot is explained. The authors present a coordinated control strategy that enables synchronized leg movements, allowing the robot to achieve stable and efficient locomotion. The control system incorporates sensory feedback to adapt the leg movements according to the terrain conditions.

To evaluate the performance of the bio-inspired hexapod robot, the researchers conducted experiments on various terrains, including flat surfaces, slopes, and obstacles. The experimental results demonstrate that the robot exhibits improved stability and maneuverability compared to traditional hexapod designs. The robot successfully navigates through complex terrains and demonstrates enhanced adaptability. In conclusion, Kim et al. (2019) proposes a bio-inspired design for hexapod robots to improve stability and maneuverability. By replicating the leg morphology and movement patterns of insects, the researchers achieve enhanced performance in terms of locomotion.The presented bio-inspired design and control strategy provide valuable insights for the development of more efficient and adaptable hexapod robots in the future.

The paper titled "*Gait optimization for hexapod robots using particle swarm optimization" by Zhang et al. (2020)*[7] focuses on optimizing the gait patterns of hexapod robots using a particle swarm optimization (PSO) algorithm. The authors aim to improvethe robot's locomotion efficiency and adaptability by optimizing the gait parameters. The researchers highlight the significance of gait optimization in achieving efficient andstable locomotion for hexapod robots. They propose the utilization of a PSO algorithm, which is a nature-inspired optimization technique that simulates the behavior of a swarm of particles searching for optimal solutions in a multidimensional space. The paper provides a detailed description of the gait optimization process. The authors explain the representation of the gait parameters and the fitness evaluation criteria used inthe PSO algorithm. They discuss the objective functions used to measure the robot's performance, such as energy efficiency, stability, and speed.

Furthermore, the researchers present the implementation of the PSO algorithm for gait optimization in hexapod robots. They describe the iterative process of the algorithm, where the swarm of particles updates its positions based on the best solutions found so far. This iterative process continues until convergence is achieved, resulting in optimizedgait parameters.

To evaluate the effectiveness of the proposed gait optimization approach, the authors conducted simulations and experiments on a hexapod robot. They compared the performance of the optimized gait with that of pre-defined gaits. The results demonstrate that the PSO-based gait optimization significantly improves the robot's locomotion efficiency, adaptability, and stability.

In conclusion, Zhang et al. (2020) propose a gait optimization approach for hexapod robots using a PSO algorithm. By optimizing the gait parameters, the researchers achieve improved locomotion performance in terms of energy efficiency, stability, and adaptability. The presented approach offers valuable insights for enhancing the locomotion capabilities of hexapod robots and can contribute to advancements in variousapplications such as exploration and search-and-rescue missions.

The paper titled *"Reinforcement learning-based control system for adaptive locomotion of hexapod robots" by Li et al. (2021)*[8] focuses on developing a control system for hexapod robots based on reinforcement learning (RL). The authors aim to enable the robot to learn and optimize its locomotion patterns through RL, leading to enhanced adaptability and robustness. The researchers highlight the potential of RL techniques in improving the locomotion capabilities of hexapod robots. RL is a learning paradigm where an agent interacts with itsenvironment and learns optimal actions through trial and error. By applying RL to the control system, the hexapod robot can adapt its locomotion strategies to varying terrains and achieve efficient and stable movement. The paper provides a detailed description of the RL-based control system. The authorsexplain the RL framework, including the definition of the state, action, and reward functions. They discuss the use of neural networks as function approximators to modelthe policy and value functions in RL.

Furthermore, the researchers present the training process of the RL-based control system. They describe how the robot interacts with the environment, collects data, and updates its policy based on the received rewards. The training process involves multiple iterations to optimize the policy and improve the robot's locomotion performance. To evaluate the effectiveness of the RL-based control system, the authors conducted simulations and experiments on a hexapod robot. They compared the performance of theRL-trained robot with that of a conventionally programmed robot. The results demonstrate that the RL-based control system enables the robot to adapt its locomotion patterns to different terrains, resulting in improved stability and efficiency.

In conclusion, Li et al. (2021) proposes a control system for hexapod robots based on RL techniques. By utilizing RL, the robot can learn and optimize its locomotion strategies through interaction with the environment. The presented RL-based control system offers a promising approach to enhance the adaptability and robustness of hexapod robots, enabling them to navigate diverse terrains with improved efficiency and stability. Furthermore, the researchers present the locomotion control algorithms for the hybrid strategy. They discuss the decision-making process that determines when to switch between rolling and walking gaits based on the terrain conditions. They also explain thecoordination of leg movements during the transition between gaits.

To evaluate the performance of the hybrid locomotion strategy, the authors conducted experiments on various terrains, including flat surfaces, slopes, and rough terrains. They compared the robot's performance with that of robots using only rolling or walking gaits. The results demonstrate that the hybrid locomotion strategy offers advantages in terms of speed, stability, and adaptability, allowing the robot to traverse different terrains effectively. In conclusion, Wu et al. (2019) propose a hybrid locomotion strategy for hexapod robotsthat combines rolling and walking gaits. By integrating both gaits, the robot achieves improved locomotion efficiency and adaptability. The presented hybrid strategy offers valuable insights for the design and control of hexapod robots, enabling them to navigatevarious terrains with enhanced speed, stability, and maneuverability.

The paper titled *"An adaptive locomotion control system for hexapod robot over rough terrain" by Peng et al. (2019)*[9] presents an adaptive locomotion control system designed specifically for hexapod robots navigating rough terrains. The authors aim to develop a control system that enables the robot to adapt its locomotion strategies in real-time based on the terrain conditions, ensuring stability and efficiency. The researchers emphasize the challenges faced by hexapod robots when traversing roughterrains, where the ground conditions can vary significantly. To address these challenges, they propose an adaptive locomotion control system that dynamically adjusts the gait parameters and leg movements based on real-time feedback from sensors.

The paper provides a detailed description of the adaptive locomotion control system. The authors discuss the hardware setup of the hexapod robot, including the mechanical structure and sensor configuration. They describe the integration of various sensors, such as force sensors and inertial measurement units (IMUs), to capture information about the terrain and the robot's state. Furthermore, the researchers present the control algorithm used in the adaptive locomotion system. They discuss the decision-making process that takes into account thesensor feedback and dynamically adjusts the gait parameters and leg movements. The adaptive control system aims to optimize stability and efficiency by adapting the robot's locomotion in response to changes in terrain roughness and slope. To evaluate the performance of the adaptive locomotion control system, the authors conducted experiments on rough terrains with varying levels of difficulty. They compared the robot's performance using the adaptive control system with that of a fixed control system. The results demonstrate that the adaptive control system significantly improves the robot's stability, efficiency, and traversal capability in rough terrains. In conclusion, Peng et al. (2019) propose an adaptive locomotion control system for hexapod robots navigating rough terrains. The presented system dynamically adjusts thegait parameters and leg movements based on real-time sensor feedback, enabling the robot to adapt its locomotion strategies to different terrains. The research offers valuable insights for enhancing the performance of hexapod robots in challenging environments and can contribute to advancements in applications such as search-and-rescue missions and exploration.

Introduction:

Hexapod robots are six-legged robotic systems that mimic the locomotion patterns of insects. With their unique locomotion capabilities, hexapods have gained significant attention in both research and practical applications. This literature review aims to provide an overview of the current state of research on hexapod robots, focusing on theirdesign, control, locomotion strategies, and applications.

Design of Hexapod Robots:

Several research studies have focused on the design aspects of hexapod robots. Chen and Chen (2018) proposed a modular hexapod robot design that allows for easy reconfiguration and adaptation to different terrains. They utilized modular segments with integrated actuators and sensors, enabling the robot to achieve versatile locomotion and adaptability. Similarly, Kim et al. (2019) presented a bio-inspired hexapod robot design that mimicked the structure and leg morphology of insects, resulting in improved stability and maneuverability.

Control Strategies:

The control of hexapod robots plays a crucial role in achieving stable and efficient locomotion. Researchers have explored various control strategies for hexapod robots. Zhang et al. (2020) developed a gait optimization algorithm based on particle swarm optimization, which enabled the hexapod robot to adapt its gait parameters to different environments. Additionally, Li et al. (2021) proposed a neural network-based control system that allowed the hexapod robot to learn and optimize its locomotion patterns through reinforcement learning, resulting in enhanced adaptability and robustness.

Locomotion Strategies:

Hexapod robots employ diverse locomotion strategies to navigate through different terrains. Research studies have investigated various approaches to achieving efficient locomotion. Wu et al. (2019) presented a hybrid locomotion strategy that combined rolling and walking gaits, enabling the robot to traverse both flat and uneven surfaces effectively. Furthermore, Nguyen et al. (2022) proposed a compliant locomotion strategy for hexapod robots, incorporating passive compliance in the leg joints to improve stabilityand energy efficiency during locomotion.

Applications:

Hexapod robots have found applications in various fields, including search and rescue operations, exploration, and agriculture. Liu et al. (2021) developed a hexapod robot equipped with sensors and cameras for disaster response and search missions in hazardous environments. The robot demonstrated superior mobility and maneuverabilityin complex terrains, making it suitable for rescue operations. Moreover, Chen and Lee (2020) designed a hexapod robot for agricultural tasks such as pest detection and crop monitoring. The robot's ability to traverse challenging agricultural environments facilitated efficient data collection and analysis.

III. Project Implementation

a) Design Procedures

The robot consists of the following parts. The designs are modelled to meet certain requirements that have been highlighted in the section below for each deign component.

The proposed design consists of three parts of the leg:

- Coxia – Hip Joint
- Femur – Knee Joint
- Tibia – Foot Joint

This contributes to 18 degrees of freedom and thereby allowing a flexible maneuverability.

1. Coxia Servo Mount

   As defined, this is the Hip joint that allows movement in X-Y plane. This was designed in such a way that the entire leg design became modular. As shown in the figure below, the cylindrical structure within the mount and the mounting hole, allowsthe leg to be removed and replaced without having to disassemble the entire body.

   Another feature of this design is the compact space. The servo mounts were required to be designed in a way that the servos are simply able to slide in and out.

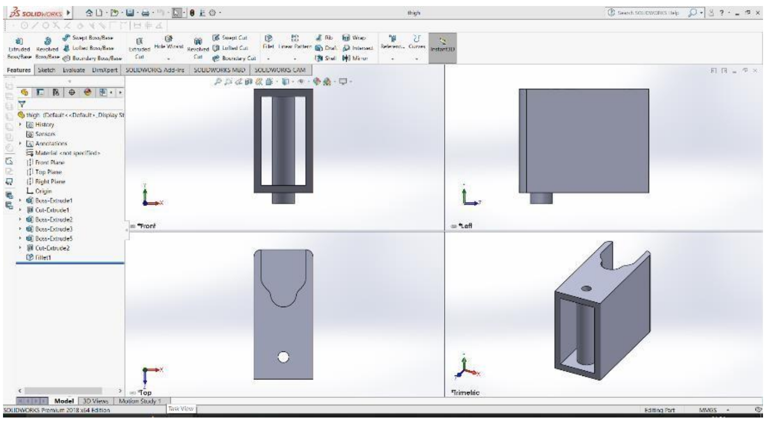


Figure 5: Coxia Servo Mount

2. Femur Servo Mount

This is the knee joint that allows movement in Y-Z plane. As the middle joint, it alsosupports in movement of Tibia with the help of Femur-to-Tibia link.
Another key feature of this design is the wire conceal space given in the form of twoparallel rectangular cuts on the sides.

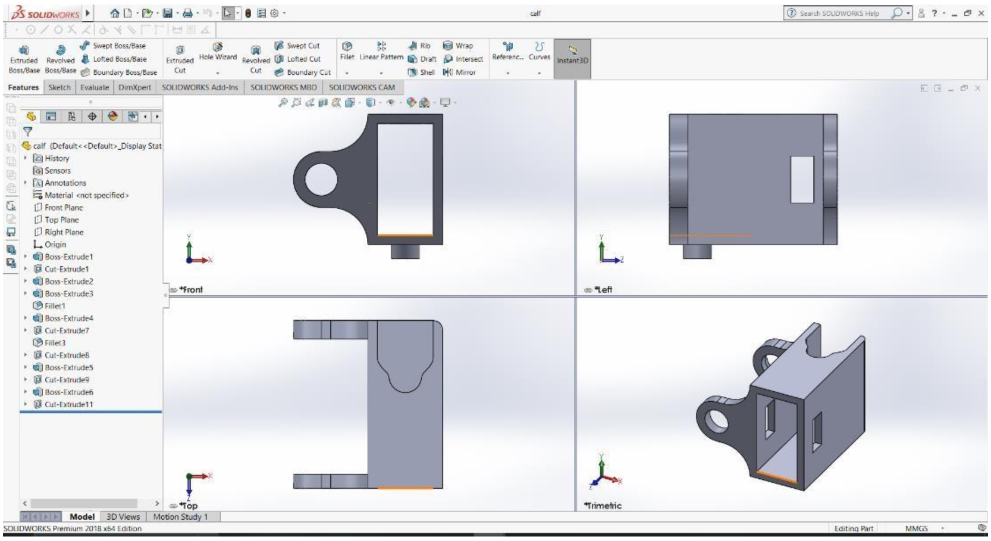


Figure 6: Femur Servo Mount

3. Tibia Servo Mount

The tibia mount is responsible for movement of foot in X-Z as well as Y-Z plane.
The mount has been made angular instead of circular as it occupies lesser surface area and hence forming a compact size.

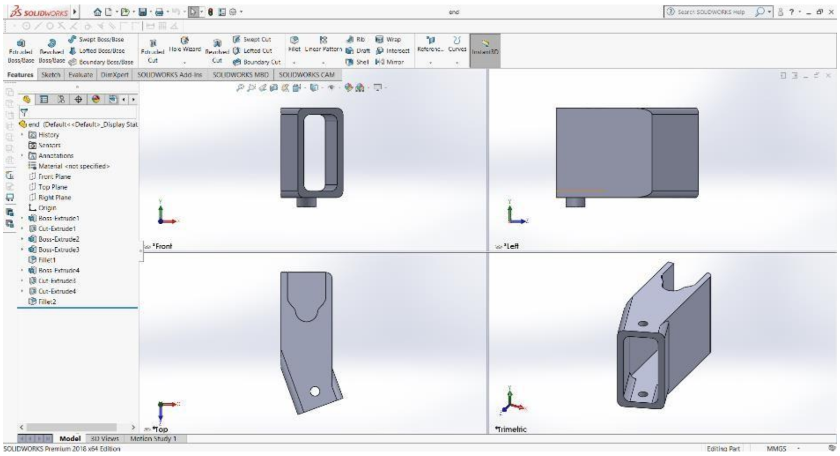


Figure 7: Tibia Servo Mount

4. Femur to Tibia Link

This particular link connects Femur and Tibia joints. A key feature of this design is the engraved space for servo horns. This provides an aesthetic and neater look.
This design has also been made angular for the same reason mentioned in point

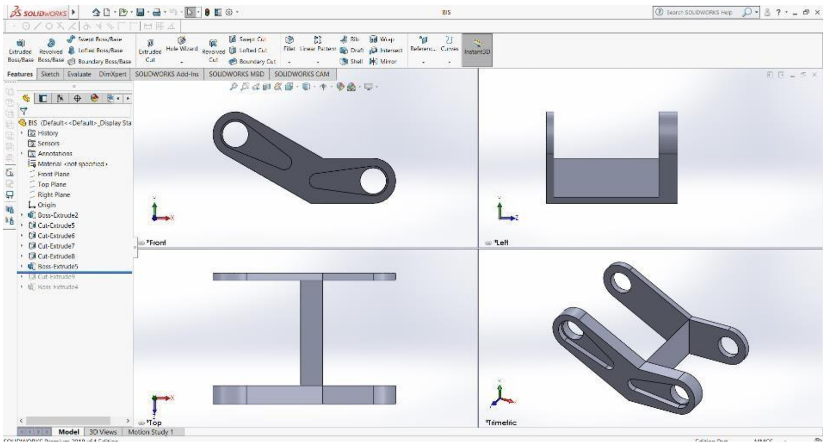


Figure 8: Femur to Tibia Servo Mount

5. Robot Shoe

The requirement of the robot was to give provision for placement of sensor. The shoe design, being removable allows space for any targeted application sensor. Apart from this, the show also gives an aesthetic look to the robot.

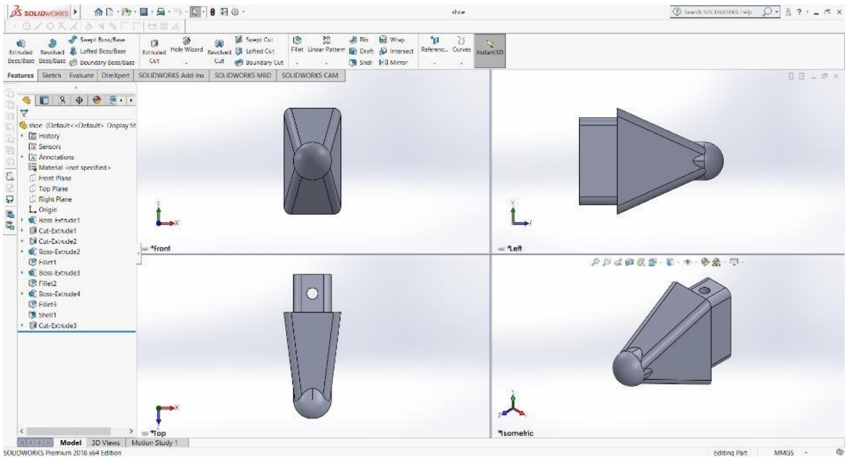


Figure 9: Robot Shoe

6. Robot Body

The body has a key feature of compact size. The spacing at the back also allows room forremovable battery.

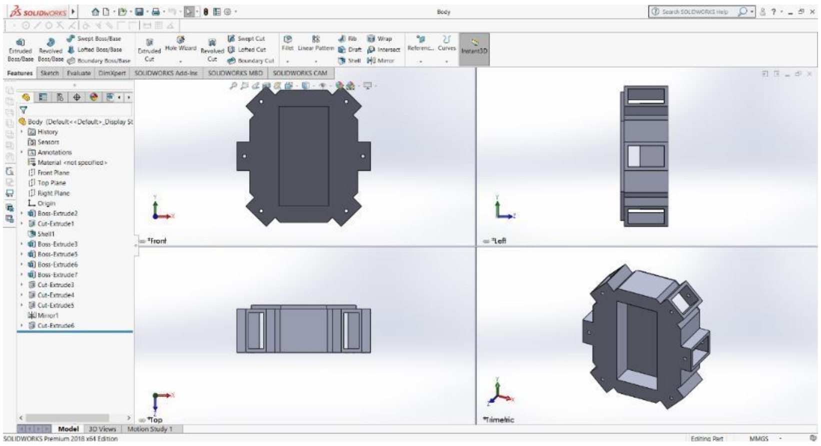


Figure 10: Robot body

7. Robot Cover

The cover has been designed using surface modelling.

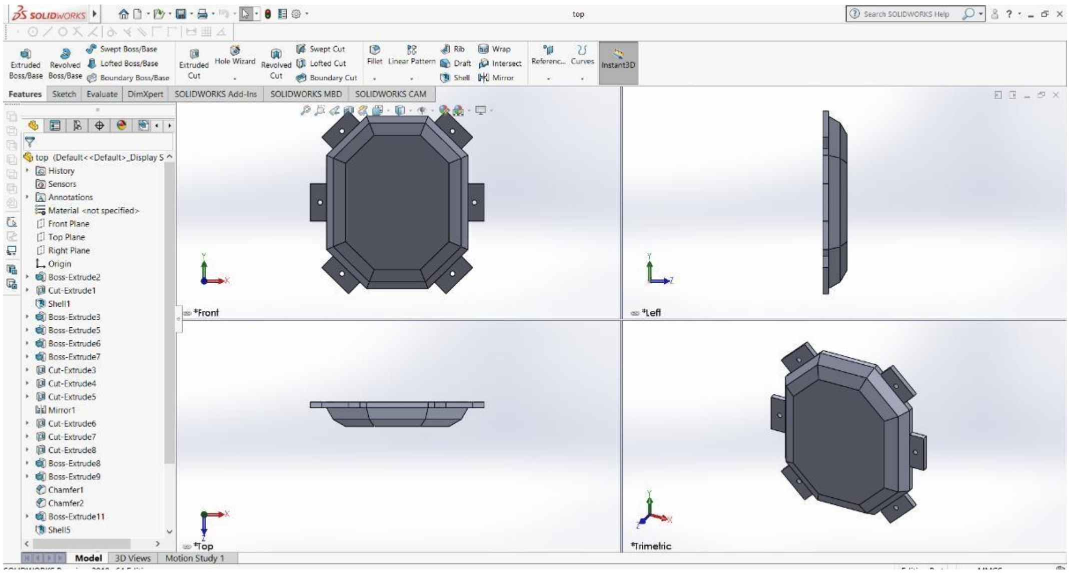


Figure 11: Robot Cover

8. Assembly

Leg Assembly

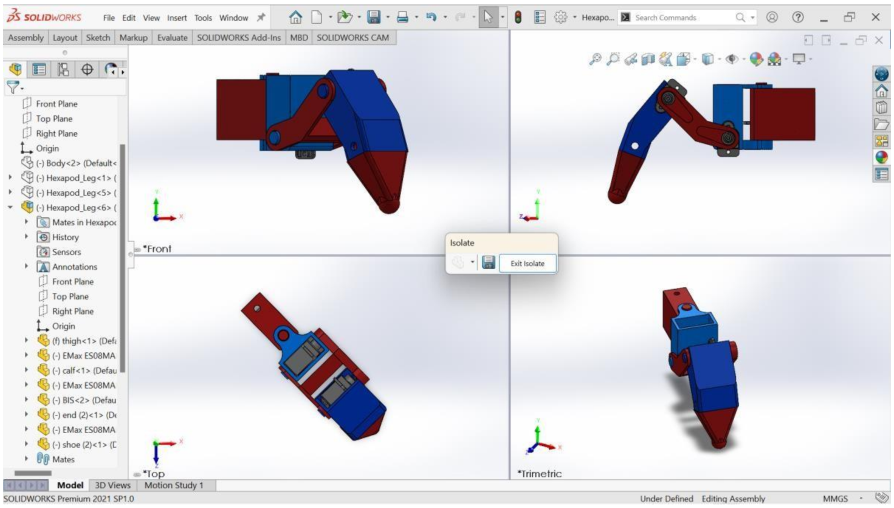


Figure 12: Leg Assembly

Robot Assembly

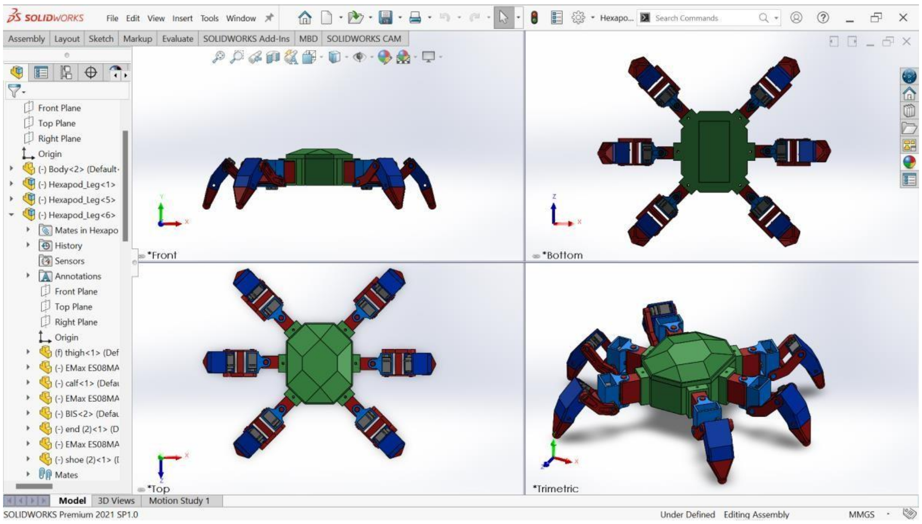


Figure 13: Robot Assembly

b) Design Challenges

1. Overall Size Reduction

The primary objective was to reduce the overall dimensions of the robot in order to increase mobility and portability.

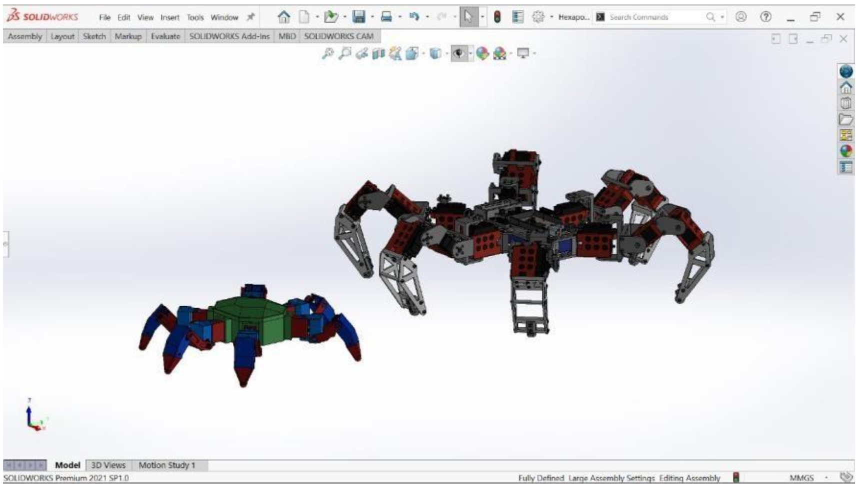


Figure 14: Size comparison of V1 and V3 (isometric view)

To tackle this, we designed the legs in such a way that the tabs of servos used for mounting purpose was discarded from operation and a suitable provision was made to mount the servo without tabs.

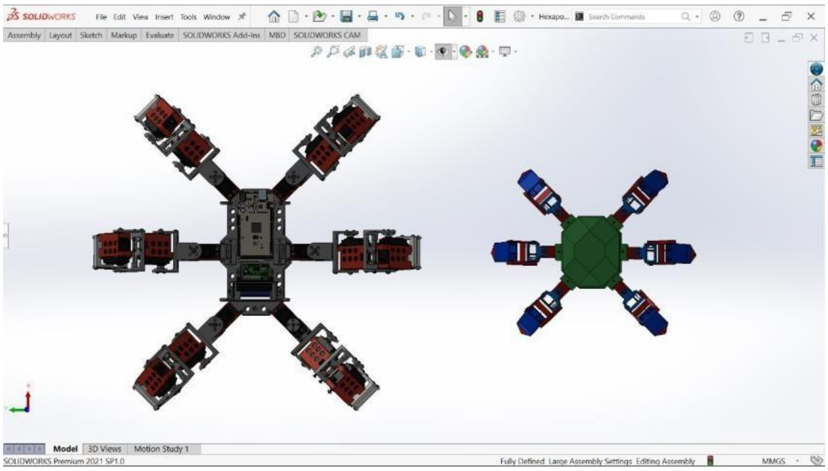


Figure 15: Size comparison of V1 and V3 (top view)

2. Replaceable legs

Since the servos often get damaged while in operational state, provision for swappable legs was supposed to be made so that the leg can be easily replaced in case of any uncertain event.

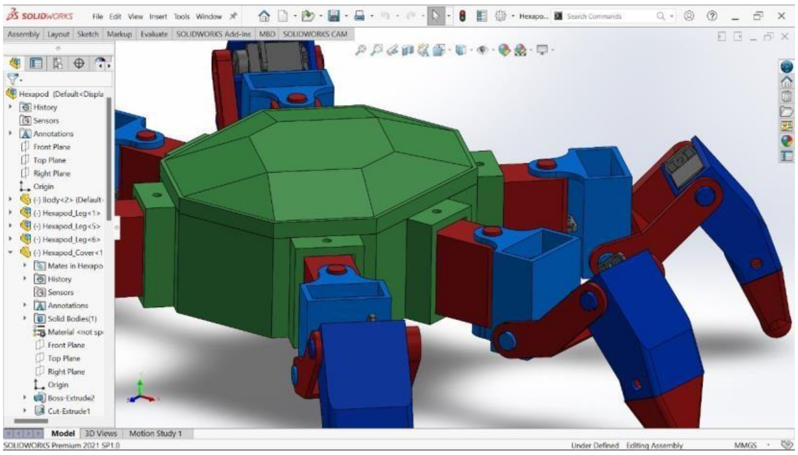


Figure 16: Easily removable leg mechanism

3. Sensor Provision

To make the robot capable of performing multiple operations, the sensors or the end effector need to be changed according to the requirements. In order to generalize this, a swappable mechanism was designed to tweak the attachments as per required tasks.

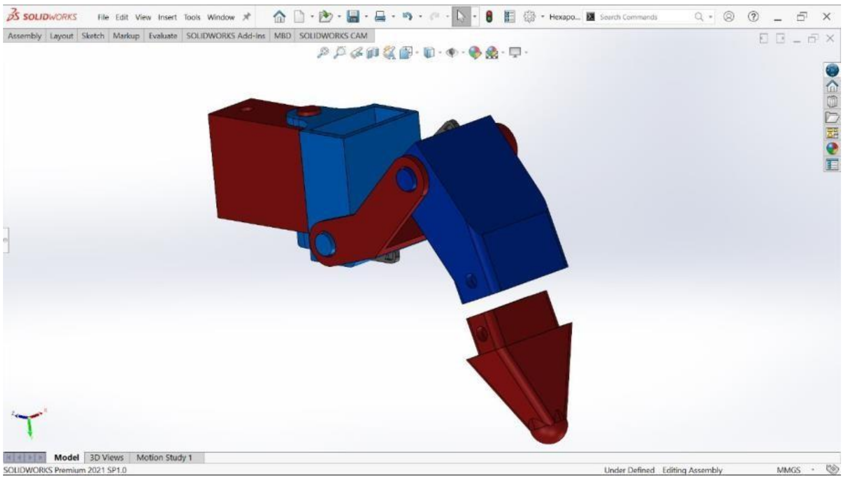


Figure 17: Sensor provision mechanism

4. Horn groove

As the horns were out of the body which was affecting the overall aesthetics of the robot, grooves were made for servo horns to make the surface of the robot smooth.

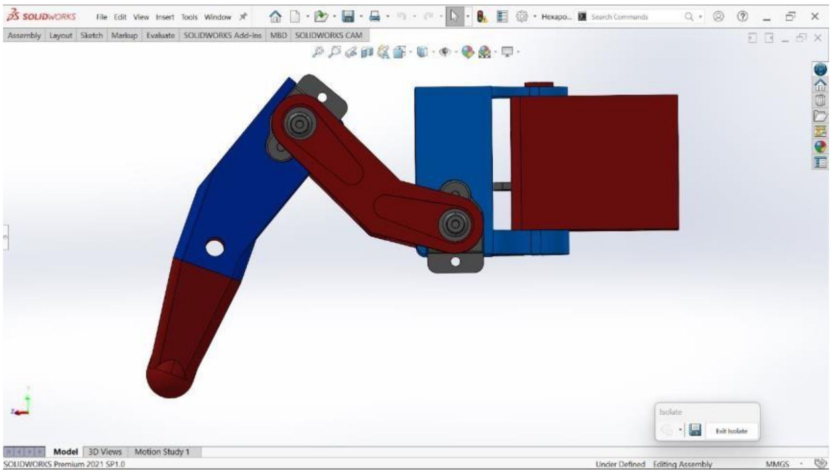


Figure 18: Horn groove mechanism

5. Wire Conceal

In the previous versions, the wires from servos were out of the body making it unorganized. To solve this, proper routing was done and provision to pass wires from body was made.

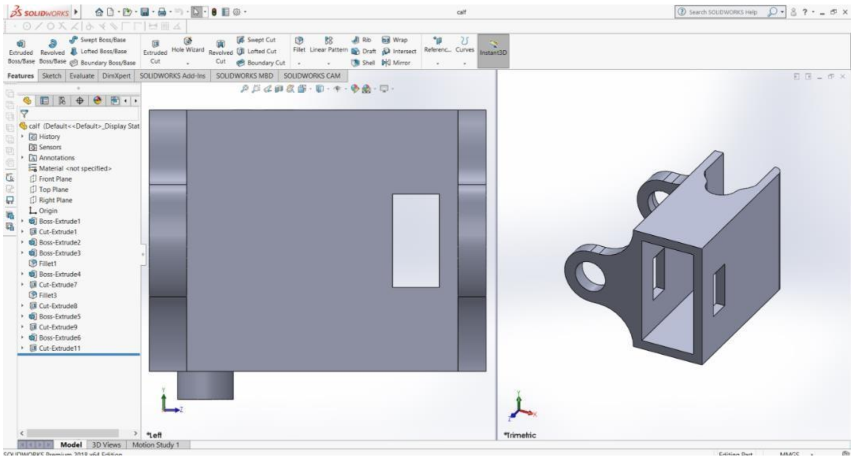


Figure 19: Provision for wire concealment

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6. Removable battery pack

As the battery was inside the body in previous versions, making it hard to access and charge from outside, suitable provision was made to recharge or remove the batter externally without opening the whole body.

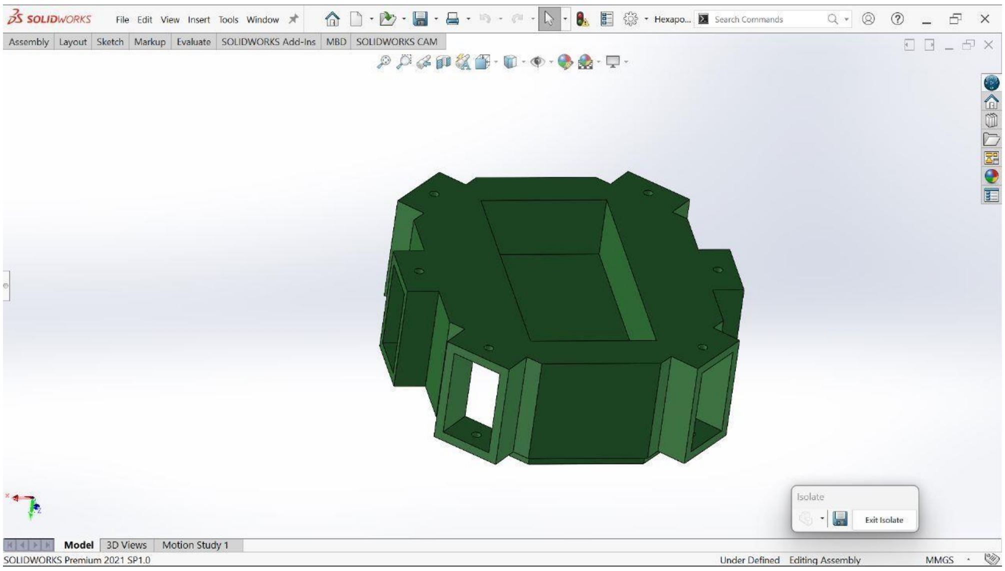


Figure 20: Provision to swap/charge battery

c) Interfacing of Hardware and Electronics

1. Controller

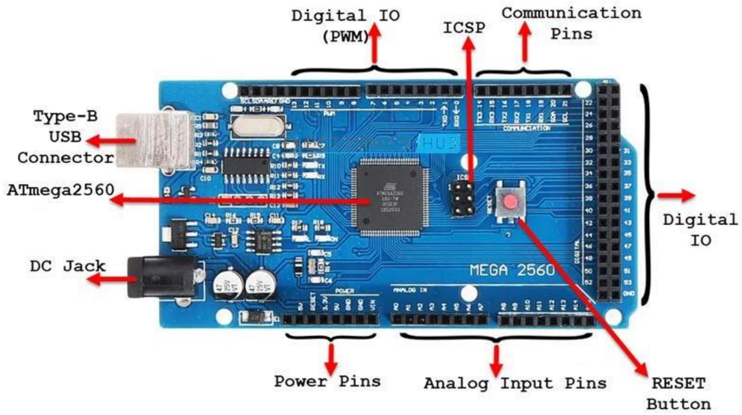


Figure 21: Arduino ATMEGA 2560 [10]

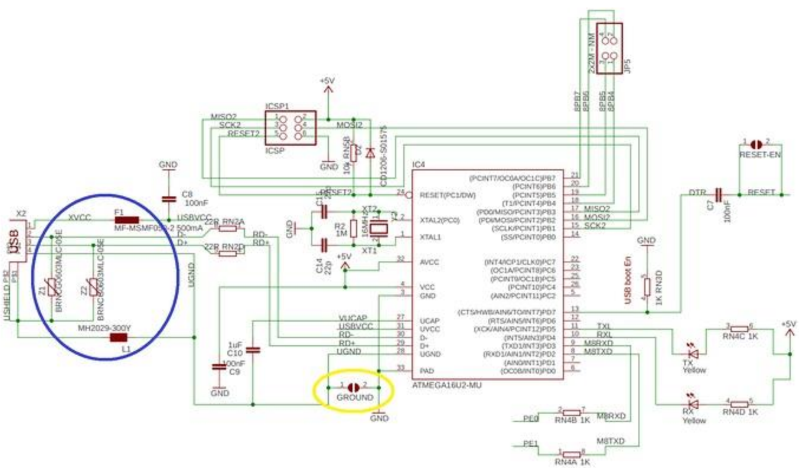


Figure 22: Arduino ATMEGA 2560 Circuit Diagram [11]

The ATmega2560 offers a range of features that make it suitable for a variety of applications. Here are some key features:

1. Memory: The microcontroller has a total of 256 KB of Flash memory for storing the program code. This allows for the implementation of complex applications and projects. It also provides 8 KB of SRAM (Static Random Access Memory) for

storing data during program execution and 4 KB of EEPROM (Electrically Erasable Programmable Read-Only Memory) for non-volatile data storage.

2. I/O Pins: The ATmega2560 has a generous number of 54 digital input/output pins, with 15 of them capable of PWM (Pulse Width Modulation) output. These pins can be used to interface with various external components such as sensors, displays, motors, and more.
3. Analog Inputs: It features 16 analog input channels, allowing for the measurement of analog signals. These inputs are commonly used to interface with sensors that provide analog output, such as temperature sensors or light sensors.
4. Communication Interfaces: The microcontroller supports multiple communication interfaces, including UART (Universal Asynchronous Receiver/Transmitter), SPI (Serial Peripheral Interface), and I2C (Inter-Integrated Circuit). These interfaces enable communication with other devices such as other microcontrollers, sensors, and modules.
5. Timers and Interrupts: The ATmega2560 includes a set of timers and interrupts that provide precise timing and event-driven capabilities. These features are crucial for tasks such as controlling motors, generating PWM signals, or handling external events.
6. Programming: The ATmega2560 can be programmed using the Arduino development environment, which provides a user-friendly interface and a vast ecosystem of libraries and resources. It also supports in-system programming (ISP) and boot loading, allowing for easy firmware updates.

SPECIFICATIONS:

The ATmega2560 is a microcontroller developed by Microchip Technology (formerly Atmel Corporation). It is part of the AVR family of microcontrollers and is widely used in various applications, including robotics, automation, and embedded systems. Here are some key specifications of the ATmega2560:

- Microcontroller Architecture: The ATmega2560 is based on the AVR RISC (Reduced Instruction Set Computer) architecture.

- Clock Speed: It operates at a maximum clock speed of 16 MHz.
- CPU Core: The microcontroller features an 8-bit AVR CPU core, which includes general-purpose registers, arithmetic logic units, and control logic.
- Flash Memory: The ATmega2560 has 256 KB of in-system self-programmable Flash memory, which is used for storing the program code.
- SRAM: It has 8 KB of static random-access memory (SRAM) used for storing data during program execution.
- EEPROM: The microcontroller provides 4 KB of electrically erasable programmable read-only memory (EEPROM) for non-volatile data storage.
- I/O Pins: The ATmega2560 offers a total of 86 I/O pins, including digital input/output (I/O) and analog input pins. Some of these pins also support special functionalities such as PWM (Pulse Width Modulation) output, interrupt capability, and serial communication.
- Timers and Counters: It includes various hardware timers and counters, including six 16-bit Timer/Counters and one 8-bit Timer/Counter. These timers can be used for tasks such as generating accurate timing intervals and PWM signals.
- Communication Interfaces: The microcontroller supports multiple communication interfaces, including USART (Universal Synchronous and Asynchronous Receiver

Transmitter), SPI (Serial Peripheral Interface), and I2C (Inter-Integrated Circuit) for serial communication with other devices.

- Analog-to-Digital Converter (ADC): It includes a 10-bit ADC with a multiplexed input to convert analog signals into digital values.

- Operating Voltage: The ATmega2560 typically operates at a voltage range of 1.8V to 5.5V, making it compatible with a wide range of power supply options.

- Development Tools: The microcontroller is widely supported by development tools and programming environments, including the Arduino development platform, making it popular among hobbyists and developers.

WHY ATmega 2560?

ATmega2560 microcontroller was chosen for our hexapod robot because of several reasons like:-

Sufficient I/O Pins: The ATmega2560 offers a large number of I/O pins (86 in total), which can be advantageous for controlling the multiple legs and other components of a hexapod robot. The ample I/O pins provide flexibility in connecting and controlling various sensors, actuators, and peripherals.

Adequate Flash Memory: With 256 KB of Flash memory, the ATmega2560 provides ample storage space for the robot's program code. This allows for implementing complex control algorithms, sensor fusion techniques, and other functionalities required for a hexapod robot.

Availability of Development Tools: The ATmega2560 is well-supported by development tools and programming environments, including the popular Arduino platform. This extensive support simplifies the development process and allows for faster prototyping and testing of the hexapod robot's software.

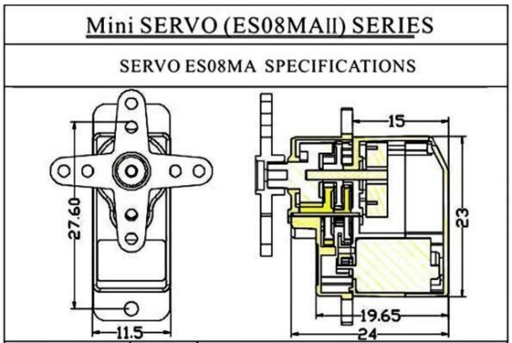
Integrated Peripherals: The microcontroller incorporates various integrated peripherals such as timers, UART (serial communication), SPI, I2C, and ADC, which are commonly used in robotics applications. These integrated peripherals simplify the interface with sensors, actuators, and other external devices, reducing the need for additional components or external ICs.

Cost-Effective Solution: The ATmega2560 is known for its affordability and cost-effectiveness, making it a popular choice for hobbyist projects and small-scale robotics applications. This affordability can be beneficial when considering the overall cost of the hexapod robot project.

Community Support: The ATmega2560 has a large community of developers and enthusiasts, which means there is a wealth of online resources, tutorials, and code examples available. This community support can be valuable in troubleshooting issues, sharing knowledge, and finding solutions to challenges encountered during the development of the hexapod robot.

2. Actuator

Figure 23: EMAX ES08MA II – 18 [12]



Operating Voltage:		4.8~6.0V
STD Direction:		Counter Clockwise / Pulse Traveling 1500 to 1900usec
Stall Torque:	4.8V	1.6 Kgf.cm(21.0 oz.in)
Operating Speed:	4.8V	0.12 Sec/60° at no load
Stall Torque:	6.0V	2.0 Kgf.cm(28.0 oz.in)
Operating Speed:	6.0V	0.10 Sec/60° at no load
Size:		23X11.5X24 mm
Weight:		12 g
Plug Available		FUT ;JR
Other		Analog ;Metal

Figure 24: ES08MA II Specifications [13]

The Emax ES08MA II is a servo motor designed for use in various robotic and RC (radio-controlled) applications. It is known for its compact size, reliability, and affordability.

- Size and Weight: The Emax ES08MA II servo motor has a compact size, measuring approximately 32mm x 11.5mm x 24mm (L x W x H). It is lightweight, weighing around 12 grams, making it suitable for small-scale projects and applications where space is limited.

- Operating Voltage: The servo motor operates on a DC voltage range of 4.8V to 6V. It is commonly powered by a 4-cell AA battery pack or an external power supply within this voltage range.

- Torque and Speed: The Emax ES08MA II provides a torque output of approximately 1.8 kg/cm (at 4.8V) and 2.0 kg/cm (at 6V). It offers a speed of approximately 0.12 seconds per 60 degrees rotation (at 4.8V) and 0.10 seconds per 60 degrees rotation (at 6V).
- Construction: The servo motor features a durable plastic housing that protects the internal components. It has a 3-wire interface for power, ground, and control signals. The output shaft is made of metal for enhanced strength and reliability.
- Control Interface: The Emax ES08MA II servo motor supports the standard PWM (Pulse Width Modulation) control signal. It accepts a control pulse ranging from 1.0ms to 2.0ms, with a neutral position at around 1.5ms.
- Reliable and Durable: The servo motor is made with high-quality materials, including a metal output shaft and durable plastic housing, which makes it robust and long-lasting.
- Good Torque and Speed: The EMAX08ma II servo motor provides a torque output of approximately 1.8 kg/cm (at 4.8V) and 2.0 kg/cm (at 6V), and it offers a speed of approximately 0.12 seconds per 60 degrees rotation (at 4.8V) and 0.10 seconds per 60 degrees rotation (at 6V). This makes it well-suited for applications that require precise and quick movements.
- Affordable: The EMAX08ma II servo motor is relatively affordable, making it a popular choice among hobbyists and students who are on a tight budget.

SPECIFICATIONS

specifications of the ES08MAII servo motor:

Dimensions: 32mm x 11.5mm x 24mm

Weight: Approximately 9 grams

Operating Voltage: 4.8V - 6.0V

Stall Torque: 1.5 kg/cm (at 4.8V), 1.8 kg/cm (at 6.0V)

Speed: 0.12 sec/60° (at 4.8V), 0.10 sec/60° (at 6.0V)

Operating Angle: 180°

Gear Type: Plastic

Motor Type: Coreless

Connector Type: JR style, 3-pin servo connector

CONNECTIONS

how to connect a servo motor to an Arduino board:

1. Gather the Components: You will need the following components:
    - Arduino board (e.g., Arduino Uno)
    - Servo motor (e.g., Emax ES08MA II)
    - Jumper wires
2. Power the Servo Motor: Connect the servo motor's power and ground wires to the Arduino board:
    - Connect the servo motor's red wire to the 5V pin on the Arduino board.
    - Connect the servo motor's black or brown wire to the GND (ground) pin on the Arduino board.
3. Connect the Control Signal Wire: The control wire will determine the position of the servo motor shaft. Connect it as follows:
    - Connect the servo motor's control wire (usually orange or yellow) to a digital pin on the Arduino board. For example, connect it to digital pin 9.

4. Upload the Arduino Sketch: Write a program (sketch) to control the servo motor. Here is a simple example that moves the servo motor back and forth:

#include <Servo.h> Servo servoMotor; // Create a Servo object void setup() { servoMotor.attach(9); // Attach the servo to digital pin 9 } void loop() { servoMotor.write(0); // Move the servo to 0 degrees delay(1000); // Wait for 1 second servoMotor.write(180); // Move the servo to 180 degrees delay(1000); // Wait for 1 second }

5. Upload the Sketch: Connect your Arduino board to your computer using a USB cable. Open the Arduino IDE, copy the sketch into a new sketch file, and click the "Upload" button to upload the code to the Arduino board.

6. Verify the Operation: Once the code is uploaded, the servo motor should start moving back and forth between 0 and 180 degrees with a 1-second delay between movements.

3. Step Down Voltage Converter

A UBEC (Universal Battery Elimination Circuit) is an electronic device used in remote-controlled (RC) vehicles and other applications to regulate voltage and provide a stable power supply to the electronic components. It is commonly used in situations where the power source voltage needs to be converted or regulated to a lower, consistent voltage level.

Figure 24: UBEC 5V 5A [14]

FEATURES:

- Voltage Regulation: The primary function of a UBEC is to regulate the voltage supplied to the electronic components. It takes a higher input voltage, typically from a battery pack or power source, and converts it to a lower, more consistent voltage suitable for powering the receiver, servos, and other electronic devices in an RC system. Common output voltages for UBECs are 5V and 6V, although other options may be available.
- Stability and Efficiency: UBECs are designed to provide a stable and constant output voltage regardless of changes in the input voltage or load conditions. They often incorporate advanced circuitry, such as switching regulators or linear voltage regulators, to achieve high efficiency and minimize power loss.
- Current Rating: UBECs come with different current ratings, indicating the maximum amount of current they can supply to the connected devices. It is important to select a UBEC with an appropriate current rating that matches the power requirements of the electronic components in your application.

- Input and Output Connections: UBECs typically feature input and output connections for easy integration into an RC system. The input side is connected to the power source, such as a battery pack, while the output side is connected to the electronic components, such as the receiver and servos. The input voltage range and connector types may vary depending on the specific UBEC model.
- Overcurrent and Overheat Protection: Many UBECs incorporate built-in protection mechanisms to prevent damage from overcurrent or overheating. These protections help ensure the safety and longevity of the connected components and the UBEC itself.

- Application Flexibility: UBECs are widely used in RC vehicles, drones, robotic systems, and other applications where a stable and regulated power supply is required. They offer a convenient and efficient solution for powering electronic components and avoiding potential voltage fluctuations that could affect their performance.

- SPECIFICATIONS

The UBEC (Universal Battery Elimination Circuit) is a device commonly used in radio-controlled (RC) models and other electronic applications to regulate the voltage from a battery source to a lower voltage suitable for powering various components. While there are different models of UBECs available on the market, I can provide you with the general specifications of a typical UBEC rated at 5V and 5A:

Output Voltage: 5V - This UBEC is designed to provide a stable output voltage of 5 volts.

Output Current: 5A - It can deliver a maximum continuous output current of 5 amps.

Input Voltage: Varies - UBECs can typically handle a wide range of input voltages, depending on the specific model. Common input voltage ranges for UBECs are around 6V to 25V, allowing them to be compatible with different types of batteries used in RC models.

Efficiency: UBECs are generally designed to be highly efficient, with efficiencies often exceeding 90%.

Protection Features: UBECs may include built-in protection features such as over-current protection, over-temperature protection, and short-circuit protection, which help safeguard the connected devices and the UBEC itself.

Output Connector: UBECs typically have output connectors compatible with standard connectors like JST, XT60, or Deans.

Size and Weight: The physical dimensions and weight of a UBEC can vary depending on the model, but they are generally compact and lightweight for ease of installation and use.

CONNECTIONS

To connect a UBEC (Universal Battery Elimination Circuit) to an Arduino, we need to follow these steps:

- Identify the input and output connectors of the UBEC. The input side is where you connect the power source (battery), and the output side is where you get the regulated voltage (5V) for your Arduino.

- Connect the battery or power source to the input side of the UBEC. Make sure to observe the correct polarity (positive and negative connections) to avoid damaging the UBEC or the battery.
- Connect the output side of the UBEC to the Arduino. The UBEC's output voltage should be connected to the Arduino's 5V pin. Use jumper wires to make the connections. Connect the positive (red) wire from the UBEC to the Arduino's 5V pin, and connect the negative (black) wire from the UBEC to the Arduino's GND (ground) pin.

UBEC (Output +) -> Arduino (5V pin)

UBEC (Output -) -> Arduino (GND pin)

Ensure that all connections are secure and well-insulated to prevent any accidental short circuits or loose connections.

- Finally, you can power up the battery or power source connected to the UBEC. The UBEC will regulate the voltage and supply a stable 5V output to the Arduino, which can power your Arduino board and connected components.

WHY UBEC?

Using a UBEC (Universal Battery Elimination Circuit) in a hexapod or any robotic project can provide several benefits:
Voltage Regulation: A UBEC can regulate the voltage from a battery source to a stable and consistent 5V output. This is important because many electronic components, such as microcontrollers like Arduino, operate at 5V or have specific voltage requirements. By using a UBEC, you ensure that your components receive the correct voltage, preventing damage or erratic behavior caused by fluctuations in the power supply.

Power Distribution: A hexapod robot typically consists of multiple components such as motors, sensors, and controllers, all requiring power. Using a UBEC allows you to efficiently distribute power to these components. The UBEC can provide a separate, regulated 5V power supply for the control circuitry, while other components that require higher voltages can be powered separately.

Compatibility with Different Power Sources: UBECs are designed to be compatible with various types of battery sources commonly used in robotic projects, such as lithium-ion batteries or LiPo (Lithium Polymer) batteries. They can handle a wide input voltage range, allowing you to use different battery configurations and capacities.

Efficiency: UBECs are typically designed to be highly efficient, converting the input voltage to the desired output voltage with minimal energy loss. This ensures that the power from the battery is utilized efficiently, maximizing the runtime of your hexapod robot.

Protection Features: Many UBECs come with built-in protection features, such as over-current protection, over-temperature protection, and short-circuit protection. These features help safeguard your components and the UBEC itself from potential damage due to voltage spikes, excessive current, or other electrical issues.

3. **Perception Module**

Figure 25: ESP CAM [15]

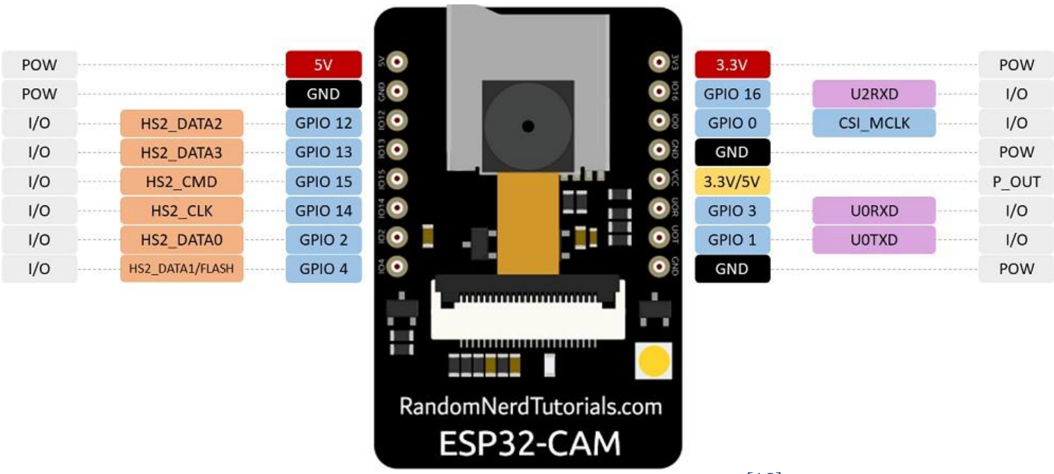


Figure 26: ESP 32 CAM Pinout [16]

The ESP32-CAM is a small-sized development board that combines an ESP32 module and a camera module, making it capable of capturing images, streaming video, and performing other image-related tasks. It is widely used for various Internet of Things (IoT) and surveillance applications. Here's some information about the ESP32-CAM:

1. ESP32 Module: The ESP32-CAM is built around the ESP32 microcontroller, which is a powerful Wi-Fi and Bluetooth-enabled system-on-a-chip (SoC). The ESP32

provides dual-core processing, ample memory, and extensive peripheral support, making it suitable for a wide range of IoT applications.

2. Camera Module: The ESP32-CAM features an OV2640 camera module that supports image resolutions of up to 2 megapixels (1600x1200 pixels). It can capture JPEG images and stream video at varying frame rates, depending on the resolution and configuration.
3. Connectivity: The ESP32-CAM has built-in Wi-Fi and Bluetooth connectivity. This allows it to communicate with other devices, connect to the internet, and interact with cloud services. It supports the popular TCP/IP protocols and can function as a client or access point (AP).
4. GPIO Pins: The development board provides GPIO (General Purpose Input/Output) pins that allow for easy interfacing with external components, sensors, and actuators. These pins can be used to control LEDs, relays, and other devices.
5. Storage Options: The ESP32-CAM has onboard flash memory for storing program code and other data. It also supports external microSD cards for additional storage capacity, which can be useful for saving images or recording video footage.
6. Programming: The ESP32-CAM can be programmed using the Arduino IDE (Integrated Development Environment) or other compatible programming environments. Arduino libraries and examples are available to facilitate development and ease the integration of the camera functionality.
7. Power Supply: The board requires a 5V power supply, which can be provided through a micro-USB connector or directly via the VIN pin. It also has a regulated 3.3V output pin that can be used to power external components.
8. Applications: The ESP32-CAM is well-suited for a wide range of applications, including surveillance systems, home automation, robotics, image recognition, remote monitoring, and more. Its compact size and integrated camera make it convenient for projects that require image capture or streaming capabilities.

SPECIFICATIONS

The ESP32-CAM is a popular development board that combines an ESP32 microcontroller with a camera module, allowing for the development of IoT projects with image and video capabilities. Here are the specifications of the ESP32-CAM:

Microcontroller: ESP32-D0WDQ6 - Dual-core 32-bit Tensilica LX6 microprocessor running at 240 MHz.

Wi-Fi: 802.11 b/g/n 2.4 GHz Wi-Fi with support for WPA/WPA2/WPA2-Enterprise/WPS encryption.

Bluetooth: Bluetooth v4.2 BR/EDR and BLE (Bluetooth Low Energy) support.

Memory: 4 MB Flash memory for program storage.

Camera: OV2640 - 2 MP (1600x1200 pixels) CMOS image sensor module with anintegrated lens.

Operating Voltage: 5V (can be powered through the USB port or an external power supply).

Digital I/O Pins: 10 GPIO pins that support UART, SPI, I2C, PWM, and other digital communication protocols.

Analog Input Pins: 1 x 12-bit ADC channel.

UART: 3 UART interfaces for serial communication.

SPI: 1 SPI interface.

I2C: 1 I2C interface.

Programming: Can be programmed using the Arduino IDE or using ESP-IDF (Espressif IoT Development Framework).

USB: Micro USB port for power supply and programming.

Additional Features: Built-in LED indicators, reset button, and boot button.

Dimensions: The board measures approximately 40mm x 27mm.

CONNECTIONS

To connect an ESP32-CAM module with an Arduino, we need to follow these steps:

- Power Supply: The ESP32-CAM requires a stable 5V power supply. Connect a 5V power source, such as a USB cable or an external power supply, to the ESP32-CAM board.

- Serial Communication:

a. Connect the TX pin of the ESP32-CAM (usually GPIO1) to the RX pin of the Arduino.

b. Connect the RX pin of the ESP32-CAM (usually GPIO3) to the TX pin of the Arduino.

c. Connect the GND (ground) pins of both the ESP32-CAM and Arduino together.

- GPIO0 Connection: Connect the GPIO0 pin of the ESP32-CAM to the GND pin temporarily. This step is necessary to put the ESP32-CAM into programming mode.

- Reset Connection: Connect the RST (reset) pin of the ESP32-CAM to a digital pin on the Arduino. This connection allows the Arduino to control the reset function of the ESP32-CAM.

- GPIO Pins:

a. If you need to use other GPIO pins on the ESP32-CAM, connect them to the desired digital pins on the Arduino.

b. Ensure that the voltage levels of the ESP32-CAM and Arduino are compatible (e.g., 3.3V for ESP32-CAM and 5V for Arduino). You may need to use voltage level shifters or voltage dividers to ensure proper communication.

- Upload Firmware:

a. Remove the connection between GPIO0 and GND on the ESP32-CAM.

b. Connect the Arduino to your computer via USB.

c. Upload the appropriate firmware or sketch to the ESP32-CAM using the Arduino IDE or ESP-IDF.

4. Wireless Communication and Control Module

The ESP32 is a powerful and versatile system-on-a-chip (SoC) microcontroller module developed by Espressif Systems. It is widely used in various Internet of Things (IoT) projects and applications due to its rich feature set.

Figure 27: ESP32 [17]

1. Dual-Core Processor: The ESP32 features a dual-core Xtensa LX6 processor with clock speeds up to 240 MHz. Having two cores allows for multitasking and efficient handling of multiple tasks simultaneously.
2. Wireless Connectivity: One of the key features of the ESP32 is its built-in Wi-Fi and Bluetooth connectivity. It supports Wi-Fi 802.11 b/g/n and Bluetooth 4.2/BLE, enabling easy integration with wireless networks and communication with other devices.
3. Memory: The ESP32 provides ample memory for data storage and program execution. It typically comes with 520 KB of SRAM (Static Random Access Memory) and up to 4 MB of Flash memory for program storage. This memory can be expanded using external SPI Flash or PSRAM (Pseudo Static Random Access Memory) if needed.
4. GPIO Pins: The ESP32 offers a significant number of GPIO (General Purpose Input/Output) pins, which can be used to interface with various sensors, actuators, and external devices. These pins support multiple functions, such as digital input/output, analog input, PWM (Pulse Width Modulation), and more.

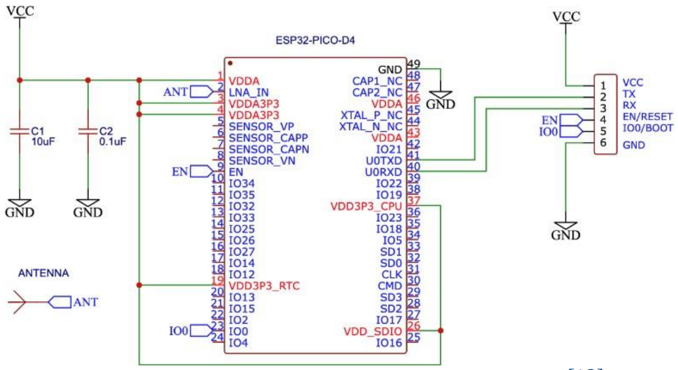


Figure 28: ESP32 Circuit Diagram [18]

5. Peripherals: The ESP32 includes a wide range of peripherals and interfaces to support different application requirements. These include UART (Universal Asynchronous Receiver/Transmitter), SPI (Serial Peripheral Interface), I2C (Inter-Integrated Circuit), I2S (Inter-IC Sound), ADC (Analog-to-Digital Converter), DAC (Digital-to-Analog Converter), and more.

6. Energy Efficiency: The ESP32 is designed to operate with low power consumption, making it suitable for battery-powered or energy-efficient applications. It offers multiple power modes, sleep modes, and features like powermanagement units to optimize power usage.

7. Development Ecosystem: The ESP32 is well-supported by a vast development ecosystem. It can be programmed using various programming frameworks and IDEs, including the Arduino IDE, Espressif's ESP-IDF (IoT Development Framework), MicroPython, and others. It also benefits from a wide range of libraries and community support.

8. Applications: The ESP32 is suitable for a wide range of IoT applications, including home automation, smart devices, industrial monitoring and control, wearable devices, robotics, wireless sensor networks, and more. Its versatility and connectivity options make it a popular choice among developers.

SPECIFICATIONS

the specifications of the ESP32 module:

- Microcontroller: Xtensa dual-core 32-bit LX6 microprocessor running at up to 240 MHz.

- Wi-Fi: 802.11 b/g/n 2.4 GHz Wi-Fi with support for WPA/WPA2/WPA2-Enterprise/WPS encryption.
- Bluetooth: Bluetooth v4.2 BR/EDR and BLE (Bluetooth Low Energy) support.
- Memory:

520 KB SRAM (Static Random-Access Memory)

4 MB Flash memory for program storage (can be expanded externally using SPI flash).

- Operating Voltage: 2.2V to 3.6V.
- Digital I/O Pins: Numerous GPIO (General-Purpose Input/Output) pins available for digital input/output, including support for UART, SPI, I2C, PWM, etc.
- Analog Input Pins: 12-bit SAR (Successive Approximation Register) ADC with up to 18 channels.
- UART: Up to 3 UART interfaces for serial communication.
- SPI: Up to 4 SPI (Serial Peripheral Interface) interfaces.
- I2C: Up to 2 I2C (Inter-Integrated Circuit) interfaces.
- CAN: 2 Controller Area Network (CAN) interfaces.
- Ethernet: 10/100 Ethernet MAC interface with dedicated DMA (Direct Memory Access) controller.
- USB: USB 2.0 full-speed Host/Device interface with dedicated DMA controller.
- Operating Temperature: -40°C to +85°C.
- Additional Features: Built-in RTC (Real-Time Clock), cryptographic hardware acceleration, touch sensor inputs, temperature sensor, hall sensor, etc.

CONNECTIONS

To connect an ESP32 module with an Arduino board, we need to follow these steps:

- Power Supply:

The Arduino board is typically powered through the USB port or an external power supply. Ensure that the Arduino is connected to a stable power source.

The ESP32 module requires a separate power supply. Connect a 3.3V power source (such as a voltage regulator or a 3.3V power pin on the Arduino) to the VCC and GND pins of the ESP32 module. Be careful not to connect the ESP32 directly to the 5V power supply of the Arduino, as it may damage the ESP32.

- Serial Communication:

Connect the TX pin of the Arduino to the RX pin of the ESP32 module.

Connect the RX pin of the Arduino to the TX pin of the ESP32 module.

Connect the GND (ground) pins of both the Arduino and the ESP32 module together.

- Reset Connection:

Connect the RST (reset) pin of the ESP32 module to a digital pin on the Arduino. This connection allows the Arduino to control the reset function of the ESP32 module.

- GPIO Pins:

If you need to use specific GPIO pins on the ESP32 module, connect them to the desired digital pins on the Arduino. Ensure that the voltage levels are compatible (3.3V for the ESP32 and 5V for the Arduino). You may need to use voltage level shifters or voltage dividers to ensure proper communication.

- Programming:

The ESP32 can be programmed using the Arduino IDE or the Espressif IoT Development Framework (ESP-IDF). Install the necessary libraries and board definitions for the ESP32 in the Arduino IDE.

Write your code using the Arduino programming language and upload it to the Arduino board. Make sure to select the correct board and serial port in the Arduino IDE.

When using the ESP32 module, you can communicate with it from the Arduino board using serial commands or protocols such as UART, SPI, or I2C.

WHY ESP32?

We used ESP32 in our hexapod because of the following reasons:

- Processing Power: The ESP32 module features a powerful dual-core processor running at up to 240 MHz. This processing power enables the ESP32 to handle complex calculations and control multiple tasks simultaneously, making it suitable for controlling the movements and behavior of a hexapod robot.

- Wi-Fi and Bluetooth Connectivity: The ESP32 has built-in Wi-Fi and Bluetooth capabilities, allowing for wireless communication and control of the hexapod. With Wi-Fi, you can connect the hexapod to a network, enabling remote control, monitoring, or integration with other devices and systems. Bluetooth connectivity offers the possibility of controlling the hexapod using a smartphone or other Bluetooth-enabled devices.

- GPIO Pins and Peripheral Interfaces: The ESP32 module provides numerous GPIO pins and various peripheral interfaces, such as UART, SPI, and I2C. These interfaces allow for the connection of sensors, actuators, and other external components that are crucial for the operation of a hexapod. The GPIO pins can be used to control servos, read sensor inputs, or communicate with other microcontrollers or devices.

- Extensive Software Ecosystem: The ESP32 has a large and active community of developers, resulting in a wide range of libraries, examples, and resources available for programming and controlling the module. The ESP32 can be programmed using the Arduino IDE, which is beginner-friendly and widely supported, making it easier for hobbyists and developers to get started with their hexapod projects.

- Cost-Effectiveness: The ESP32 module offers a good balance of features, performance, and cost. It provides a cost-effective solution for implementing advanced functionalities in a hexapod robot while offering competitive performance compared to other microcontrollers.

6. Power

Figure 29: MURATA (SONY) US18650VTC6 3000mAh (7c) LI-ION BATTERY – 2 [19]

The MURATA (SONY) US18650VTC6 is a high-quality lithium-ion battery known for its reliable performance and capacity. Here is some information about the MURATA US18650VTC6 battery:

1. Chemistry: The MURATA US18650VTC6 battery utilizes lithium-ion (Li-ion) chemistry, which provides a high energy density and excellent cycle life. Li-ion batteries are widely used in portable electronic devices due to their favorable energy-to-weight ratio.
2. Capacity: The US18650VTC6 battery has a capacity of 3000mAh (milliampere-hours), which indicates the amount of charge the battery can hold. A higher capacity means the battery can power devices for a longer duration before requiring recharging.
3. Voltage: The nominal voltage of the US18650VTC6 battery is 3.6 volts, with a maximum voltage of 4.2 volts when fully charged. It is important to consider the voltage requirements of the devices you intend to power with this battery.
4. Discharge Rate: The US18650VTC6 battery has a discharge rate of 7C, which means it can provide a continuous discharge current of up to 7 times its capacity. This high discharge rate makes it suitable for applications that require a significant amount of power.

5. Protection Circuit: The US18650VTC6 battery may come equipped with a protection circuit that helps prevent overcharging, over-discharging, and short circuits. This circuitry ensures the safety and longevity of the battery, as well as the devices it powers.
6. Applications: The US18650VTC6 battery is commonly used in various devices, including but not limited to:
    - Portable electronic devices such as laptops, power banks, and digital cameras.
    - Electric vehicles (EVs) and hybrid electric vehicles (HEVs) for energy storage.
    - Flashlights and other lighting devices that require a high-capacity and high-discharge battery.
    - Robotics and drones that need reliable and long-lasting power sources.
    -

SPECIFICATIONS

the specifications of the Sony VTC6 18650 Li-ion 3000mAh battery:

Model: Sony VTC6

Battery Type: Li-ion (Lithium-ion)

Nominal Voltage: 3.6V

Maximum Voltage: 4.2V

Capacity: 3000mAh (3Ah)

Chemistry: Lithium Manganese Nickel (Li-Mn-Ni)

Maximum Continuous Discharge Current: 15A

Maximum Pulse Discharge Current: 30A Diameter:

18mm

Length: 65mm

Weight: Approximately 47 grams

WHY SONY VTC6 18650 LI-ION 3000mAh BATTERY?

Using the Sony VTC6 18650 Li-ion 3000mAh battery in our hexapod offers several advantages:

- High Capacity: The Sony VTC6 battery has a capacity of 3000mAh, which means it can provide a substantial amount of power for your hexapod robot. Higher capacity batteries can typically run your robot for a longer duration before requiring recharging.

- Rechargeable: The Sony VTC6 battery is rechargeable, allowing you to reuse it multiple times. This makes it a cost-effective choice in the long run compared to non-rechargeable batteries.

- Compact Size: The 18650-form factor of the Sony VTC6 battery is widely used in many devices, including hexapods. It has a compact size that fits well in space-limited environments and can be easily integrated into your robot's design.

- High Discharge Current: The Sony VTC6 battery has a maximum continuous discharge current of 15A and a maximum pulse discharge current of 30A. This high discharge current capability is essential for powering motors, servos, and other high-current components in a hexapod robot. It ensures that the battery can deliver sufficient power without experiencing voltage drops or overheating.

- Well-Known Brand and Quality: Sony is a reputable brand known for manufacturing high-quality batteries. The Sony VTC6 is widely regarded as a reliable and safe option for various applications, including robotics. Choosing a trusted brand helps ensure the safety and reliability of your hexapod's power supply.

- Compatibility: The 18650-battery form factor is a standard size used in many electronic devices. This compatibility makes it easier to find battery holders, charging solutions, and other accessories specifically designed for 18650 batteries.

7. Battery Holder

Figure 30: 18650 Dual SMD/SMT High-Quality Single Battery Holder [20]

The 18650 Dual SMD/SMT High-Quality Single Battery Holder is a component used for securely holding and connecting two 18650 lithium-ion batteries in electronic circuits. Here is some information about this battery holder:

1. Battery Compatibility: The 18650 Dual SMD/SMT battery holder is specifically designed for use with 18650 lithium-ion batteries. These batteries are widely used in many portable electronic devices due to their high energy density and long operating times.
2. Dual Battery Configuration: This battery holder is designed to accommodate two 18650 batteries, allowing them to be connected in parallel or series depending on the circuit requirements. The parallel configuration provides increased capacity, while the series configuration provides increased voltage.

3. SMD/SMT Design: The battery holder features a surface mount device (SMD) or surface mount technology (SMT) design. This means that it is intended for direct mounting onto a printed circuit board (PCB) using soldering techniques, offering a compact and space-saving solution for battery integration.
4. High-Quality Construction: The 18650 Dual SMD/SMT battery holder is constructed using high-quality materials to ensure durability and reliable electrical connections. It typically features metal contacts or spring-loaded terminals that securely hold the batteries and maintain good electrical contact.
5. Connection Terminals: The battery holder provides connection terminals for easy integration into the circuitry. These terminals are designed to facilitate the soldering of wires or other components to establish the necessary electrical connections between the batteries and the rest of the circuit.
6. Application: The 18650 Dual SMD/SMT battery holder finds applications in various electronic devices and projects, such as portable power banks, battery-operated gadgets, electronic toys, medical devices, and other battery-powered systems. It provides a convenient and secure solution for incorporating multiple 18650 batteries into the circuit design.

SPECIFICATIONS

The specifications of 18650 Dual High-Quality Single Battery Holder are:-

Contact Material: Stainless Steel

Plating of Contact Point: Gold

Body Material: ABS

No. of Cells: 2

Colour: Black

Mounting Type: SMD

Operating Temperature Range: -40 to 180 degrees Celsius

Shipment Weight: 0.02 Kg

Width: 40mm

Height: 15mm

Length: 78mm

Weight: 18 gm

d) Software

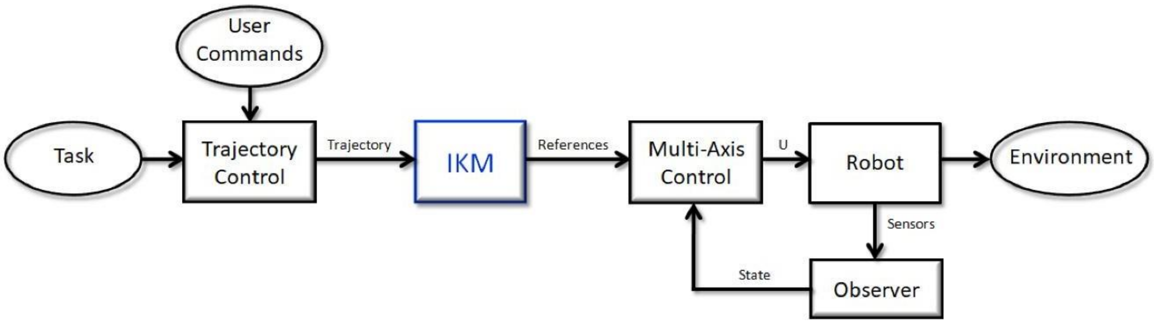
ii) Robot Kinematics Algorithm

1. User Commands: A web interface is used to send user commands to the robot. The commands include:

- Gaits
- Calibrate
- Walk
- Demo

2. Trajectory Control: and IKM Model: Based on the inputs received, IKM model for the robot is calculated and Multi-Axis Control is implemented. The different gaits such as Ripple, Tripod, Wave and Tetrapod require the joints to be at different angles.
   The definitions of these gaits are mentioned below:

   - Tripod: a group of 3 legs moves forward while the other 3 legs provide support
   - Wave: legs move forward one at a time while the other 5 legs provide support
   - Ripple: left legs move forward rear-to-front while right also do the same, but right side is offset so the right rear starts midway through the left middle stroke
   - Tetrapod: right front and left rear legs move forward together, then right rear and left middle, and finally right middle and left front legs move



3. Environment and Observer: The robot based on the commands received and trajectory calculated, then moves around in the environment and the observer makes note of the integrated platform responds to user commands. After making notes, certain improvements and calibrations are made in the sensors and robot architecture.

ii) Servo Test Code

The servo test code is the initial step of selecting the appropriate servo for the given application. This is a part of the software that was required for this project. The following code is divided into:

4. Installation and inclusion of certain libraries
5. Defining constants and variables
6. Setting up the interfaced sensors
7. Individual functions for carrying out tasks assigned to each sensor
8. Creating a loop of Servo Test procedure to be followed

PROGRAM:

```
#include    <Servo.h>
#include       <SPI.h>
#include        <SD.h>
#include "HX711.h"

File  myfile  ;
Servo servo ;
HX711 scale;

const  int  LOADCELL_DT_PIN  =  4;
const int LOADCELL_SCK_PIN = 5;
const int chipSelect = 10 ;
float vtg ;
float CurrentVal ;
int AgVal ;
float       vtg1;
float Weight ;
//int StartTime ;
//int EndTime ;
```

```
void setup() {
 Serial.begin(9600);
 servo.attach(9);
 servo.write(0);
 scale.begin(LOADCELL_DT_PIN, LOADCELL_SCK_PIN);
 scale.set_scale(164.56);
 scale.tare();
 Serial.print("Initializing SD card...");
 if (!SD.begin(10)) {
 Serial.println("initialization failed!");
 return;
 }
 Serial.println("initialization done.");
}
void loop() {
 for(int i=0; i<=360; i+=10){
 //StartTime = millis(); //Process start time
 servo.write(i);
 Serial.print("Servo Position: ");
 Serial.print(i);
 AgVal = analogRead(A0);
 CurrentVal = MeasureCurrent(AgVal);
 Serial.print(" | Current: ");
 Serial.print(CurrentVal); //current = current + (.0264 * analogRead(A0) -13.51) / 1000;//this is for the 5A mode, if 20A or 30A mode, need to modify this formula to(.19 * analogRead(A0) -25) for 20A mode and(.044 * analogRead(A0) -3.78) for 30A mode
 Serial.print(" A");
// if(CurrentVal>7.0){
//   break;
// }
```

```
 Weight  =  scale.get_units(10),  5  ;
 Serial.print(" | LoadCell Reading: ");
 Serial.print(Weight);
 Serial.println(" g");
 //EndTime = millis(); //Process End Time
 LogData(i,   CurrentVal,   abs(Weight));
 delay(5);
}
for(int i=360; i>=0; i-=10){
 //StartTime       =       millis();
 servo.write(i);
 Serial.print("Servo Position: ");
 Serial.print(i);

 AgVal = analogRead(A0);
 CurrentVal = MeasureCurrent(AgVal);
 Serial.print(" | Current: ");
 Serial.print(CurrentVal); //current = current + (.0264 * analogRead(A0) -13.51) / 1000;//this is for the 5A mode, if 20A or 30A mode, need to modify this formula to(.19 * analogRead(A0) -25) for 20A mode and(.044 * analogRead(A0) -3.78) for 30A mode/
 Serial.print(" A");
// if(CurrentVal>7.0){
//   break;
// }
 Weight  =  scale.get_units(10),  5  ;
 Serial.print(" | LoadCell Reading: ");
 Serial.print(Weight);
 Serial.println(" g");
 //EndTime = millis();

 LogData(i, CurrentVal, abs(Weight));
```

```
  delay(5);
 }
}
float MeasureCurrent(int input){
    float avg;
    vtg = input*4.887 ; //in mV
    vtg1 = vtg/1000;
    //Serial.print(vtg1);
    avg = abs((vtg1 - 2.5)/0.185);
    //Serial.println(avg);
    delay(1);
  return avg ;
}

void LogData(int pos, float current, float weight){
  myfile = SD.open("Test_2.txt", FILE_WRITE);
  if(myfile){
    myfile.print("Servo Position: ");
   myfile.print(pos);
    myfile.print("| Observed Current: ");
    myfile.print(current) ;
   // myfile.print(" A ");
    myfile.print("| Load Cell Reading: ");
    myfile.println(weight);
  }
  else {
    Serial.println("Error opening the file");
  }
  myfile.close();}
```

IV. Locomotion Analysis:

Locomotion of the robot is dependent on factors such as joint angles, link lengths, Robot geometry and coordinate system. In this chapter, we will define robot geometry such that we can conclude with its locomotion analysis. Inverse kinematics is a mathematical technique used to determine the joint angles required for a robotic system to achieve a desired end-effector position and orientation. In the case of a hexapod robot with 18 degrees of freedom (DOF), inverse kinematics can be used to calculate the joint angles necessary for the robot's legs to reach a specific position in space.

Steps For Inverse Kinematics:

- Define the Coordinate Systems: Establish a coordinate system for the robot's body and each leg. Typically, a Cartesian coordinate system is used to represent the position and orientation of the robot in space.

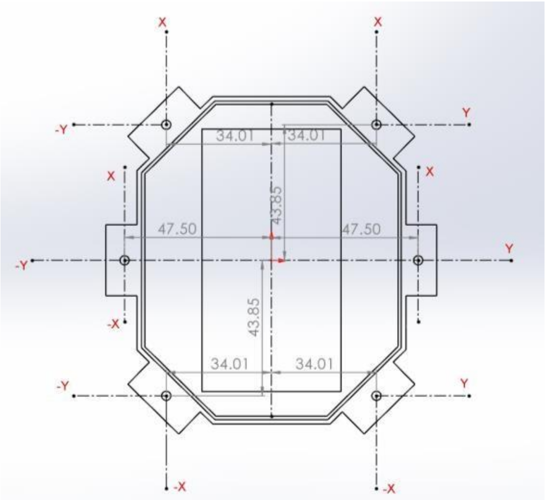


Figure 31: Distances between Centers

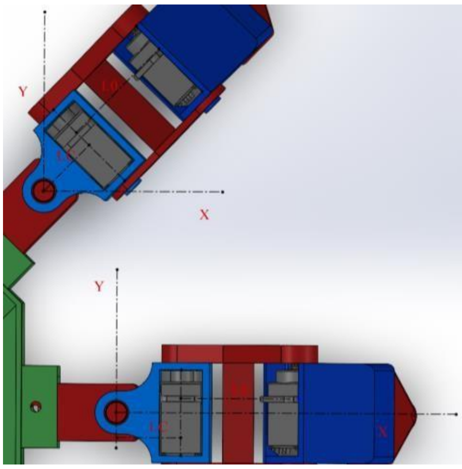


Figure 32: Top View of Robot Axis

- Determine Leg Geometry: Analyze the geometric arrangement of the hexapod's legs. This includes measuring the leg lengths and determining the location of the leg joints.

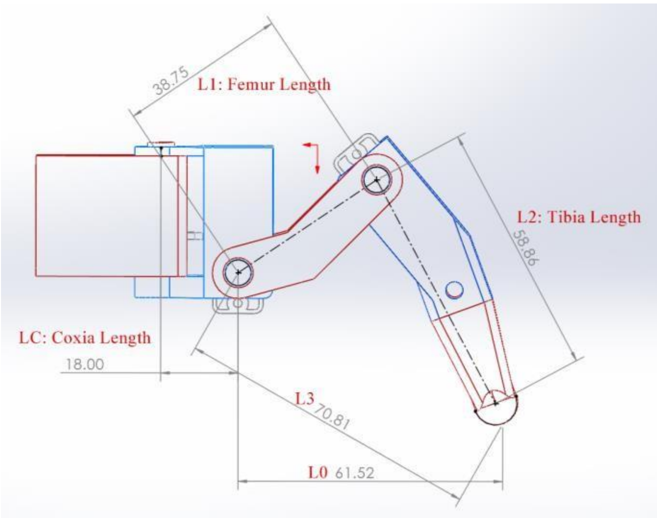
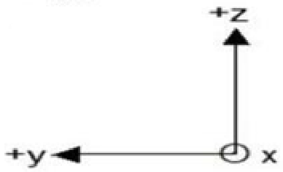


Figure 33: Length Constants of Leg

- Formulate the Forward Kinematics Equations: Develop the forward kinematics equations that relate the joint angles to the position and orientation of the end effector (foot) of each leg. These equations describe how the robot's legs move based on the jointangles.

- Invert the Forward Kinematics Equations: This step involves solving the forward kinematics equations for the joint angles. This can be a complex task and may requirenumerical methods such as the Newton-Raphson method or optimization techniques.
- Solve for Joint Angles: Once the inverse kinematics equations are derived, you can plug in the desired end-effector position and orientation values to solve for the joint angles. This step requires solving a system of nonlinear equations, which can be doneusing numerical methods or analytical techniques such as the Jacobian inverse.

$$\emptyset t = \cos^{-1}\left(\frac{L1^2+L2^2-L3^2}{2 \cdot L1 \cdot L2}\right)$$
$$\emptyset f = \cos^{-1}\left(\frac{L1^2+L2^2-L3^2}{2 \cdot L1 \cdot L3}\right)$$
$$\gamma f = \tan^{-1}\left(\frac{Z}{L0}\right)$$
$$L0 = \sqrt{(X^2+Y^2) - LC}$$
$$L3 = \sqrt{(L0^2+Z^2)}$$
$$\theta f = \emptyset f + \gamma f + 14 + 90$$
$$\theta t = \emptyset t - 113 + 90 = \emptyset t - 23$$
$$\theta c = \tan^{-1}\left(\frac{Y}{X}\right) + 90$$



- Implementing Constraints: Consider any constraints or limitations on the hexapod's motion, such as joint limits or workspace restrictions. Ensure that the calculated joint angles satisfy these constraints.

V. Project Improvement and Progress

This chapter deals with comparison of Version I of Hextorq robot and its current version presented in the project in terms of size, weight, electronics etc.

The version-I of Hextorq robot has been designed by the company mainly for defence related applications. It is bulky in size which is what hinders its mobility. Furthermore, due to its heavy size, it cannot be used in places where size constraint is an important factor to consider. Miniature Hextorq, on the other hand, has a reduced size that helps achieve easy mobility and maneuver.

Figure 34: Hextorq by Technodune [21]

As far as the operation is considered, both robots have total of 18 degrees of freedom. Each of these 18 movements are achieved using 18 servo motors.

Version-I uses MG995 Servo Motor as an actuator, whereas Miniature version uses EMAX ES08 MA II Servo Motor.

The controller used in both robots is Mega2560 Pro ATMEGA2560-16AU USB CH340G Development Board.

Version-I consisted of a 12 V LiPo battery to power the entire robot. The battery itself weighed more and consumed a lot of space. Therefore, it was replaced with Li-Ion 2S battery pack.

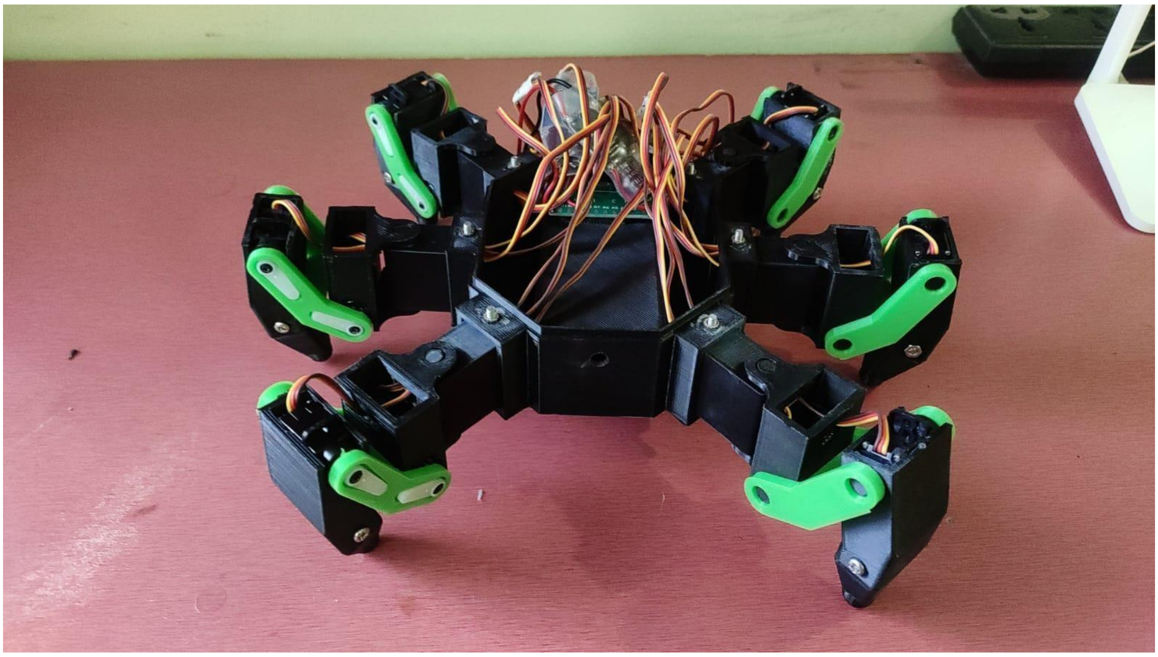


Figure 35: Miniature Hexapod (Project Version)

The scaling down of design was done using Solidworks 2018. There was about 40% - 60% reduction of the original version of robot. The aesthetics and fits were taken care of during the design process. Version-I of the robot weighed around 2.0 – 2.5 kg. The version presented through this project weighs around 0.6 – 0.7 kg. This significant reduction can play a vital role in the overall application of the robot.

VI. Experimentation and Results

Previous version of Hexapod had MG995 as the servo motor for joint motion. The problems faced with this motor were:

1. Longevity

2. Overheating

3. Torque Restrictions

To overcome the above problems and to ensure smoother operation of the robot, we tested few servos and rated them according to factors such as current draw, load handled, time duration of operation under various loads.

For the purpose of this test, we used the following components:

1. Load Cell (20 kg)
2. 5A Current Sensor
3. 7V Battery Unit
4. DC-DC Step Down Converter 3A 5V
5. SD Card Module and SD Card
6. Arduino Nano
7. TOWERPRO MG90S
8. TOWERPRO SG90S
9. EMAX ES08MA II

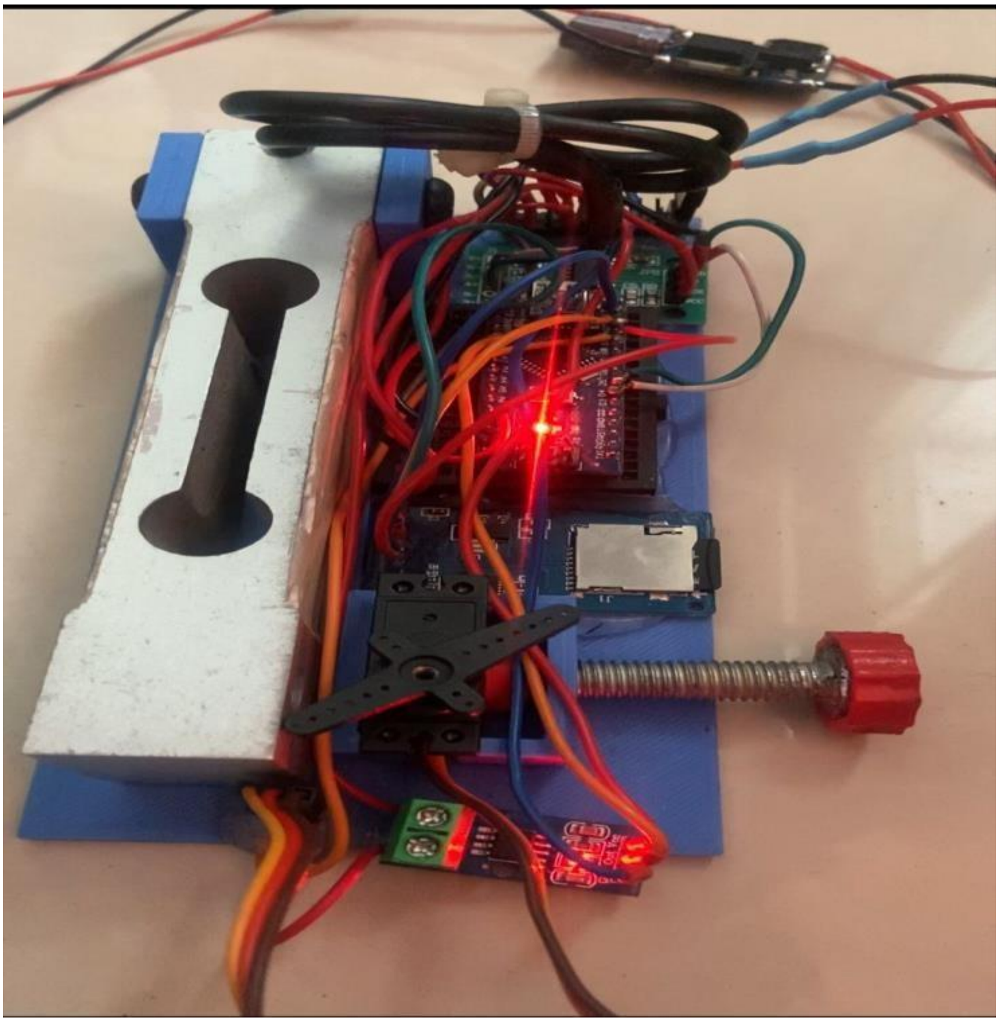
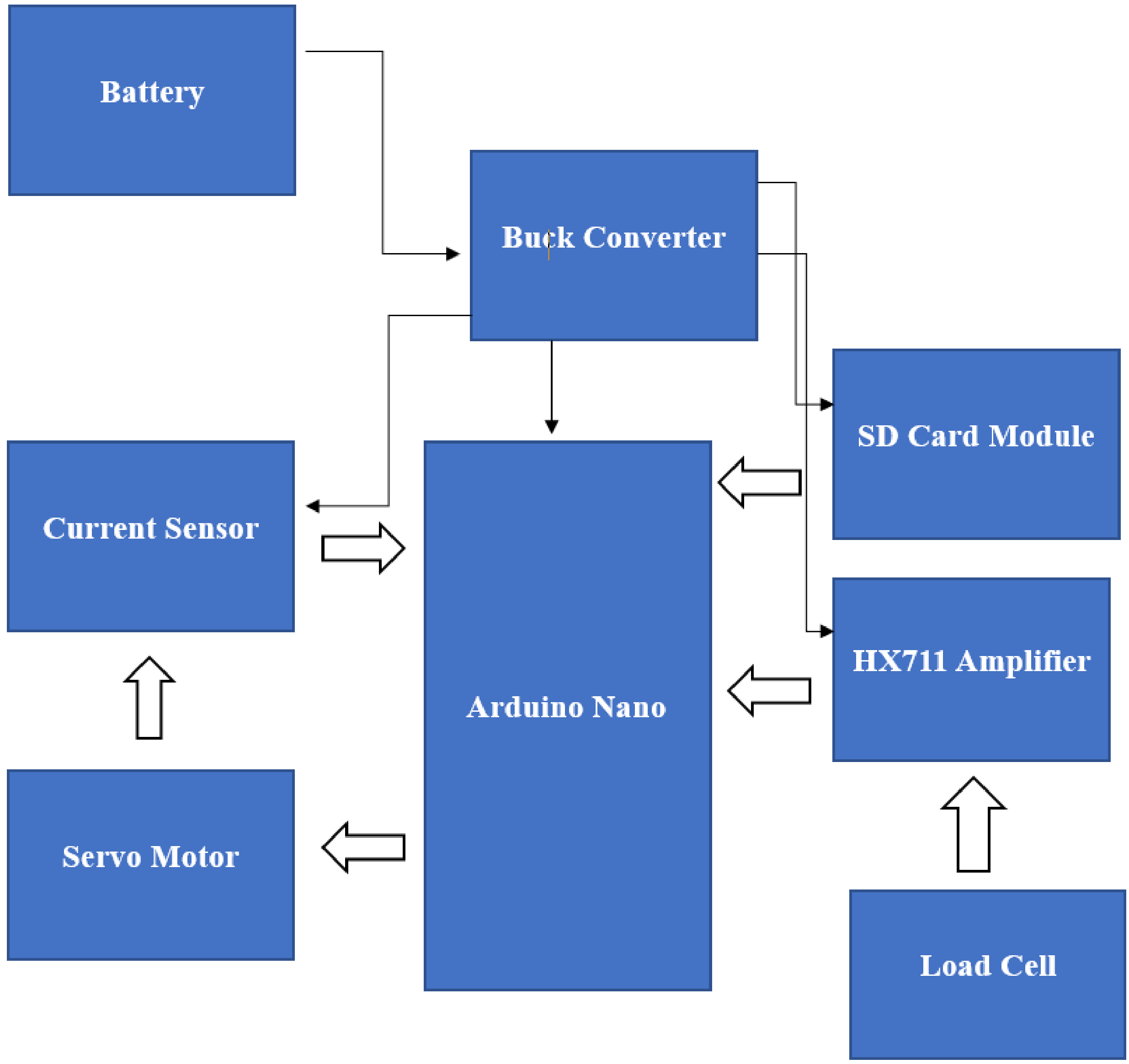


Figure 36: Servo Test Setup


Battery
Buck Converter
SD Card Module
Current Sensor
Arduino Nano
HX711 Amplifier
Servo Motor
Load Cell

Following are the test results:

1. Load Cell Reading: The amount of force on load cell applied by the servo horn.
2. Current: The amount of current drawn by Servo Motor during operation.
3. Servo Position: Angles of servo positions

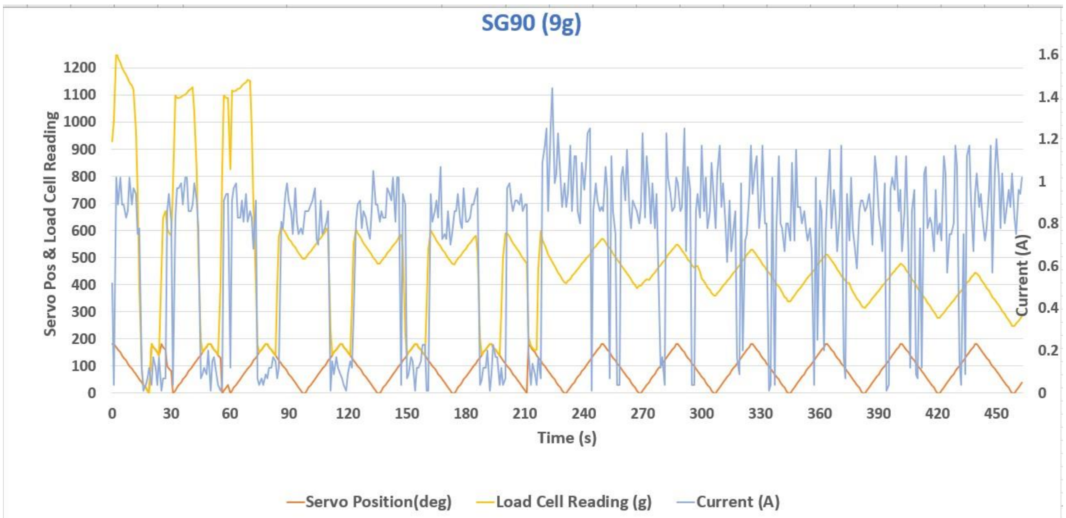


Figure 37: SG90 Readings

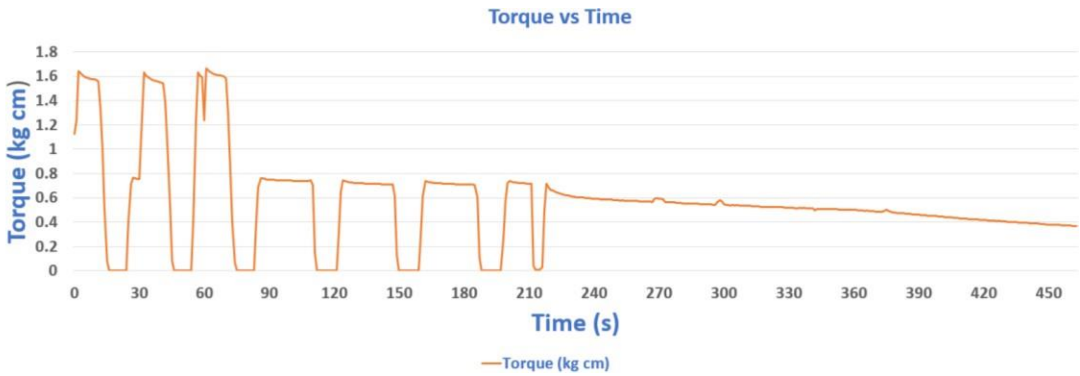


Figure 38: SG90 Torque vs Time

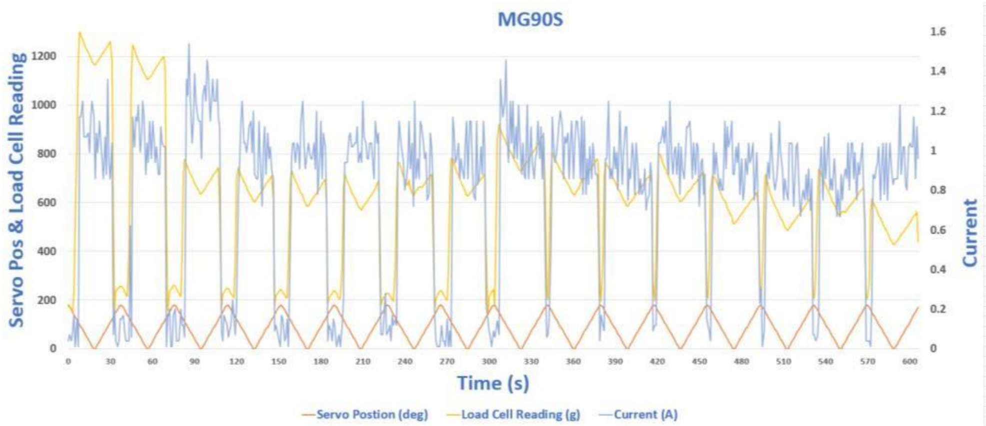


Figure 39: MG90S Test Readings

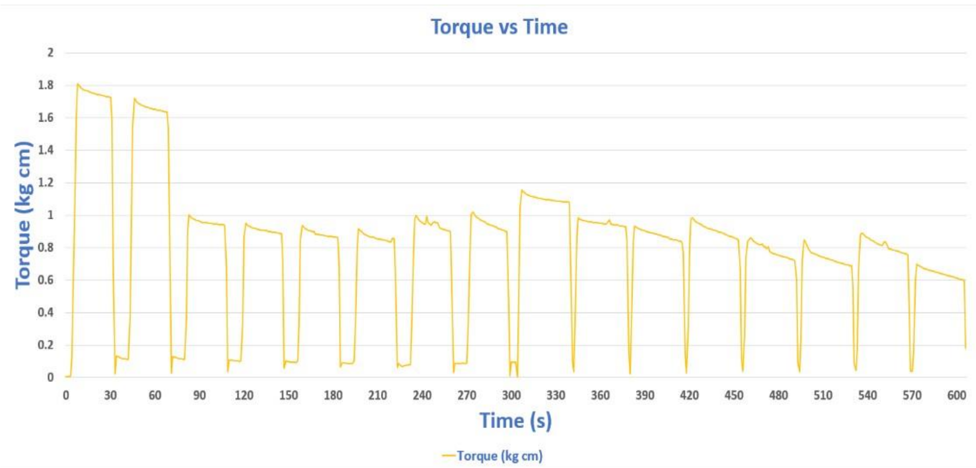


Figure 40: MG90S Torque vs Time

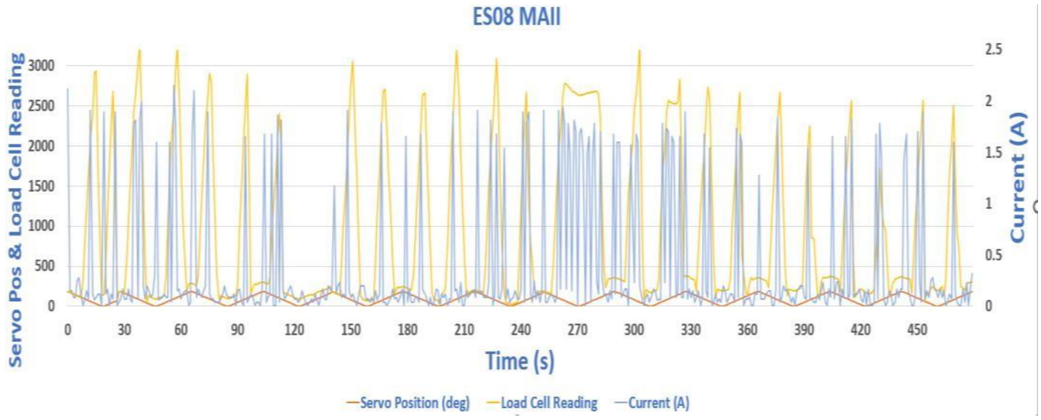


Figure 41: EMAX ES08MA II Test Readings

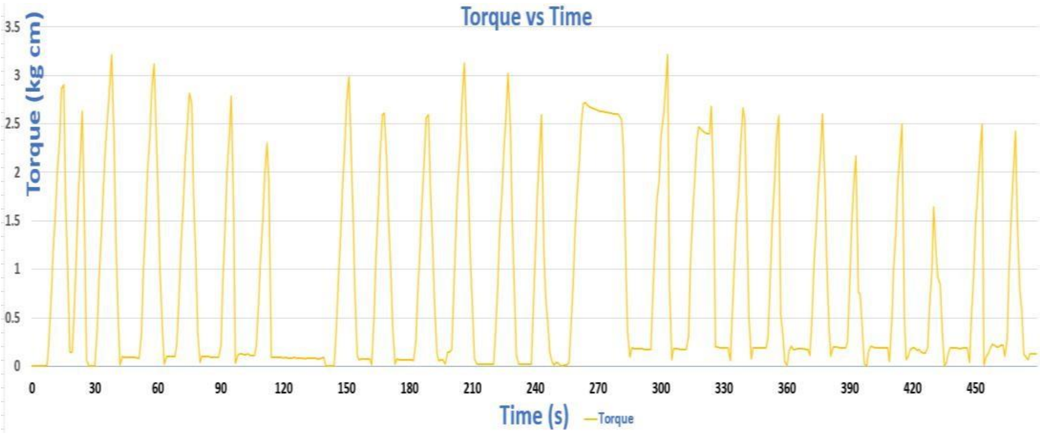


Figure 42: EMAX ES08MA II Torque vs Time

Results and Observations:

1. Current spikes during higher loads.

2. As the effectiveness of servo reduces, the amount of current it draws for an average amount of load increases. This leads to servo motor heating up and eventually causing a failure.

3. The amount of torque provided reduces as the servo approaches its failure stage.

4. EMAX ES08MA II showed the best performance and response to the test.

5. It was observed that SG90 showed a poor performance in terms of rated torque retention. Towards the end of operation, its torque dropped down to less than half of the rated torque.

6. The performance of MG90S was better compared to that of SG90, however, similar observation was made in torque readings of MG90S. The drop in rated torque wasn't significant but noticeable to an exten that the servo's performance was compromised.

7. EMAX ES08MA II showed constant readings of torque post stress-testing.

8. Hence, this proved that once the servos are exposed to high amounts of loads for long intervals, their response to the loads is crucial in detecting their durability.

Applications

The miniature hexapod robot is a versatile and compact robotic system that features six legs, enabling it to traverse various terrains and environments. This type of robot has numerous applications across different fields. Here are a few examples:

1. Surveillance and Inspection: Miniature hexapod robots can be used for surveillance and inspection tasks in areas that are difficult to access for humans. They can navigate through tight spaces, crawl over obstacles, and provide visual and audio data in real-time. These robots are particularly useful in scenarios such as search and rescue operations, monitoring hazardous environments, and inspecting infrastructure like pipelines or bridges.

2. Agriculture: Hexapod robots can play a crucial role in precision agriculture. They can be equipped with sensors and imaging systems to monitor crops, collect data on soil conditions, and detect pests or diseases. By analyzing this data, farmers can make informed decisions regarding irrigation, fertilization, and pest control, leading to optimized crop yields and reduced resource wastage.

3. Education and Research: Miniature hexapod robots serve as valuable tools for educational purposes and research in robotics. They provide a platform for students and researchers to explore locomotion principles, sensor integration, control algorithms, and programming. By experimenting with hexapod robots, individuals can gain hands-on experience and develop a better understanding of robotic systems.

4. Entertainment and Hobbies: Hexapod robots are often used in the entertainment industry and as personal projects for hobbyists. These robots can perform various movements, dance routines, or mimic animal behavior, providing entertainment value to audiences. Hobbyists can build and program their own miniature hexapod robots as a creative and challenging endeavor.

5. Industrial Applications: In industrial settings, miniature hexapod robots can be utilized for tasks such as assembly, manipulation, and material handling. Their small size and multi-legged design allow them to navigate within confined spaces

and perform precise movements. By integrating hexapod robots into manufacturing processes, efficiency can be improved, and repetitive tasks can be automated.

6. Medical and Healthcare: Hexapod robots have potential applications in the medical and healthcare domains. They can be used for tasks such as minimally invasive surgery, drug delivery, or patient assistance. The precise movements and maneuverability of hexapod robots can aid surgeons in performing delicate procedures with improved accuracy and reduced invasiveness.

7. Exploration and Mapping: Miniature hexapod robots can be employed in exploration missions, both on Earth and in outer space. These robots are capable of navigating challenging terrains, such as rocky surfaces or uneven landscapes, making them ideal for planetary exploration or mapping environments with limited accessibility. By equipping hexapod robots with cameras, sensors, and mapping tools, they can collect valuable data and create detailed maps of unknown areas.

8. Environmental Monitoring: Hexapod robots have the potential to contribute to environmental monitoring efforts. They can be deployed to gather data on air quality, water pollution, or the presence of hazardous substances in difficult-to-reach locations. With the integration of sensors, hexapod robots can collect samples, measure environmental parameters, and transmit the information in real-time,aiding in environmental conservation and management.

9. Swarm Robotics: Miniature hexapod robots can operate collectively as a swarm, working together to accomplish tasks that would be challenging or impossible for individual robots. Swarm robotics enables collaborative behaviors such as formation control, cooperative transportation, or distributed sensing. This approach finds applications in fields like disaster response, where a swarm of hexapod robots can collaborate to search for survivors in rubble or perform coordinated actions to mitigate the effects of natural disasters.

10. Education and Outreach: Miniature hexapod robots are valuable educational tools for introducing robotics and engineering concepts to students. They can be used in robotics workshops, science fairs, or educational programs to teach programming, mechanics, and control systems. The interactive nature of hexapod robots engages students and fosters their interest in STEM (Science, Technology, Engineering, and Mathematics) fields.

11. Industrial Inspection: Hexapod robots are well-suited for inspecting industrial equipment and infrastructure. They can navigate complex machinery and structures, identifying potential defects, faults, or maintenance requirements. By utilizing hexapod robots for inspection tasks, industries can enhance safety, reduce downtime, and optimize maintenance schedules.
12. Search and Rescue: The compact size and maneuverability of miniature hexapod robots make them valuable assets in search and rescue operations. They can enter confined spaces, crawl through debris, and explore disaster-stricken areas to locate survivors or assess the extent of damage. These robots can be equipped with cameras, sensors, or communication devices to gather information and relay it to rescue teams.

References

1. Warehouse robot by Amazon Robotics ; https://www.aboutamazon.com/news/tag/robotics.
2. Spot by Boston Dynamics for Field Operations; https://www.bostondynamics.com/products/spot
3. Several of Animal-Inspired Robots; https://www.israel21c.org/7-amazing-robots-based-on-animals/
4. PhantomX Hexapod MK-IV by Trossen Robotics; https://www.trossenrobotics.com/phantomx-hexapod-mk4.aspx
5. Chen, X., & Chen, Y. (2018). A modular hexapod robot for versatile locomotion. Robotics and Automation Letters, 3(4), 3312-3319. DOI: 10.1109/LRA.2018.2852232
6. Burkus, E., Fodor, J.C. and Odry, P., 2013, September. Structural and gait optimization of a hexapod robot with particle swarm optimization. In 2013 IEEE 11th International Symposium on Intelligent Systems and Informatics (SISY) (pp. 147-152). IEEE.
7. Schilling, M., Konen, K., Ohl, F.W. and Korthals, T., 2020. Decentralized deep reinforcement learning for a distributed and adaptive locomotion controller of a hexapod robot. In 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (pp. 5335-5342). IEEE.
8. Schilling, M., Konen, K., Ohl, F.W. and Korthals, T., 2020. Decentralized deep reinforcement learning for a distributed and adaptive locomotion controller of a hexapod robot. In 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (pp. 5335-5342). IEEE.
9. Schilling, M., Konen, K., Ohl, F.W. and Korthals, T., 2020. Decentralized deep reinforcement learning for a distributed and adaptive locomotion controller of a hexapod robot. In 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (pp. 5335-5342). IEEE.
10. Arduino ATMEGA 2560; https://www.electronicshub.org/arduino-mega-pinout/
11. Arduino ATMEGA 2560 Circuit Diagram; https://forum.arduino.cc/t/arduino-mega-schematic/688702
12. EMAX ES08MA II; https://www.amazon.in/-/hi/EMAX-ES08MA-%E0%A4%AE%E0%A4%BF%E0%A4%A8%E0%A5%80-%E0%A4%8F%E0%A4%A8%E0%A4%BE%E0%A4%B2%E0%A5%89%E0%A4%97-%E0%A4%B8%E0%A4%B0%E0%A5%8D%E0%A4%B5%E0%A5%8B/dp/B07KYK9N1G
13. ES08MA II Specifications; https://emaxmodel.com/products/emax-es08a-ii-mini-plastic-gear-analog-servo-1-8kg-sec-for-rc-models-robot
14. UBEC 5V 5A; https://rees52.com/ubec-5v5a-external-switching-power-supply-regulator-rs3365-5584-accessories/
15. ESP CAM; https://www.amazon.in/TECHDELIVERS%C2%AE-Espressif-Development-Bluetooth-OV2640/dp/B0918MZM38
16. ESP 32 CAM Pinout; https://randomnerdtutorials.com/esp32-cam-ai-thinker-pinout/
17. ESP32; https://www.mouser.in/ProductDetail/Espressif-Systems/ESP32-DevKitC-32UE?qs=GedFDFLaBXFguOYDKoZ3jA%3D%3D
18. ESP32 Circuit Diagram; https://michaelangerer.dev/esp32/pcb/2021/09/10/esp32-pico-d4-minimal-pcb.html
19. MURATA (SONY) US18650VTC6 3000mAh (7c) LI-ION BATTERY – 2; https://robu.in/product/sony-vtc6-18650-li-ion-3000-mah-battery/
20. 18650 Dual SMD/SMT High-Quality Single Battery Holder ; https://robu.in/product/18650-dual-smd-smt-high-quality-single-battery-holder/

21. Hextorq by Technodune; http://technodune.com/
22. https://markwtech.com/robots/hexapod/
23. https://robu.in/
24. https://www.trossenrobotics.com/phantomx-hexapod-mk4.aspx
25. https://howtomechatronics.com/projects/arduino-ant-hexapod-robot/
26. https://en.wikipedia.org/wiki/Hexapod_(robotics)
27. https://www.bostondynamics.com/products/spot
28. https://www.amazon.jobs/en/teams/amazon-robotics