DESIGN AND DEVELOPMENT OF HEXAPOD

by

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Submitted to the department of Mechanical Engineering

in partial fulfilment of the requirements

for the degree of

Bachelor of Technology

in

Mechanical Engineering

ABES Engineering College, Ghaziabad

Dr. A.P.J. Abdul Kalam Technical University, Uttar Pradesh Lucknow

May, 2023

DECLARATION

We hereby declare that this submission is our own work that, to the best of our knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

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This is to certify that project report entitled "**DESIGN AND DEVELOPMENT OF HEXAPOD"** which is submitted by **Kishan Poddar, Hemant Saini, Abhay Singh and Aakash Lakra** in partial fulfilment of the requirement for the award of degree B.Tech. in Department of Mechanical Engineering of Dr. A.P.J. Abdul Kalam, Technical University, is a record of the candidates' own work carried out by them under my supervision. The matter embodied in this thesis is original and has not been submitted for the award of any other degree.

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ACKNOWLEDGEMENT

It gives us a great sense of pleasure to present the report of the B.Tech. Project undertaken during B.Tech Final Year. We owe special debt of gratitude to ***Senior Assistant Professor Mr. Saurabh*** *Department of Mechanical Engineering, ABES Engineering College, Ghaziabad for his constant support and guidance throughout the course of our work. His sincerity, thoroughness and perseverance have been a constant source of inspiration for us. It is only his cognizant efforts that our endeavours have seen light of the day.*

We also take the opportunity to acknowledge the contribution of ***Dr. Ravi Shankar Raman,*** *Head of Department of Electronics & Communication Engineering, ABES Engineering College, Ghaziabad for his full support and assistance during the development of the project.*

We also do not like to miss the opportunity to acknowledge the contribution of all faculty members of the department for their kind assistance and cooperation during the development of our project. Last but not the least, we acknowledge our friends for their contribution in the completion of the project.

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ABSTRACT

This project report presents the design and development of a successful hexapod robot model. The project team conducted thorough motion and structural analysis to optimize the robot's gait pattern, minimize energy consumption, and ensure its structural integrity. Motion analysis software was used to simulate the robot's movement, while finite element analysis was employed to determine the stresses and deformations that would occur under different loads and conditions. The team reinforced the robot's weak points, improved its strength and stability. The successful project demonstrates the importance of motion and structural analysis in the design and development of hexapod robots. Motion and structural analysis are essential in the design and development of hexapod robots because they help to optimize the robot's performance, improve its safety, and ensure its reliability. Without this analysis, it would be difficult to create a hexapod robot that is efficient, stable, and safe to operate. Therefore, the successful project serves as a testament to the importance of motion and structural analysis in the design and development of hexapod robots.

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Motivation

We take great pride in our successful completion of the "**DESIGN AND DEVELOPMENT OF HEXAPOD** " project.

Our team utilized all of our skills and experience to the fullest extent. Despite our limited experience, we were able to accomplish the task with great efficiency.

We are also grateful for the continuous support and motivation provided by the faculty throughout the proje

CHAPTER 1
INTRODUCTION

Hexapod robots, also known as six-legged robots, are one of the most fascinating and versatile types of robots in the field of robotics. They are designed to imitate the locomotion of insects and arachnids, and can be used for various applications such as surveillance, exploration, search and rescue, and military operations. Hexapod robots have a unique and efficient locomotion system that enables them to navigate through complex environments with ease, making them ideal for use in areas where wheeled or tracked vehicles may face difficulty.

Our objective for this project is to create and construct a hexapod robot entirely from the ground up. The project will involve a combination of mechanical, electrical, and software engineering, and will require the integration of various components such as motors, sensors, and microcontrollers. The primary objective of this project is to gain a comprehensive understanding of hexapod locomotion and develop a functional hexapod robot.

Overall, this project will provide a valuable learning experience and will allow to gain hands-on experience in the design, development, and operation of a hexapod robot. By the end of the project, we hope to have a functional hexapod robot and we look forward to sharing our findings and experiences with the rest of the robotics community. Hexapod robots have several advantages over traditional wheeled robots, including better mobility over rough terrain and the ability to navigate over obstacles.

1.1 INTRODUCTION TO HEXAPOD ROBOTICS

Robotics is a branch of engineering and technology that deals with the design, construction, operation, and use of robots. A robot is a machine that is capable of carrying out complex actions automatically or remotely, with some degree of autonomy.

Hexapod robotics refers to the use of six-legged robots, or hexapods, in various applications such as research, exploration, and entertainment. Hexapod robots have several advantages over traditional wheeled robots, including better mobility over rough terrain and the ability to navigate over obstacles.

Hexapod robotics is a rapidly growing field that has emerged from the study of insect locomotion. Hexapods, also known as six-legged robots, are machines that are designed to move and navigate in ways similar to insects. Hexapod robots have many potential applications in a variety of industries, including search and rescue, agriculture, and manufacturing. In this chapter, we will explore the origins of hexapod robotics, the motivations for their development, the current advancements in the field, the applications of hexapod robots, and some of the research works in the field.

Hexapod robots can be designed to operate autonomously or be controlled remotely by a human operator. They can be used for a wide range of applications such as search and rescue, surveillance, agriculture, and mining.

One of the key challenges in hexapod robotics is developing efficient algorithms for gait generation and control. The movement of the six legs must be coordinated to ensure stable and efficient locomotion. Additionally, hexapod robots must be able to adapt to changing terrain and navigate around obstacles.

1.2.1 ORIGIN

The origins of hexapod robotics can be traced back to the study of insect locomotion. Insects are known for their ability to navigate complex and uneven terrain, and researchers have long been fascinated by the way that they move. In the 1950s, researchers began to study the biomechanics of insect locomotion, and this research eventually led to the development of hexapod robots.

The first hexapod robot was developed in the early 1980s by a team of researchers at Carnegie Mellon University. The robot, called the Hexapod Walking Machine, was designed to mimic the locomotion of insects, and it had six legs that were controlled by a complex series of hydraulic pumps and valves. While this early hexapod robot was limited in its capabilities, it represented an important breakthrough in the field of robotics.

The first hexapod robot was developed in 1982 by a team of researchers at the University of California, Berkeley, led by Ronald Fearing. This robot, called the "Sprawl," had six legs and used a simple gait to move.

Since then, hexapod robots have been used in a variety of applications, including research, exploration, and entertainment. In the 1990s, hexapod robots were used in search and rescue missions, and by the early 2000s, they were being used in military applications, such as reconnaissance and surveillance. Hexapod robots have been valuable tools in scientific research and exploration. Their six-legged design provides stability and maneuverability, enabling them to traverse challenging terrains. Hexapods have been used in studying ecosystems, particularly in environments that are difficult to access or too dangerous for humans.

1.2 SIGNIFICANCE AND SUBJECT BACKGROUND

Hexapod robots, with their six legs, have significant potential in various industries, including manufacturing, search and rescue, and agriculture. Here are some of the significant advantages and significance of hexapod robots:

1. Enhanced mobility and manoeuvrability: One of the significant advantages of hexapod robots is their enhanced mobility and manoeuvrability. With six legs, hexapod robots can traverse various terrains, including uneven, rough, and steep surfaces, which are difficult or impossible for wheeled robots.
2. Increased stability: The design of hexapod robots allows them to maintain stability even on uneven or inclined surfaces, making them suitable for search and rescue operations and exploration missions.
3. Adaptability to various environments: Hexapod robots are versatile and can be designed to work in various environments, including underwater, extreme weather conditions, and hazardous environments, where human intervention may not be possible.
4. Efficient energy consumption: Hexapod robots consume less energy compared to their wheeled counterparts while traversing on rough terrain. With their multi-leg design, they can absorb shocks and distribute the load of the robot, resulting in less energy consumption.
5. Precision and accuracy: Hexapod robots can be designed with precision and accuracy in mind, making them ideal for applications such as surgical procedures, inspection, and monitoring tasks.

6. Increased efficiency in agricultural applications: Hexapod robots can be used in agriculture to increase efficiency and productivity. They can perform tasks such as weed detection, crop monitoring, and pesticide spraying, resulting in higher crop yields and reduced costs.

7. Humanitarian applications: Hexapod robots have significant potential for humanitarian applications, including search and rescue operations during natural disasters or in hazardous environments.

Overall, the significance of hexapod robots lies in their enhanced mobility, adaptability, efficiency, and precision, making them suitable for a wide range of applications, from agriculture to exploration and search and rescue operations.

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1.3 FUTURE SCOPE AND CURRENT ADVANCEMENTS

Today, hexapod robotics is a rapidly evolving field, with new advancements and breakthroughs being made every year. Some of the current advancements in hexapod robotics include the development of more advanced control systems, the integration of artificial intelligence and machine learning, and the development of new materials that are stronger and lighter than traditional materials.

One of the key advancements in hexapod robotics is the development of more advanced control systems. Hexapods are highly complex machines that require precise control in order to move and navigate in their environment. As a result, researchers are constantly working to develop new control systems that can provide more precise and accurate control over the robot's movements. These new control systems often incorporate advanced sensors, such as cameras and LIDAR, which allow the robot to detect and respond to changes in its environment.

1.4 RESEARCH STATUS

Early research works on hexapod robots focused mainly on their locomotion and gait control. The following are some of the early research works on hexapod robots:

1. Locomotion and Gait Control: Researchers explored the locomotion and gait control of hexapod robots using various techniques such as central pattern generators, neural networks, and fuzzy logic controllers. For instance, Yamaguchi et al. (1995) proposed a central pattern generator-based control method to generate stable walking motions of a hexapod robot.

2. Kinematics and Dynamics: Kinematics and dynamics of hexapod robots were also studied to understand the motion of their legs and body. Researchers developed analytical models to study the leg kinematics and dynamics of hexapod robots (Yim et al., 1998), and developed a dynamic model to investigate the effects of leg compliance on the performance of hexapod robots (McGhee et al., 1998).

3. Biomimetics: Early research works on hexapod robots also explored the application of biomimetics in designing and controlling these robots. Researchers

developed a biomimetic hexapod robot inspired by the cockroach's locomotion mechanism (Cruse et al., 1998).

4. Applications: Hexapod robots were initially explored for industrial applications, such as inspection and maintenance of pipes and vessels in chemical plants. Researchers developed hexapod robots equipped with sensors and cameras for inspection and maintenance operations (Park et al., 2000).

Overall, early research works on hexapod robots mainly focused on locomotion and gait control, kinematics and dynamics, biomimetics, and industrial applications. These early studies laid the foundation for further research and development of hexapod robots in various fields such as search and rescue, agriculture, education, and entertainment.

CHAPTER 2
LITERATURE REVIEW

Kee-Jung Huang [1] created a robot that can be controlled like a regular vehicle, it had the ability to navigate over obstacles thanks to its high ground clearance. The robot can initiate running motion with a flight phase. The success of this robot is due in part to the way its rhythmic movements, flexible legs, and contact with the ground work together to create a stable and efficient platform.

Daniel Soto-Guerrero [2] demonstrated that the unique holonomic property of the Hexa-Podopter can be utilized to apply a simple controller for achieving stable point-to-point flight control, while also offering a more stable platform for embedded sensors compared to traditional multi-copters. They also developed automatic walking-pattern generators to leverage the hybrid flying-walking design.

J. Lee et al. **[3]** analyzes the kinematics of a hexapod robot with redundant degrees of freedom. It investigates the inverse kinematic problem, and develops a solution using the pseudo-inverse Jacobian. The robot's forward kinematics is also examined, and a closed-form solution is derived. The results show that the robot's redundant degrees of freedom can be used to improve its overall performance.

R. F. N. Rodrigues et al. [4] presents the design and development of a hexapod robot for humanitarian demining. The robot is designed to detect and remove landmines in conflict zones. It is equipped with sensors for mine detection and a manipulation system for mine removal. The paper presents the mechanical design, control system, and experimental results of the robot.

S. S. Kim et al. [5] describes the development of a modular hexapod robot for mobile manipulation tasks. The robot is composed of several modules that can be assembled in different configurations depending on the task. The paper presents the mechanical design, control system, and experimental.

Canh Toan Nquyen [6] showed the feasibility and usefulness of the proposed 5-DOF soft DEAs in driving the locomotion of the insect-inspired hexapod robot. In this they have 5-DOF soft actuators can be utilized as active joints within a simple structure and compact design for different robotic applications such as walking robots, artificial eyes, medical manipulators, active vibration stabilization of optical devices, haptic devices, etc.

Pierre Larochelle [7] described a design and the development of a novel six-legged robotic walking machine named Sphere Walker. They took the inspiration from a turtle to manufacture a six-legged walking machine. The Sphere Walker has six legs that are arranged into pairs with each pair being supported and actuated by a single spherical four-bar mechanism.

Jie Chen [8] studied a three-joint leg mechanism mechanism was designed for the HITCR-II hexapod robot with consideration given to insect leg morphology and desired mobility. A leg locomotion planner was also developed to generate optimal swing on rough terrains Moving forward, the research focused on implementing dynamic control schemes for the legs, exploring additional optimality criteria proposed by biologists, and developing gait planning strategies for the walking robot.

G.M Nelson [9] used the cockroach as a model for a robot, citing its diverse capabilities such as speed, agility, and integration of sensory information. To design the robot's mechanics and controller, a dynamic simulation was created. The robot was designed to use cockroach leg functions for locomotion, turning, and climbing. This approach could lead to robots with enhanced mobility and adaptability in various environments.

M. K Gopinath et.al [10] presents the development of a terrain-adaptive hexapod robot for planetary exploration. The robot is designed to traverse rough terrain on extra-terrestrial surfaces. It is equipped with sensors for environmental perception and a control system for motion planning. The paper presents the mechanical design, control system, and experimental results of the robot.

J. Wang et.al [11] discusses the design of a hexapod robot for underwater inspection and maintenance tasks. The robot is equipped with sensors for navigation and imaging, and is capable of performing manipulation tasks. The paper presents the mechanical design, control system, and experimental results of the robot.

H Abid et.al [12] This paper presents the control system design of a hexapod robot for humanitarian demining. The robot is designed to detect and remove landmines in conflict zones. It is equipped with sensors for mine detection and a manipulation system for mine removal. The paper presents the mechanical design, control system, and experimental results of the robot.

J Kim et.al [13] The paper describes the design and development of a lightweight hexapod robot for locomotion on soft ground. The robot is equipped with sensors for environmental perception and a control system for motion planning. The paper presents the mechanical design, control system, and experimental results of the robot.

L. Lui et.al [14] The paper presents a kinematic analysis and trajectory planning of a hexapod robot for pipe inspection. The robot is designed to inspect pipelines for defects. The paper develops a mathematical model of the robot's motion and proposes a trajectory planning algorithm. The paper presents the mathematical model, trajectory planning algorithm, and experimental results of the robot.

Y. Zhang et.al [15] The paper proposes a multi-sensor fusion-based fault diagnosis method for hexapod robots. The approach uses sensor data to detect and isolate faulty components in real-time. A fuzzy logic algorithm is used to fuse sensor information and diagnose faults. The proposed method is validated using experimental results, which demonstrate its effectiveness in detecting and isolating faults in a hexapod robot.

N. Chatterjee et.al [16] This paper describes the design and development of a hexapod robot for urban search and rescue applications. The robot is equipped with sensors and cameras to aid in search and rescue missions. It is capable of traversing rough terrain and climbing stairs. The paper presents the mechanical design, control system, and experimental results of the robot.

A. Pathak et.al [17] This paper presents the design and development of a hexapod robot for automated inspection of wind turbine blades. The robot is equipped with sensors for blade inspection and a control system for motion planning. The paper presents the mechanical design, control system, and experimental results of the robot.

S. Chen et.al [18] proposes a biomimetic hexapod robot inspired by cockroach locomotion. The robot's leg design and control system are based on the biomechanics of cockroaches. The paper presents the mechanical design, control system, and experimental results of the robot.

Guoliang Zhong et.al [19] developed a new hexapod robot, with legs that can distribute radially around the robot body and switch to manipulators for task execution. The developed robot was more stable when lifting weight or climbing slopes due to its ability to redistribute its legs. The radially free distribution mechanism allows for a wider workspace, greater fault tolerance, and improved slope climbing ability.

Xilun Ding et.al [20] presents detailed investigation of how a hexagonal hexapod gaits was conducted, including both normal and fault tolerant gaits. The study compared the gaits of rectangular and hexagonal six-legged robots in terms of stability, fault tolerance, terrain adaptability, and walking ability. Additionally, a novel mixed gait was proposed for hexagonal six-legged robots, which combines features of both insect and mammal gaits. This comprehensive analysis sheds light on the potential benefits of hexagonal hexapod gaits and may lead to further improvements in the design and control of hexapod robots.

Huayang Li et.al [21] introduced a new hexapod robot that consists of two walking platforms and an actively actuated waist joint. The mechanical structure of the robot was determined based on considerations of walking stability, energy consumption, and operating dexterity. Additionally, they analyzed the reachable workspaces of three common 2-DOF parallel leg mechanisms and calculated the reachable workspace of the robot body with shank-ground interferences.. The feasibility of integrating the analytical workspace in obstacle-surmounting was verified through a demonstration in which the robot climbed a 45-degree staircase.

M. Cesaretti et.al [22] discuss the design and operation performance of the Cassino Hexapod Robot is discussed in a study, which includes a detailed analysis of its design features and simulation results. The study also includes experimental tests conducted on a built prototype. The robot has six legs with three degrees-of-freedom each that can be controlled independently or co-ordinately. The robot can perform different types of locomotion such as tripod gait, wave gait or omnidirectional gait.

Jovan Menezes et.al [23] presents a framework for mapping, trajectory planning and navigation for hexapod robots using ROS (Robot Operating System). It describes the hardware and software architecture of a custom-built hexapod robot with six legs and 18 degrees-of-freedom. It also demonstrates the implementation of various algorithms such as SLAM (Simultaneous Localization And Mapping), A* (A-star) path planning and PID (Proportional-Integral-Derivative) control for autonomous navigation.

Poramate Manoonpong et.al [24] address common research questions in hexapod robotics, which primarily focus on developing intelligent autonomous hexapod robots that can leverage their biomechanics, morphology, and computational systems to achieve autonomy, adaptability, and energy efficiency comparable to insects. The review covers three key areas: biomechanics, which focuses on the design of smart legs; locomotion control; and high-level cognition control. Additionally, the authors discuss the transfer of knowledge between biology and robotics and how the next generation of bioroboticists can benefit from this interdisciplinary approach.

Aditya Srinivas Manohar et.al [25] corrects some errors in a previous paper that compared the reachable workspaces of regular and irregular axially symmetric hexapod robots. The errors include some incorrect symbols in equations; some missing references; some wrong labels in figures; some typos in text; and some formatting issues.

CHAPTER 3
NEED OF PROJECT

Hexapod robots are versatile and agile machines that are capable of navigating through rough terrain and performing tasks that other robots cannot accomplish. They have a unique leg configuration that allows them to achieve high stability and manoeuvrability, making them ideal for a wide range of applications. Here are some reasons why we need hexapod robots:

1. Locomotion: Hexapod robots have a six-legged configuration that enables them to move in all directions and overcome obstacles with ease. Their legs can also adapt to different terrains, such as stairs, slopes, and uneven surfaces. This makes them ideal for search and rescue operations, where they can navigate through rubble and debris to locate survivors.

2. Stability: Hexapod robots have a high degree of stability due to their leg configuration and gait control. They can maintain balance even on unstable surfaces, such as rocky terrain, and can adjust their body posture to prevent falling. This stability makes them ideal for applications such as inspection and monitoring, where precise movement and control are critical.

3. Payload Capacity: Hexapod robots have a high payload capacity, allowing them to carry heavy equipment and sensors. This makes them ideal for applications such as agriculture, where they can carry sensors for crop monitoring and spraying.

4. Adaptability: Hexapod robots are highly adaptable and can be designed to perform a wide range of tasks. They can be equipped with different sensors, tools, and actuators to perform tasks such as drilling, cutting, and welding. This adaptability

makes them ideal for industrial applications, where they can perform repetitive tasks with high accuracy.

5. Cost-effectiveness: Hexapod robots are cost-effective compared to other types of robots, such as wheeled or tracked robots. They require less maintenance, have a longer lifespan, and can operate in harsh environments without incurring high repair costs. This makes them ideal for applications such as search and rescue, where multiple robots may be required to cover a large area.

In summary, hexapod robots are highly versatile and adaptable machines that are ideal for a wide range of applications. Their unique leg configuration, stability, payload capacity, adaptability, and cost-effectiveness make them an attractive choice for industries such as search and rescue, agriculture, inspection and monitoring, and industrial automation. As technology advances and new materials become available, the potential for hexapod robots will only continue to grow, and we can expect to see them being used in even more applications in the future.

CHAPTER 4
METHODOLOGY

4.1 KINEMATIC ANALYSIS OF LEGS

4.1.1 INTRODUCTION

In the last thirty years, there has been extensive research focused on creating walking robots that can imitate the natural abilities of animals and insects. However, these robots face a significant challenge when it comes to navigating through irregular terrain. Legged locomotion is a crucial aspect that allows these robots to coordinate their movements and move safely across diverse landscapes. The goal is to create machines that can operate independently and autonomously, thereby reducing the reliance on human intervention..

As animals are naturally adapted to different types of surfaces, scientific communities have drawn inspiration from natural elements present in animals to develop similar mechanisms. Researchers have focused on various aspects, including mechanical design, control, navigation, and more, and have imitated them to some extent in the development of walking robots. This has involved studying the gait patterns of animals such as dogs, cats, and insects, and exploring the role of sensors and perception in animals, among other areas.

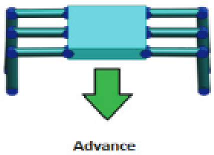
Overall, the development of walking robots has the potential to revolutionize various industries, including search and rescue, agriculture, and space exploration.

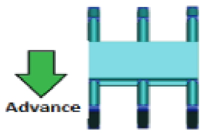
4.1.2 LEG CONFIGURATION IN WALKING PODS

Walking robots are classified based on the number of extremities they possess, with robots having two, four, six or eight legs falling into different categories . Another classification considers the arrangement or fixation points of the legs concerning the body and their orientation to the base.

The configuration of the legs in these robots is primarily inspired by the gait of animals, such as reptiles that have legs and bodies designed to move efficiently over swamps and muddy terrain. Mammals, on the other hand, have their body above the legs, which provides less support to the base but allows for lower power consumption in supporting the body while requiring better stability than other animals.

The orientation of a walking robot's legs in relation to its body can be categorized into three configurations: frontal, sagittal, and circular. The first two configurations are commonly observed in some animals. In the frontal configuration, the legs move perpendicular to the direction of the robot's forward movement, whereas in the sagittal configuration, the legs move parallel to the robot's legs. On the other hand, in the circular configuration, the legs are arranged radially around the robot's body, providing the mechanism with the ability to move in any direction.





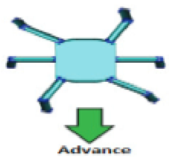


Fig. 4.1 (A) Frontal Configuration

Fig. 4.2 (B) Sagittal Configuration

Fig. 4.3 (C) Circular Configuration

Various joint configurations can be involved in classifying walking robots in relation to their body. This classification can include mammalian, reptilian, and arachnid types, among others..

In the mammalian configuration (as shown in Fig. 2), the legs are positioned below the body, and the knees can assume various positions depending on the specific application requirements.

Fig. 4.4 (A) Knees Outwards

Fig. 4.5 (B) Knees With Same Orientation

Fig. 4.6 (C) Knees Inwards

The Reptilian type (as depicted in Fig. 3(a)) is characterized by legs positioned at both ends of the protruding body, with the knees situated to the side of the base. In contrast, the spider-like configuration (as shown in Fig. 3(b)) is characterized by legs situated on both sides of the body, with the knees positioned at the top of the spider's body.

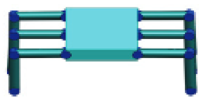


Fig. 4.7 (A) Reptile Type Configuration

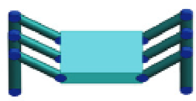


Fig. 4.8 (B) Spider Type Configuration

4.1.3 LEG CHARACTERISTICS

The characteristics of the robot's legs depend on various factors, such as the application requirements, terrain conditions, leg workspace, required energy for movement, and weight capacity. These factors are crucial in determining the physical design and purpose of the robot's legs. To achieve maximum leg workspace with minimal structure, two types of geometrical arrangements are commonly used in leg design, considering three degrees of freedom for each foot. The first type (shown in Fig. 4(a)) has its first axis parallel to the robot's vertical axis, while the second and third axes are parallel to the transverse plane of the base. This configuration has been used in robots like "LittleDog". The second type (shown in Fig. 4(b)) has the second and third axes parallel to each other and perpendicular to the first axis. An example of this configuration is the robot Silo4.

Fig. 4. 9 (A) Geometric Arrangement Type One

Fig. 4. 10 (B) Geometric Arrangement Type Two.

To minimize the structure and maximize the work space and momentum for body movement, a single leg is used for leverage, while the movements of other joints are kept short. This design is based on the second geometric arrangement (Fig. 5), which has three degrees of freedom. The first angle θ1 is rotated 180° around an axis perpendicular to the axes of θ2 and θ3; the latter are rotated 90° and 180° respectively, with their axes parallel to each other.

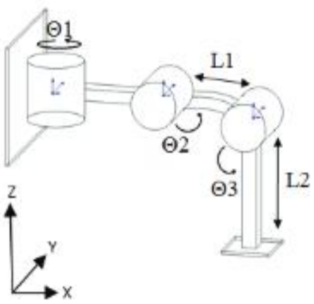


Fig. 4. 11 (A) Leg Configuration

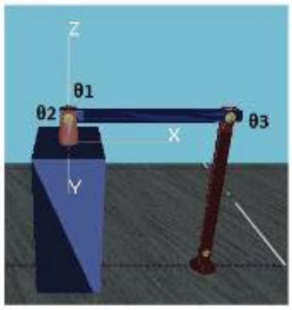


Fig. 4. 12 (B) Leg Configuration In Opengl.

After determining the geometrical parameters of the legs, it is crucial to coordinate their three degrees of freedom (as shown in Fig. 5 (b)) to achieve locomotion. To achieve this, it is necessary to mathematically describe the connection between joint variables, leg position, and orientation. Kinematics is used to analyze movement independently of the functions that produce it, enabling the establishment of the relationship between the joint variable space and the workspace where the hexapod robot can move its legs.

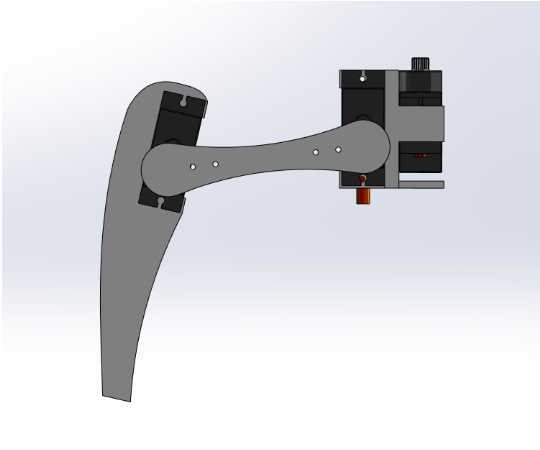


Fig. 4. 13 (A) Front View

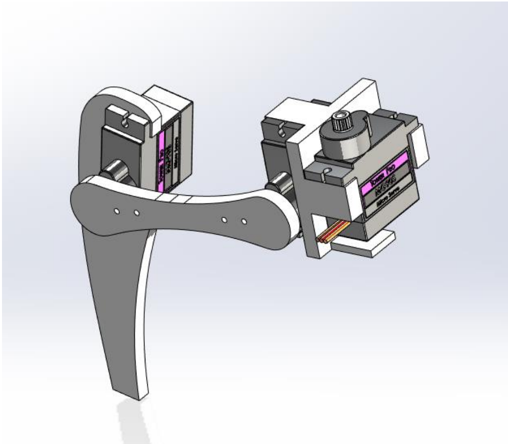


Fig. 4. 14 (B) Isometric View

4.2 ENGINEERING CALCULATIONS

Engineering calculation for mechanical feasibility and structural strength: This involves using engineering principles and calculations to determine if the design of the hexapod is mechanically feasible and structurally strong enough to withstand the expected loads and stresses. This could involve calculations related to materials, forces, and stresses, as well as testing and simulation to validate the results.

4.2.1 MATERIAL SELECTION

There are several reasons why PLA (Polylactic Acid) is a popular choice for 3D printing:

1. Biodegradability: PLA is a biodegradable thermoplastic made from renewable resources like corn starch or sugarcane. This makes it an eco-friendly choice for 3D printing.
2. Easy to print: PLA is easy to work with and does not require a heated build platform like some other materials. It also has a low shrinkage rate, which means

less warping and better dimensional accuracy.

3. Low toxicity: PLA is a non-toxic material, making it safe to use in a home or classroom setting.
4. Range of colors: PLA is available in a wide range of colors, making it a popular choice for creating colorful prints.
5. Affordable: PLA is one of the most affordable materials for 3D printing, making it accessible to a wide range of users.

However, it's worth noting that PLA may not be the best choice for all applications. It has lower heat resistance compared to some other materials, which means it may not be suitable for high-temperature applications. Additionally, it can become brittle over time, so it may not be the best choice for parts that will be subject to a lot of stress or wear and tear.

4.2.2 STRESS CALCULATION

Assumptions:

1. When a beam is bent, any transverse sections that were originally plane will remain plane after bending.
2. Hook's law can be applied to the bending of the beam.
3. The distance between the longitudinal fibers from the centroidal axis remains the same before and after bending.
4. Each layer of the beam is allowed to freely expand or contract during bending.

Calculation:

- For a straight beam we use the bending equation $\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$ but in this case we have to use the bending of curve bar equation.
- To find the stresses on the femur we have perform following calculations.
- Using the **Winkler- Bach formula.**
    - σ = stress due to the bending moment M
    - M = uniform bending moment on femur.
    - A = area of femur.
    - R = radius of curvature of femur.
    - h^2 = constant for the cross section of the femur.
    - y = distance of the curve from the centroidal axis.

$$\boldsymbol{\sigma = \frac{-M}{AR} * \left[1 - \frac{R^2}{h^2} * \left(\frac{y}{R-y}\right)\right]}$$

➢ the bending moment (M) dis negative because the radius of curvature is decreasing.

R **(**radius of curvature of femur**)** = 5.75mm

D(depth) = 3.49mm

Thickness of femur = 4mm

Area of the femur = 3.49*4= 14 mm^2.

- Finding the value of h^2 (constant for the cross section of the femur).

$$h^2 = \frac{R^3}{D} * ln\left(\frac{(2R + D)}{2R - D}\right) - R^2$$

$$h^2 = \frac{5.75^3}{3.49} * ln(\frac{(2 * 5.75) + 3.49}{(2 * 5.75) - 3.49}) - 5.752$$

$$h^2 = \frac{180.9}{3.49} * ln(\frac{15}{8}) - 33.0625$$

$$h^2 = \frac{180.9}{3.49} * 0.6286 - 33.0625$$

$$h^2 = 70.02 - 33.0625 = 36.95mm^2$$

- Finding the value of y (distance of the curve from the centroidal axis.)

$$y = \frac{R * h^2}{R^2 + h^2}$$

$$y = \frac{5.75 * 36.95}{5.752 + 36.95}$$

$$y = \frac{212.5164}{51.96} = 4.09 \text{ mm}$$

- Finding the value of M (bending moment).

$$M = Load * (27.5 + 3.49)$$

$$M = 21.582 * (30.99) = 668.826\ N - mm$$

- Finding the value of stress due to the bending moment 'M'.

  Using the following equation:

$$\sigma = \frac{-M}{AR} * [1 - \frac{R^2}{h^2} * (\frac{y}{R-y})]$$

$$\sigma = \frac{-668.826}{14 * 5.75} * [1 - \frac{5.75^2}{36.9} * (\frac{4.09}{5.75 - 4.09})]$$

$$\sigma = \frac{-668.826}{80.5} * [1 - \frac{33.0625}{36.9} * (\frac{4.09}{1.01})]$$

$$\sigma = -11.3 * [1 - 5.2]$$

$$\sigma = -11.3 * -4.2$$

$$\sigma = 47.46\ N/mm2$$

So, the approximate value of stress due to bending moment 47.46 $*10^6$ N/m^2 or 4.7 $* 10^7$ N/m^2.

4.2.3 SELECTION CRITERIA FOR SERVO MOTOR

1. Main body radius (R) = 75 mm 3(approx.)
2. Total weight(W)= 600gm (total weight of the hexapod)
3. Weight distribution on three legs, (say left front, left back and right mid as the needs at least 3 legs to stand and maintain the balance), of the hexapod (w) = $\frac{W}{3}$.

$$\frac{600}{3} = 200\ gm.$$

4. Torque required(T) = $w\ *\ R$

$$T = 0.2(kg) * 75$$

$$T = 1.5\ kg\ cm.$$

Servo Motor (Sg 90) specification:

Operating voltage: 3.0V to 7.2V

Torque at 4.8V: 2 kg-cm

Torque at 6.6V: 2.2 kg-cm

Hence, the required torque is 1.5 kg cm which is lesser than the torque generated by the servo motors of choice.

4.3 PART MODELLING

Part modelling of a hexapod involves creating a three-dimensional representation of its various components using computer-aided design (CAD) software. The hexapod typically consists of three main components: the body, legs, and joints.

The body is the main structural component of the hexapod and houses the various electronic components, sensors, and other hardware. It is typically modelled as a box or rectangular prism with holes and cut-outs for mounting the legs, electronics, and other components.

The legs of the hexapod are typically modelled as a series of interconnected segments, with each segment being able to move independently of the others. The number and length of the segments vary depending on the design of the hexapod, but typically range from two to four segments per leg.

The joints of the hexapod are typically modelled as spherical or cylindrical connectors that allow the legs to move in multiple directions. The joints are typically attached to the body and the segments of the legs, and are designed to provide smooth, precise movement.

Once the individual components of the hexapod have been modelled, they can be assembled into a complete 3D model. The model can be used to simulate the movement of the hexapod and to test its functionality before it is built.

Overall, modelling the joints as spherical or cylindrical connectors and assembling the components into a complete 3D model of the hexapod allows for a comprehensive evaluation of its design and functionality.

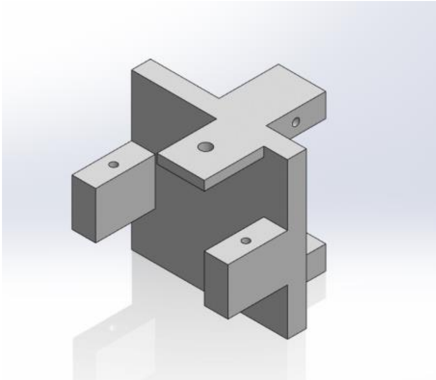


Fig. 4. 15 Coxa

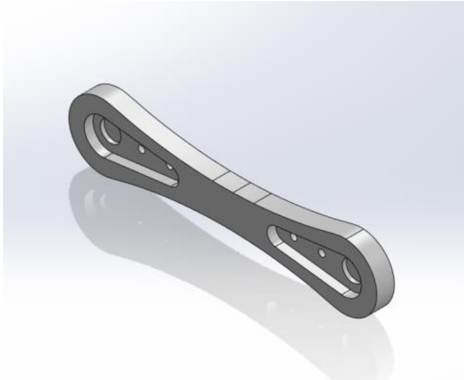


Fig. 4. 16 Femur

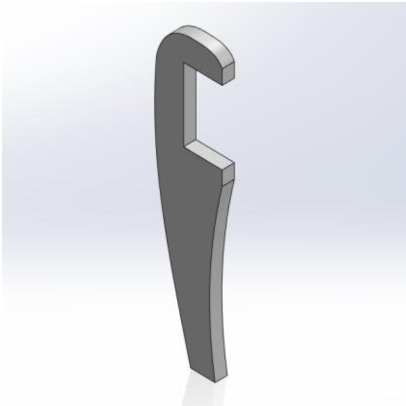


Fig. 4. 17 Tibia

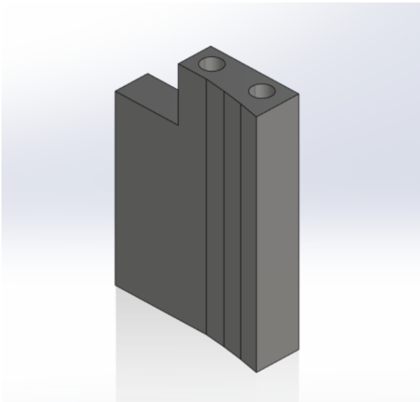


Fig. 4. 18 Holding Plate

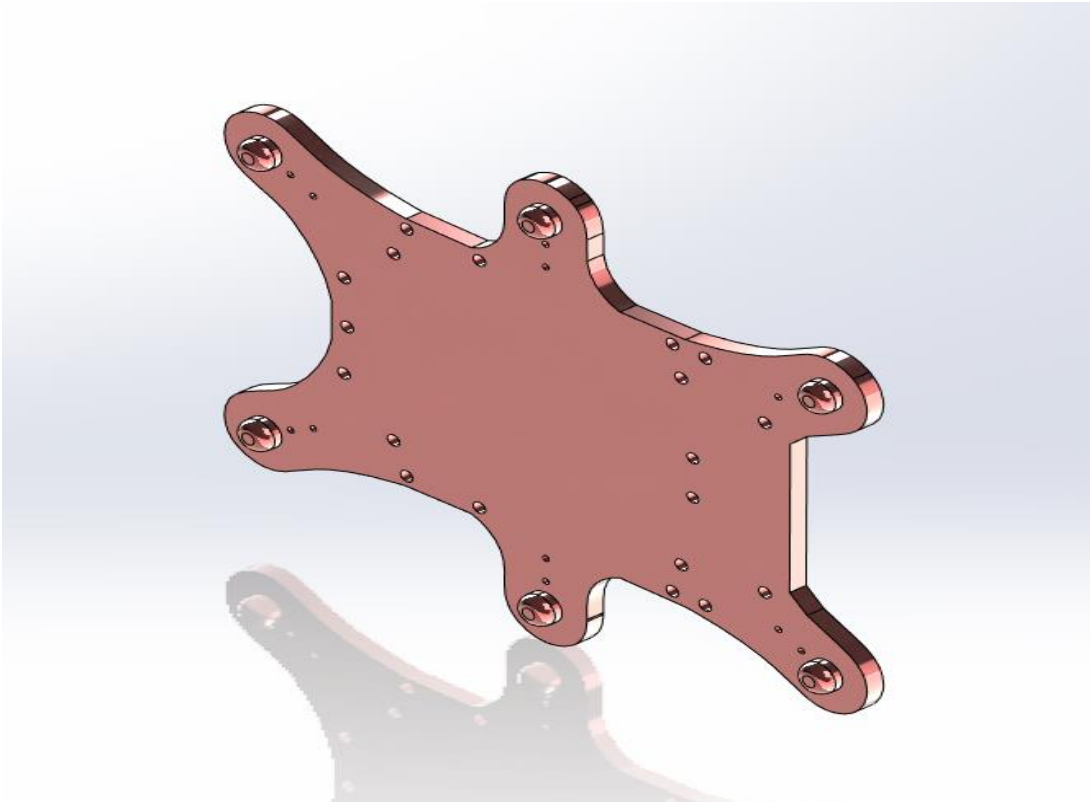


Fig. 4. 19 Main Body

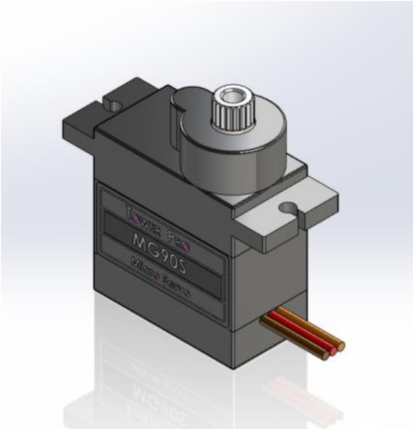


Fig. 4. 20 Servo Motor(Sg90)

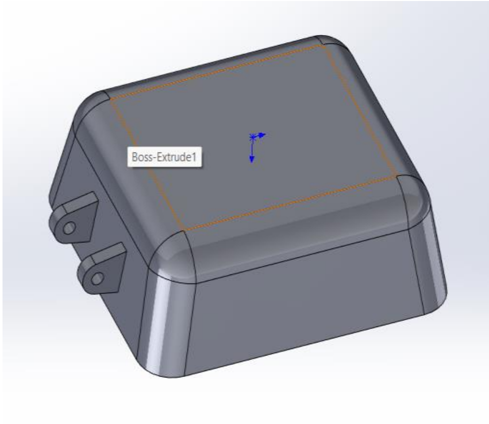


Fig. 4. 21 Battery Lid

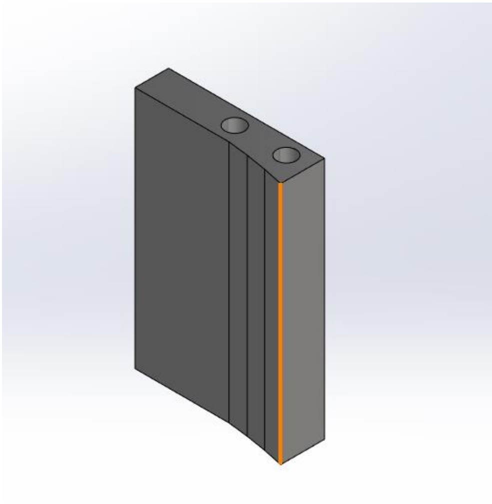


Fig. 4. 22 Holding Plate

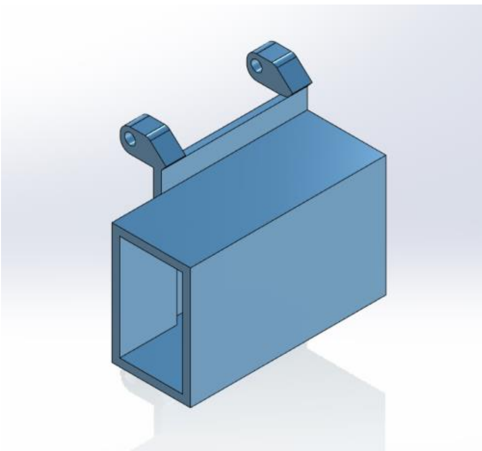


Fig. 4. 23 9v Battery Holder

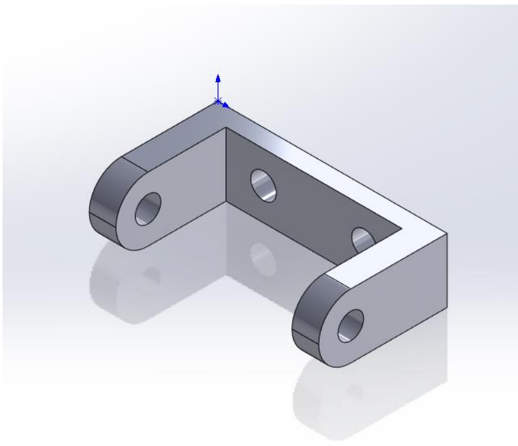
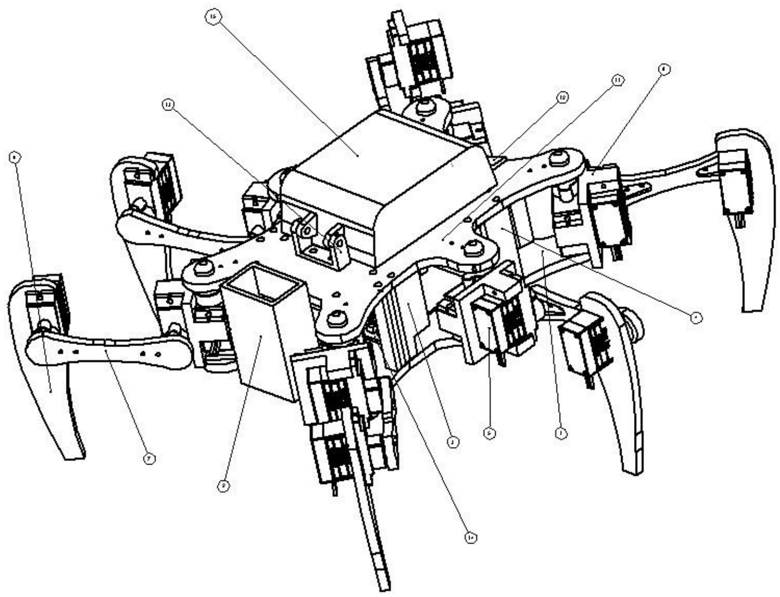


Fig. 4. 24 Battery Lock



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bottom body		1
2	9v battery holder		1
3	back holding plate arduino		2
4	back holding plate		2
5	servo_MG90S		18
6	Tibia		6
7	Fimer		6
8	coxa		6
9	9V Battery		1
10	Receiver_Holder (1)		1
11	Top body		1
12	Battery Lock		1
13	Battery Hinge		1
14	Arduino		1
15	battery lid		1

Fig. 4. 25 Nomenclature Of Hexapod

4.4 STATIC ANALYSIS

4.4.1 NEED FOR STATIC/STRESS ANALYSIS

Stress analysis is the process of evaluating the behaviour of structures and mechanical components under various loading conditions. The need for stress analysis arises from the fact that structures and mechanical components are often subjected to complex and variable loads during their lifespan, which can lead to material fatigue, deformation, and failure.

Stress analysis is crucial in the design and development of hexapod robots for several reasons:

1. Load-bearing capacity: Hexapod robots must be able to support their own weight as well as any additional weight they may carry, such as batteries, or other equipment. Stress analysis is necessary to determine the maximum load that the robot's legs can withstand without deformation or failure.
2. Stability and balance: Hexapod robots must maintain stability and balance while moving on uneven terrain. Stress analysis can help identify potential points of stress concentration and deformation in the robot's legs and body, which can affect its stability and balance.
3. Fatigue resistance: Hexapod robots may be required to operate for extended periods of time, which can lead to material fatigue and failure. Stress analysis can help identify potential areas of fatigue and deformation in the robot's legs and body, which can be addressed through design modifications or material selection.

4.4.2 ESTABLISHMENT OF MODEL

The Hexapod was modelled using SolidWorks with a primary focus on creating a small and aesthetically pleasing design that could be 3D printed. The dimension of robot is 150mm x 128mm

4.4.3 MESHING

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	3.99794 mm
Minimum element size	0.473565 mm
Mesh Quality	High
Re-mesh failed parts independently	Off

Table 4.1 Mesh

Mesh information - Details

Total Nodes	21712
Total Elements	12460
Maximum Aspect Ratio	5.7909
% of elements with Aspect Ratio < 3	95.3
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:04
Computer name:	DELL

Table 4.2 Meshing Details

4.4.4 LOADING AND BOUNDARY CONDITIONS

The leg assembly comprises the Coxa, femur, and tibia, which feature two joints and offer two degrees of freedom. Any additional movements are restricted. The Assembly section in the earlier part of the document describes how the joints are constructed. Here, we focus on the joints' behavior under loads and boundary conditions. The figure displays the assembly's joints.

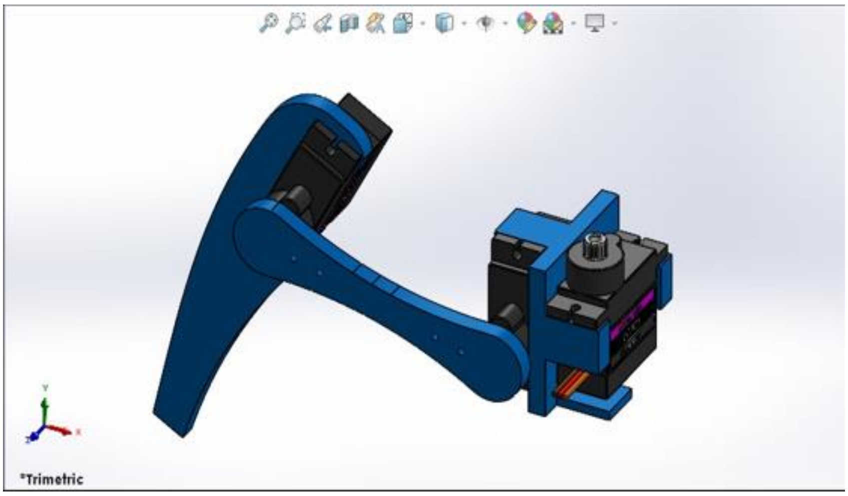


Fig. 4. 26 Leg Assembly

Boundary Conditions: -

A steady-state analysis simulation was performed using Polylactic Acid (PLA) as the material and a solid mesh type at a temperature of 298 Kelvin.

Fixtures: -

The upper and lower face of coxa have been fixed by applying fixtures.

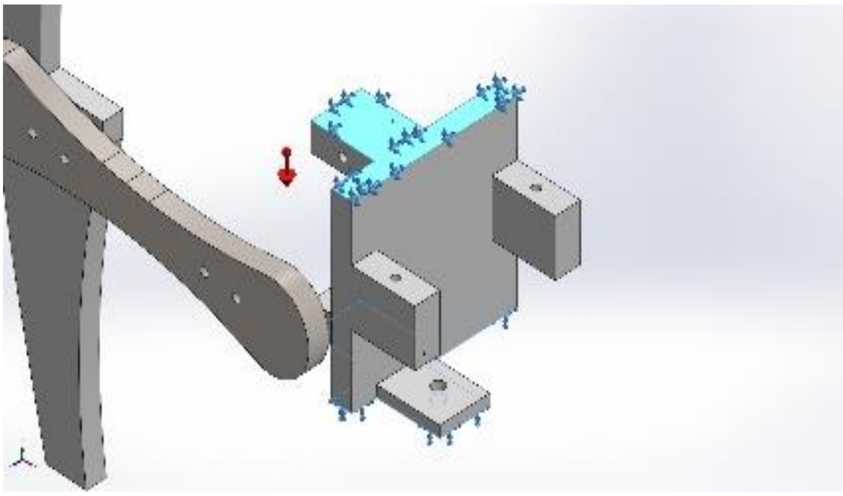


Fig. 4. 27 Leg Assembly Showing Fixtures For Analysis

Loads: -

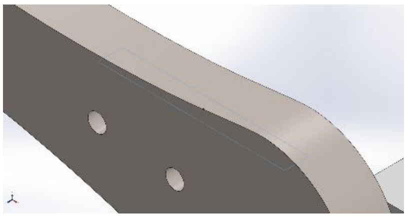
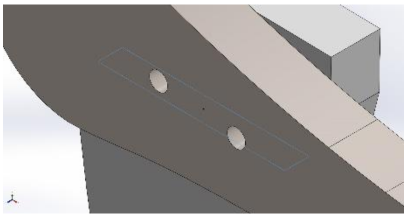
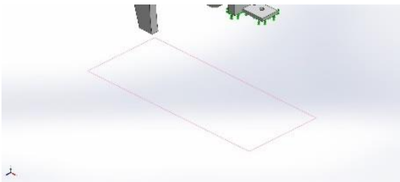
Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 21.5 N
Force-2		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 21.5 N
Gravity-1		**Reference:** Top Plane **Values:** 0 0 -9.81 **Units:** m/s^2

Table 4.3 Loads

4.4.5 SIMULATED RESULTS

Name	Type	Min	Max
Stress1	VON: von Mises Stress	5.904e-01N/m^2 Node: 7256	4.394e+07N/m^2 Node: 614

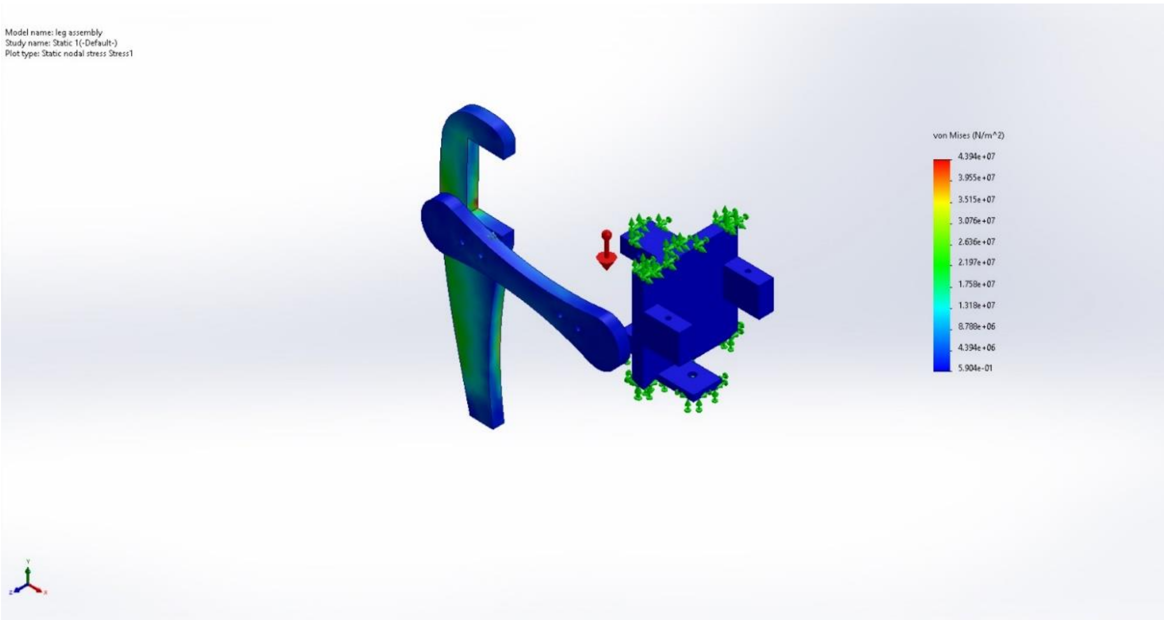


Fig. 4. 28 Stress Analysis

ne	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.335e-10 Element: 5189	1.579e-03 Element: 289

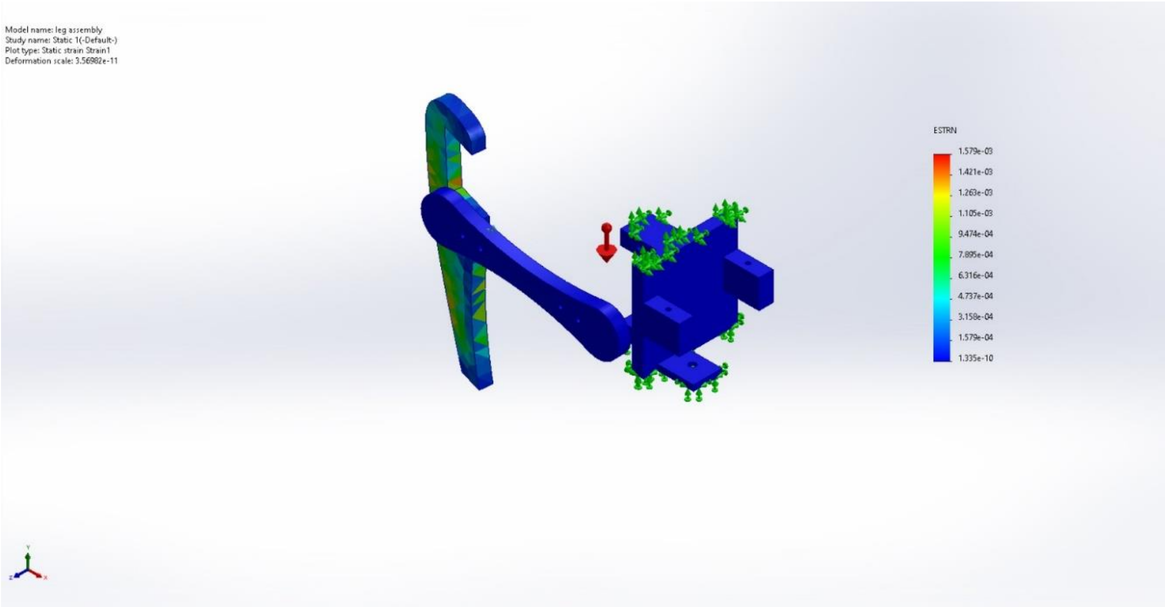


Fig. 4. 29 Strain Analysis

Name	Type	Min	Max
Factor of Safety1	Automatic	1.365e+00 Node: 614	1.016e+08 Node: 7256

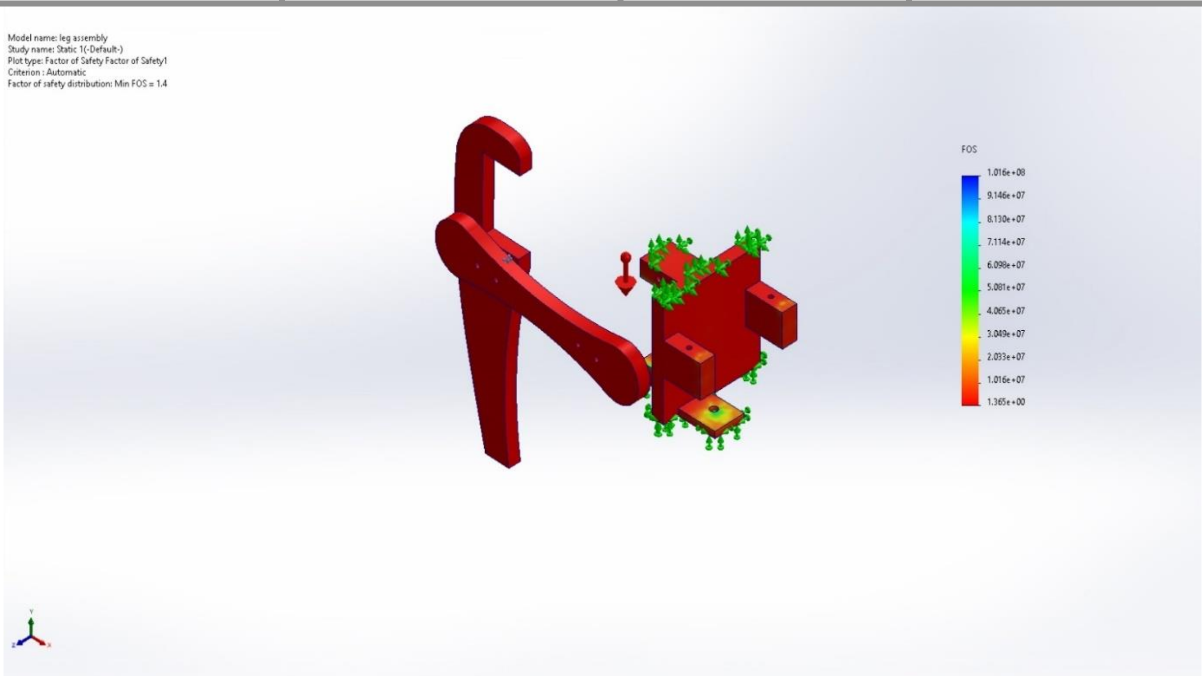


FIG. 4. 30 FOS

4.5 MOTION ANALYSIS

4.5.1 NEED OF ANALYSIS

A hexapod robot is a six-legged robot that uses a complex system of joints and actuators to move and navigate through its environment. To understand the motion of a hexapod robot, it is necessary to perform a motion analysis that takes into account the robot's 18 degrees of freedom.

The 18 degrees of freedom of a hexapod robot are distributed among its six legs, with each leg having three degrees of freedom. These degrees of freedom include the movement of the leg in the x, y, and z planes, as well as the rotation of the leg around these planes.

We approached the motion analysis of a hexapod robot by utilizing SolidWorks Motion Analysis. This software allowed us to model the physical structure of the robot, simulate its movements in a virtual environment, and analyze key factors such as velocity, acceleration, and displacement

4.5.2 RESULTS OF ANALYSIS

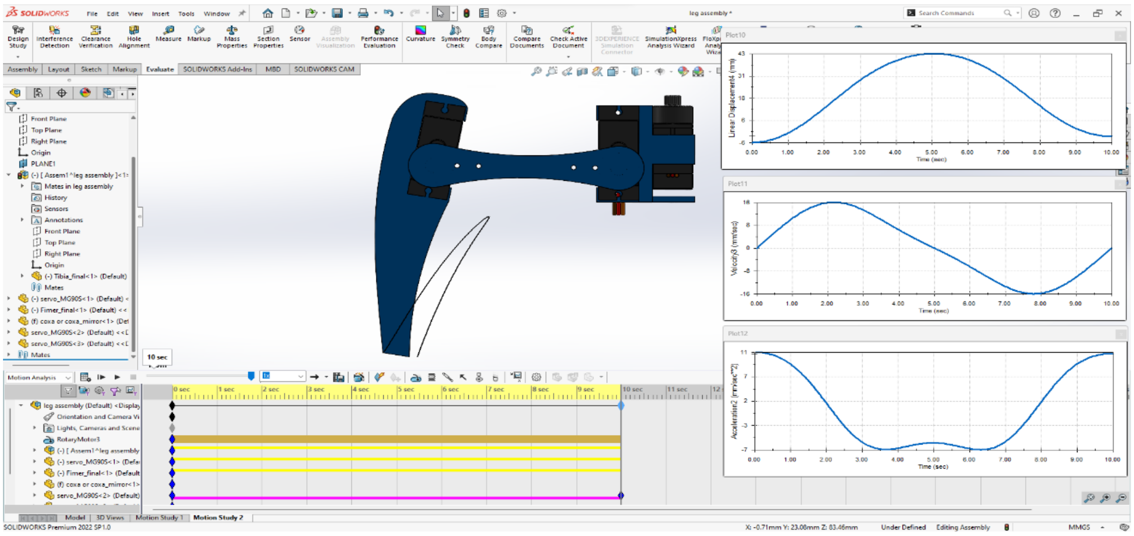


Fig. 4. 31 Motion Analysis

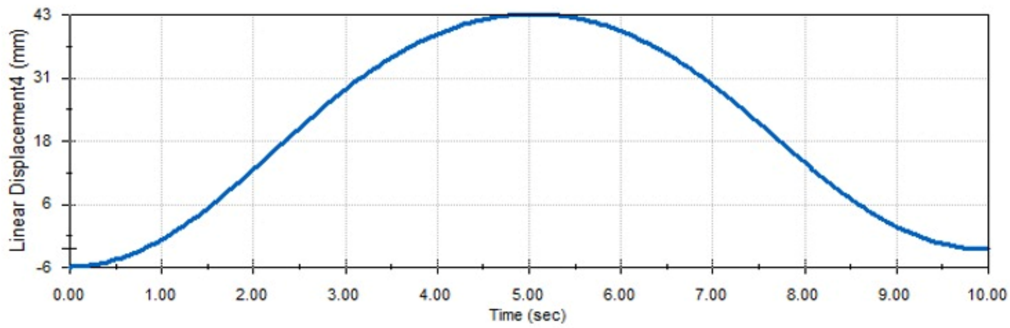


Fig. 4. 32 Linear Displacement Vs Time Graph

In above graph, the Femur exhibits one degree of freedom (D.O.F.), allowing it to move in a single direction at any given time. When the Femur rotates 60 degrees along the y-axis, the Tibia can travel a maximum linear distance of 43mm from it's initial position over a duration. The figure shows that the Tibia reached its furthest position at the 5-second mark and is gradually returning to its position.

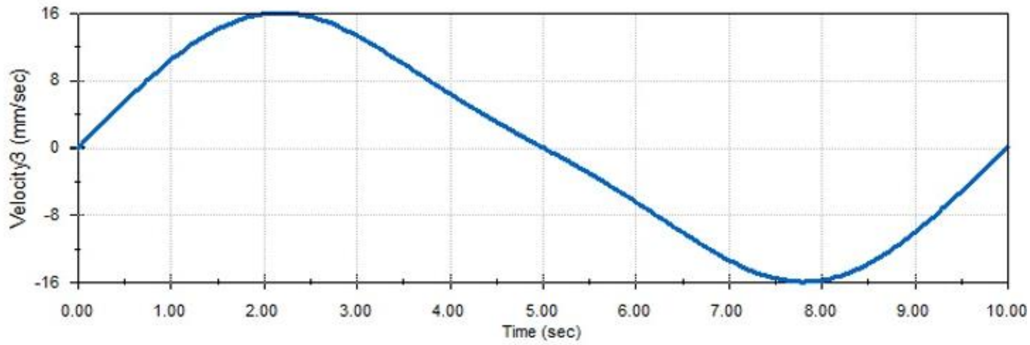


Fig. 4. 33 Velocity Vs Time Graph

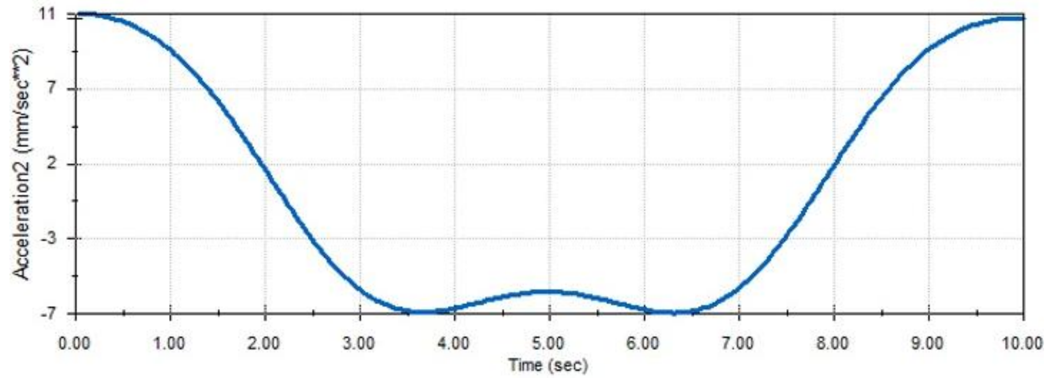


Fig. 4. 34 Acceleration Vs Time Graph

4.6 3D PRINTING AND ASSEMBLY

Once the parts have been modelled and analysed, they can be 3D printed using a suitable material.

The printed parts can then be assembled into the final hexapod design, using appropriate tools and fasteners.

Selection of material for 3D Printing: -

There are several reasons why PLA (Polylactic Acid) is a popular choice for 3D printing:

6. Biodegradability: PLA is a biodegradable thermoplastic made from renewable resources like corn starch or sugarcane. This makes it an eco-friendly choice for 3D printing.
7. Easy to print: PLA is easy to work with and does not require a heated build platform like some other materials. It also has a low shrinkage rate, which means less warping and better dimensional accuracy.
8. Low toxicity: PLA is a non-toxic material, making it safe to use in a home or classroom setting.
9. Range of colors: PLA is available in a wide range of colors, making it a popular choice for creating colorful prints.
10. Affordable: PLA is one of the most affordable materials for 3D printing, making it accessible to a wide range of users.

However, it's worth noting that PLA may not be the best choice for all applications. It has lower heat resistance compared to some other materials, which means it may not be suitable for high-temperature applications. Additionally, it can become brittle over time, so it may not be the best choice for parts that will be subject to a lot of stress or wear and tear.

Fig. 4. 35 (A) 3D Printed Parts

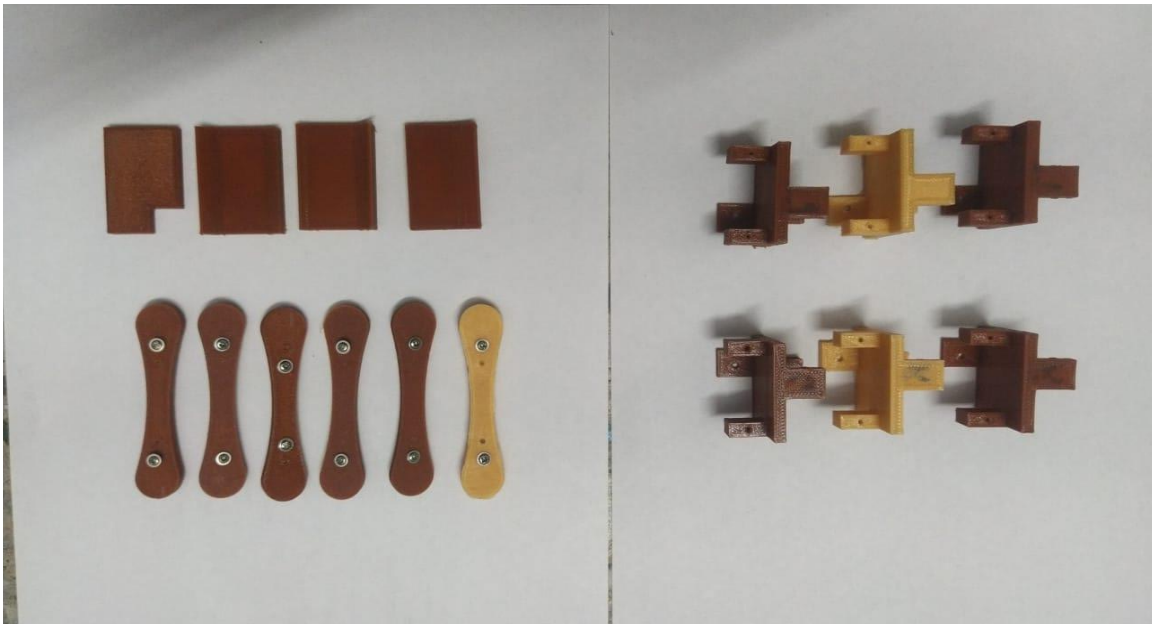


Fig. 4. 36 (B) 3D Printed Parts

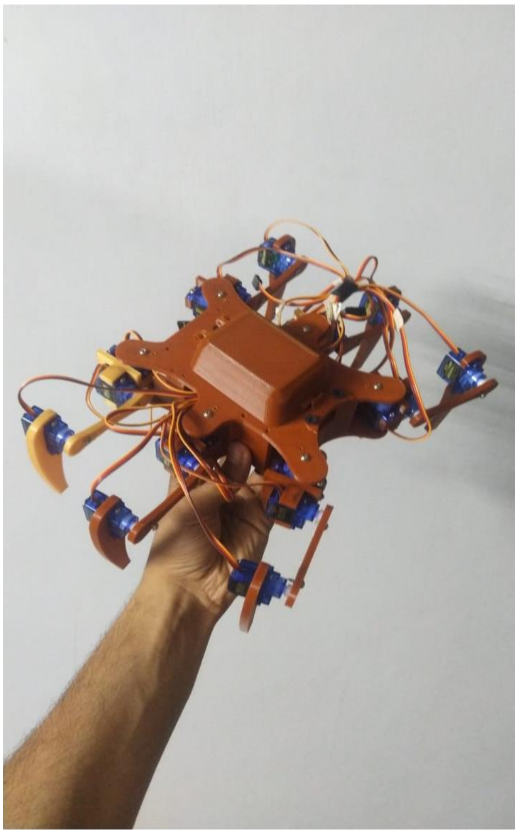
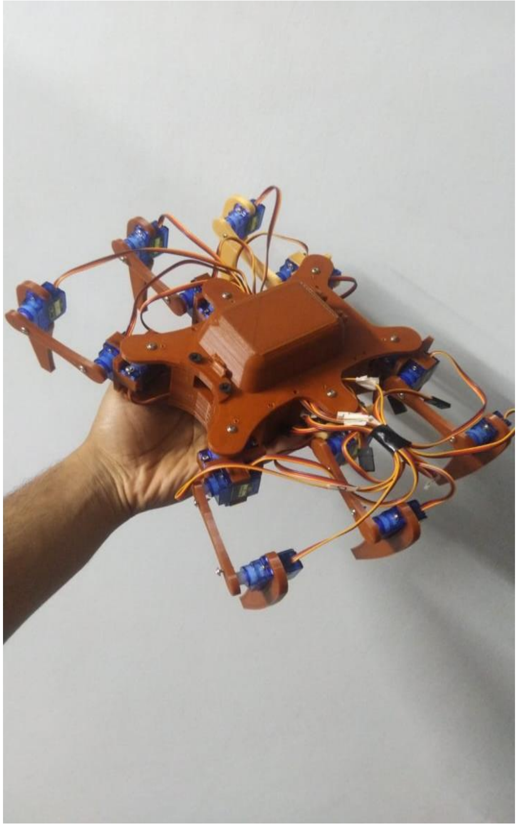
 

Fig. 4. 37 Assembled Hexapod

4.7 ELECTRONICS NETWORKING AND CODING

4.7.1 ELECTRONIC COMPONENTS

Item	Quantity
SG90 (Servo Motors)	18
16 CHANNEL PWM SERVO MOTOR DRIVER - 12-BIT	2
UNO R3 (or any preferable Arduino Board)	1
Jumper Wires	(As per the requirement)
3.7 Volt Battery (Rechargeable)	2
Battery Charger	1

Table 4.4 Electronic Components

4.7.2 CODING

Platform: Arduino IDE

Coding Language: C++

The hexapod will likely be controlled by an onboard microcontroller or computer, which will need to be programmed with suitable software. This could involve writing code in languages such as C++ or Python, and designing a suitable control system for the hexapod.

The code uses the AdafruitPWMServoDriver library to interface with the PCA9685 servo controllers and set the PWM frequency to 50Hz. The main loop of the code checks the state of the button pin and, when pressed, performs a set of walking movements that include walking forward, walking backward, turning left, and turning right. The delay function is used to set the duration of each step and turn.

Here is an example code to make a hexapod stand using two PCA9685 16 channel servo controllers and an Arduino Uno R3:

Note: - Some calibration needs to be done for the code to run properly depending upon your setup, for example, setting up the servo max and servo min values through hit and trial method.

```
#include <Wire.h>

#include <Adafruit_PWMServoDriver.h>

// Create servo driver objects

Adafruit_PWMServoDriver pwm1 = Adafruit_PWMServoDriver(0x40);
```

```
Adafruit_PWMServoDriver pwm2 = Adafruit_PWMServoDriver(0x41);


// Servo motor configurations

const uint16_t servo_min = 150;

const uint16_t servo_max = 600;

const uint8_t num_servos = 18;

uint16_t servo_pos[num_servos] = {0};

// Function to set all servos to minimum position

void setServoMin()

{

  for (uint8_t i = 0; i < num_servos; i++)

  {

    pwm1.setPWM(i, 0, servo_min);

    pwm2.setPWM(i, 0, servo_min);

    servo_pos[i] = servo_min;

  }

}

void setup()

{

  // Initialize serial communication

  Serial begin(9600);
```

```
  // Initialize servo drivers
  pwm1.begin();
  pwm2.begin();

  // Set PWM frequency to 50Hz
  pwm1.setPWMFreq(50);
  pwm2.setPWMFreq(50);

  // Set all servos to minimum position
  setServoMin();
}

// Optional – If you have a display

void loop()
{
  // Print servo positions to serial monitor
  for (uint8_t i = 0; i < num_servos; i++)
  {
    Serial.print("Servo ");
```

```
    Serial.print(i);
    Serial.print(": ");
    Serial.println(servo_pos[i]);
  }

  // Wait 1 second and repeat
  delay(1000);
}
```

4.7.3 CODE EXPLANATION

This code initializes the two PCA9685 servo drivers using the Adafruit_PWMServoDriver library, and sets the PWM frequency to 50Hz. It also defines the minimum and maximum servo positions, the number of servos used, and an array to store the current servo positions. The setServoMin() function sets all the servos to their minimum position by iterating over each servo and calling the setPWM() function on both servo driver objects.

In the setup() function, the serial communication is initialized and the servo drivers are started. The loop() function prints the current servo positions to the serial monitor and waits for 1 second before repeating.

To make the hexapod stand, you would need to modify the setServoMin() function to set the servo positions to a standing position that keeps the hexapod balanced. This would involve adjusting the servo positions for each leg, based on the hexapod's design and weight distribution. Once the standing position is determined, it can be set in the setup() function to automatically set the hexapod in a standing position when the code is run.

CHAPTER 5
RESULTS AND DISCUSSION

The team's successful design of the hexapod robot was due in large part to their thorough motion and structural analysis.

Results of stress and motion analysis conducted on a hexapod robot's legs are discussed:

- Stress analysis yielded multiple results that helped identify factors contributing to determining the optimal strength of the hexapod's legs.

- Factor of safety (F.O.S) for the leg assembly was determined to be at a satisfactory value of 1.4, indicating that the legs are strong enough to support the weight of the robot.

- Stress analysis showed minimal deformation in the assembly, suggesting that the legs maintain their shape even under stress.

- Motion analysis noted that the hexapod robot has six legs, each with three degrees of freedom.

- The analysis involved constraining the femur's angle to 60 degrees and observing the tibia's linear displacement along the y-axis.

- The maximum linear displacement observed in the tibia was 43 mm, giving insight into the range of motion of the hexapod's legs and helping with the design of its locomotion.

- These analyses provide valuable information that can be used to improve the hexapod robot's design and functionality.

CHAPTER 6
CONCLUSION AND FUTURESCOPE

6.1 CONCLUSION

In this project, we have designed, fabricated and controlled a hexapod robot that can perform basic mobility tasks. The hexapod robot has six legs with three degrees of freedom each, which are controlled by 18 servos. The robot uses an Arduino Uno microcontroller to generate PWM signals for the servos and an ultrasonic sensor to detect obstacles in front of it. The robot can be remotely controlled by a smartphone app via Bluetooth communication. The hexapod robot has several advantages over other types of robots, such as high stability, robustness, maneuverability and adaptability to uneven terrain.

This project has demonstrated the feasibility and functionality of a hexapod robot with simple hardware and software components. However, there are still some limitations and challenges that can be improved in future work. With this project we aspired to learn and get ourselves introduced to the world of Robotics and we believe we have succeeded to some extent. We hope this inspires more research and project works in future.

6.2 FUTURE SCOPE

Hexapod robots are a class of robot that has six legs. They're inspired by insects and spiders, and they can relocate in a variety of ways. Hexapod robots are being developed for a variety of operations, including hunting and deliverance, tragedy relief, and manufacturing. The unborn compass of hexapod robots is veritably hopeful. They've got the potential to be used in a wide range of operations, and they're getting less sophisticated. Some of the implicit operations of hexapod robots include

• Hunt and Deliverance: Hexapod robots can be used to search for survivors in caved structures or different risky zones. They can similarly be utilised to carry inventories and outfit delivery employees.

• Calamity relief: Hexapod robots can be used to help with calamity relief sweats. They can be utilised to clear debris, deliver inventories, and give backing to survivors.

• Manufacturing: Hexapod robots can be used in manufacturing to carry out jobs that are hazardous or tough for humans. They can also be utilised to assemble things with a high degree of perfection.

• Healthcare: Hexapod robots can be used in healthcare to help with surgery, recuperation, and other tasks. They can also be used to give fellowship to cases.

PUBLICATION DETAILS

Publication Details:

Paper is communicated to 2nd international conference on sustainable energy & Green technology (SEGT 2023, 23 & 24 June 2023) in Department of Mechanical engineering, R.K.G.I.T Ghaziabad.

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ANNEXURE 1

3-D PRINTER SPECIFICATIONS

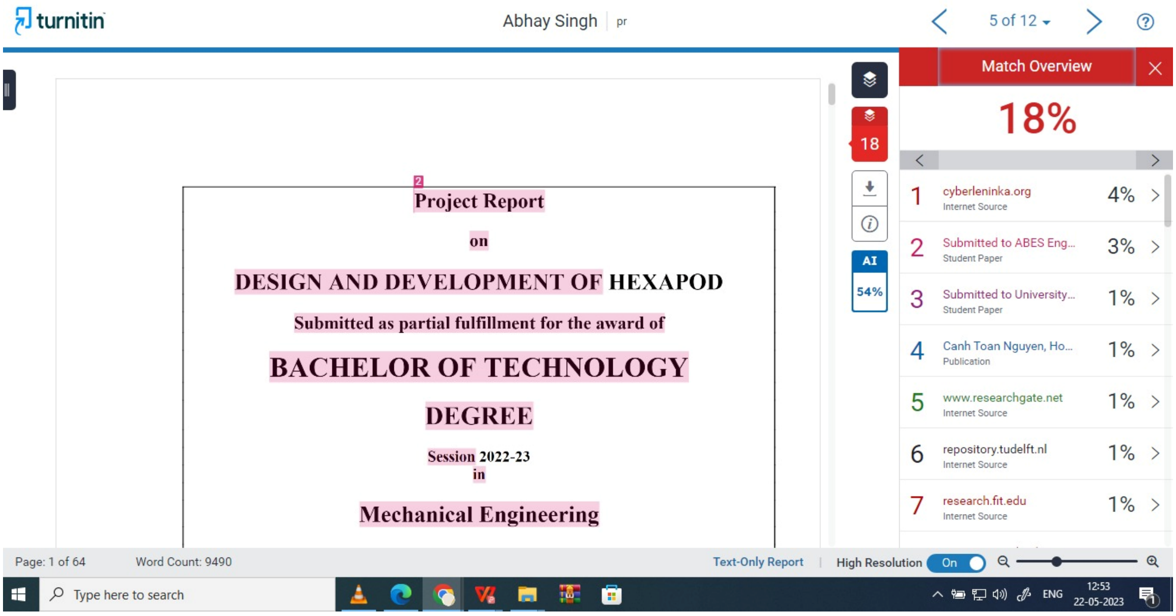
1. Model	Raised 3-D PRO 2
2. Technology	FDM
3. Nozzle Diameter	0.4
4. Filament Diameter	1.75
5. Print Speed	50 mm/s
6. Build Volume	300*300*300
7. Heated Bed Material	Silicon
8. Build Material	PLA (Poly Lactic Acid)

ANNEXURE 2

BILL OF METARIAL

Sr. No.	Part Name	Quantity	Unit Cost	Total cost
1	Top body plate	1	Rs. 45	Rs. 45
2	Bottom body plate	1	Rs. 45	Rs. 45
3	Back holding plate	1	Rs. 4	Rs. 4
4	Back holding plate	1	Rs. 4	Rs. 4
5	Tibia	6	Rs. 5	Rs. 30
6	Femur	6	Rs. 5	Rs. 30
7	Coxa	3	Rs. 11	Rs. 33
8	Coxa mirror	3	Rs. 11	Rs. 33
9	Front holder	2	Rs. 4	Rs. 8
10	Receiver holder	1	Rs. 4	Rs. 4
11	Battery holder	1	Rs. 4	Rs. 4
12	Battery lock	1	Rs. 4	Rs. 4
13	Battery lid	1	Rs. 4	Rs. 4
14	Battery hinge	1	Rs. 4	Rs. 4
15	SG 90 servos	18	Rs. 105	Rs. 1890
16	Arduino Uno R3	1	Rs. 400	Rs. 400
17	16 ch Servo controller	2	Rs. 410	Rs. 820
18	3.7V battery	4	Rs. 40	Rs. 160
19	Battery charger	1	Rs. 80	Rs. 80
		Total Items = 55		**Total = Rs. 3602**

PLAGIARISM REPORT



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