DESIGN AND DEVELOPMENT OF HEXAPOD

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1. ABSTRACT

Hexapod robots, also known as six-legged robots, are one of the most fascinating and versatile types of robots in the field of robotics. A 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 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. The study highlights the challenges and future directions in the field of hexapod robot design and development, such as enhancing the robot's sensory capabilities, improving the efficiency of its locomotion, and reducing its size and weight.

KEYWORDS: Six-Legged, Robotics, Motion Analysis, Structural Analysis

2. INTRODUCTION

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. 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.

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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.

3. PROBLEM DESCRIPTION:

There are several challenges and problems in the field of hexapod robotics that researchers are currently trying to address. Here are some of them:

Control: Developing control strategies that can efficiently and effectively handle the complex dynamics of hexapod robots is a major challenge. The control algorithms need to be adaptable and robust to handle different terrains and environmental conditions.

Power consumption: Hexapod robots often require a lot of energy to move their legs, and this can be a limiting factor in their operation. Developing more energy-efficient motors and control strategies is a major area of research.

Sensing and perception: Hexapod robots require accurate sensing and perception to navigate and interact with their environment. Developing sensors that can provide high-resolution data in real-time is a significant challenge.

Design and fabrication: Hexapod robots require careful design and fabrication to ensure that they can move efficiently and withstand the stresses of locomotion. Developing new fabrication methods and materials that can improve their performance and durability is an active area of research.

Autonomous operation: Developing hexapod robots that can operate autonomously in complex environments is a challenging problem. It requires the integration of sensing, perception, and control strategies to enable the robot to navigate and adapt to its environment.

4. PARAMETER IDENTIFICATION:

The parameter of design is to optimize the robot's gait pattern, minimize energy consumption, and ensure its structural integrity.

Strength: for strength we have used PLA (Polylactic Acid) which is a biodegradable thermoplastic made from renewable resources and also we have used 6 legs which provides all over strength.

Motion: the total number of values required to represent all motion parameters of a hexapod robot with 18 degrees of freedom would be the sum of the values required for each parameters.

Selection of electronic components: The SG90 servos were selected for their lightweight design, 1.2 kg / cm torque rating, and affordability. They operate on a voltage range of 3-6 volts. To power the servos, two 3.7V Li-ion batteries were used, which provide a combined voltage of 7.4V and can supply more than 5 amps. To precisely control the movement of the hexapod robot's legs, an 18-channel servo controller was implemented since each joint of the hexapod requires a separate servo motor. In this case, two servo controllers were used, each controlling 9 motors. The Arduino Uno R3 was selected to accommodate future plans of making the robot autonomous and adding more functions that require additional memory and IO.

Stability: A hexapod with 18 degrees of freedom can maintain stability by considering various factors such as the support polygon, center of mass, ground clearance, leg placement, and gait. The support polygon should always be within the perimeter of the hexapod's base, while the center of mass should always be located within the support polygon.

5. DIAGNOSIS OF PROBLEM:

The current scenario was thoroughly analyzed to identify the source of need and to eliminate or reduce the gap of need and supply accordingly. The next step is to follow the lean thinking process and gathered data to document the current state using the following tools:

a. Staff interview.

b. Survey questionnaire.

c. Reviewing the various research papers and the present update of work in this area.

6. SOLUTION APPROACH

6.1 MODELLING:

With detailed analysis of each and every thing and keeping the issue in mind and identifying the problem during and in the documentation process, the non-value added steps were reduced by eliminating or reducing the duplication or redundancies.

This development of the hexapod was carried out in a sequential manner starting from understanding the need and problem statement, synthesizing of kinematic mechanisms, evaluating various design options and selecting a design for further analysis and prototyping. Kinematic synthesis was carried out for determining suitable link lengths for the mechanism. The design was modelled using CAD, Solid Works.

The Hexapod was modelled using SolidWorks with a primary focus on creating a small and aesthetically pleasing design that could be 3D printed.

It was 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 were 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 varied depending on the design of the hexapod, but typically ranged from two to four segments per leg. The joints of the hexapod were typically modelled as spherical or cylindrical connectors that allowed the legs to move in multiple directions. The joints were typically attached to the body and the segments of the legs, and were designed to provide smooth and precise movement.

Structural and Motion analysis were conducted to further affirm the proof of concept and design base on the engineering calculation done prior to modelling. The FEA and motion analysis were conducted in SolidWorks.

Fig.no.1(3D Model Of Hexapod)

The leg , which is the most essential and critical part of any given Heapod, was comprised of the Coxa, femur, and tibia, which featured two joints and offered two degrees of freedom. Any additional movements were restricted. The Assembly section in the earlier part of the document described how the joints were constructed. Here, we focused on the joints' behavior under loads and boundary conditions. The figure displayed the assembly's joints.

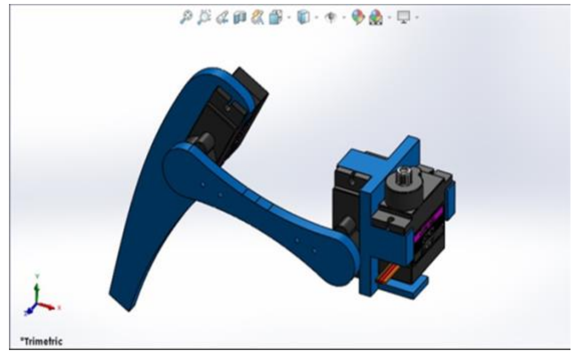

Fig.no.2 (Leg Assembly)

6.2 STRUCTURAL ANALYSIS:

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

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

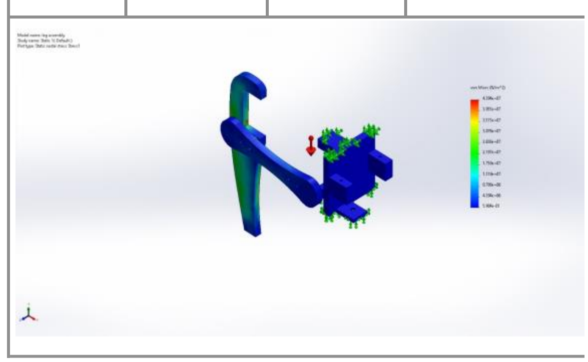

Fig.no.3(Stress Analysis)

6.3 MOTION 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.

In below 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 its 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.

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 analyse key factors such as velocity, acceleration, and displacement.

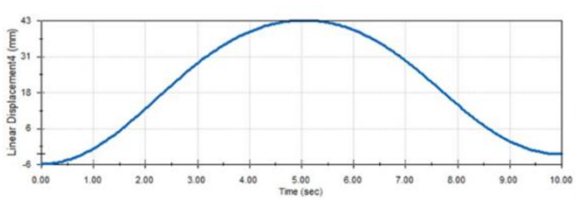

Fig.no.4 Linear Displacement vs time graph

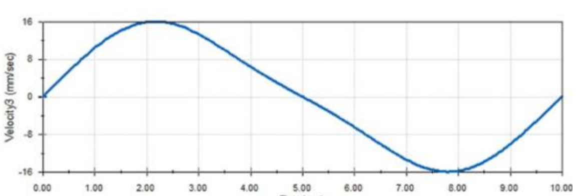

Fig.no.5 Velocity vs time graph

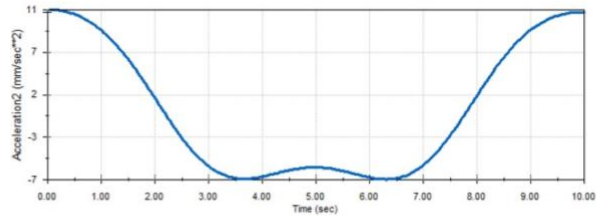

Fig.no.6 Acceleration vs time graph

6.4 MATERIAL SELECTION:

Material used for 3D printing the robot parts **PLA (Polylactic Acid).** The above material has been chosen by keeping in mind our main aim that is to develop a hexapod while minimizing the cost. This is selected on the basis of following Properties and comparison.

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.

6.5 CALCULATION:

6.5.1: Strength Calculation:

a) 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 "**a".**

b. Calculation:

1. 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.

2. To find the stresses on the femur we have perform following calculations.

3. Using the **Winkler- Bach formula** in which.

    I. σ = stress due to the bending moment M

    II. M = uniform bending moment on femur.

    III. A = area of femur.

    IV. R = radius of curvature of femur.

    V. h^2 = constant for the cross section of the femur.

y = distance of the curve from the centroidal axis.

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

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 h2 (constant for the cross section of the femur).

h^2 = R^3/D * ln (((2R + D))/ (2R - D)) - R^2

h^2 = 〖5.75〗^3/3.49 *ln (((2*5.75) + 3.49)/ ((2*5.75) – 3.49)) – 5.752

h^2=180.9/3.49 *ln (15/8) – 33.0625

h^2 = 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 = (R* h^2)/ (R^2 + h^2)

y = (5.75*36.95)/ (5.752 +36.95)

y = 212.5164/51.96 = 4.09 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:

σ = (-M)/AR*[1-R^2/h^2 *(y/(R-y))]

σ = (-668.826)/ (14*5.75) * [1- 〖5.75〗^2/36.9 * (4.09/ (5.75-4.09))]

σ = (-668.826)/80.5 * [1-33.0625/36.9 * (4.09/1.01)]

σ = -11.3 *[1-4.75]

σ = -11.3 * -3.75

σ = 42.37 N/mm^2

6.5.2: Torque Calculation (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) = W/3.
   600/3=200 gm.
4. T (Required Torque) = w * R
   T = 0.2(kg)*75
   T = 1.5 kg cm.

Servo Motor (Sg 90) specification:

1. Operating voltage: 3.0V to 7.2V
2. Torque at 4.8V: 2 kg-cm
3. Torque at 6.6V: 2.2 kg-cm

7. RESULT DISCUSSION:

The 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 as:

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

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

   b) 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.

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

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

   b) 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.

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

8. CONCLUSION:

The project aimed to showcase the feasibility and functionality of a hexapod robot using simple hardware and software components. The successful demonstration of the project shows that even with limited resources, a significant and functional project can be achieved. However, the project is not without its limitations and challenges. These limitations and challenges need to be addressed in future iterations of the project to improve its functionality and efficiency. While our project had measurable outcomes, the immeasurable positivity, energy, and positive feedback we received during and after implementation was a clear indicator of its success. The project's ultimate goal was to learn and introduce its creators to the world of robotics. While the creators believe they have achieved this goal to some extent, they acknowledge that there is still much to learn in the field. The project's success has given them the confidence to explore and experiment with more advanced projects in the future.

Overall, the project's success serves as an inspiration for future research and project work in the field of robotics. It shows that even with limited resources, a successful project can be achieved through dedication, enthusiasm, and a clear goal. The project's success is a testament to the potential of robotics, and the creators hope that it encourages others to explore and innovate in the field.

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