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# Design, Fabrication and Gait Analysis of a Dynamic Hexapod

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**ABSTRACT**
Hexapod robots are increasingly used in hazardous environments where human intervention is risky. This study presents the design of a hexapod robot with a high-speed dynamic tripod gait, which ensures stability by keeping three legs grounded while the other three move forward. A detailed gait analysis was conducted, showing that the tripod gait enables efficient load distribution and continuous movement, even in challenging terrains. The foot-end trajectories for each leg were analyzed to optimize both translational and rotational motions. Torque calculations confirm the robot's ability to carry its weight and perform smooth movement. The hexapod achieves a velocity range of 12–22 cm/s, with a battery runtime of 25.9 minutes and a body-supporting motor torque of 2.3 kg-cm. The results demonstrate that hexapod robots are well-suited for complex and risky environments through effective gait control and leg coordination.

Keywords: Tripod Gait, Torque, Foot-end trajectory, Hexapod, Arduino.



## 1. Introduction

Recently, there has been seen a significant growth in using robots in different fields like rescue missions, hazardous industrial areas etc. where human involvement is risky. Due to the stability and terrain adaptability, multi-legged robots like hexapods are increasingly being deployed to perform tasks like investigating dangerous terrain, surveillance in disaster sites, etc. Hexapods can maintain their mobility and balance even when moving on a cluttered field, stepping over obstacles, or moving through rocky surfaces, where traditional wheeled robots may struggle to move or tip over on the surface. In terms of increased stability and mobility, hexapods also have some benefits over other multilegged robots like quadrupeds, due to their ability to maintain balance using tripod gait where three legs remain on the ground while the other three move at any given time [[1],[2],[3]].

The mechanism of a hexapod robot involves the ability to control its six legs independently, allowing it to maintain its stability and not to lose its balance when moving through a challenging terrain or rocky surface. The loads of a hexapod are distributed between its six legs, which reduces the risk of tipping over, and even if one leg malfunctions, the redundancy of multiple legs ensures the smooth movement of a hexapods [[2],[4]].

Significant advancements have been made in hexapod robot technology in recent years due to advances in materials, control systems, and biomimicry. An autonomous navigation through a combination of sensors and a microcontroller-based control system is introduced in [4] where the microcontroller manages the leg actuators via a servo controller. In [5] a new method for analyzing the gait of radial symmetric hexapod is investigated focusing on the relationship between stride length and body height. An optimization of a hexapod gait control through a modular algorithm is proposed in [6] which reduces computational complexities and power consumption. In [7] a cost-effective hybrid leg structure with a wheel to enhance smooth movement on uneven terrain is presented. An insect-inspired hexapod that utilizes soft dielectric elastomer actuators with 5 degrees of freedom for enhanced locomotion is shown in [8]. In [9] a hexapod robot inspired by a desert ant is introduced, utilizing a novel navigation system, featuring a celestial compass for UV-based heading detection which enables highly accurate homing performance with minimal computational demands. A novel six-link leg mechanism for hexapod that enhances dynamic motion capability by transforming small input motions into larger output by utilizing a bipod gait for high-speed movement on flat surfaces and a tripod gait for stability on rough surfaces is presented in [10].

In the present study, A hexapod robot is designed and equipped with an enhanced control system for improved mobility and efficiency in uneven terrains. A high-speed dynamic tripod gait is utilized here for stability and faster movement which allows three legs of the hexapod to move forward while the remaining three legs push from the back of the hexapod.

## 2. Design

2.1 Components

In the design and building of this hexapod, various types of components have been used. They have been listed below in table 1.

2.2 Electrical Connection

The servo drivers were connected to an Arduino Uno. But to supply the Arduino with necessary power, another 9-volt battery was connected to it. The electrical connection can be found in Fig.1.

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Table 1 Various types of components used

| Serial | Component(s) | Specifications |
|---|---|---|
| 1 | Servo MG996R 10kg Servo with horns (Fully Metal) | 40.7×19.7×42.9mm, 55g, 4.8~6.6V |
| 2 | Arduino Uno ATmega328 | 5V |
| 3 | Wild Scorpion Li-po Battery | 3 Cells, 11.1V, 3500mAh |
| 4 | DC-DC Voltage Regulator Buck Converter | 5-40V to 1.2-36V, 100W |
| 5 | Jumper Wire | |
| 6 | 3D Printed Legs | |
| 7 | Plywood Body | |
| 8 | Grips for foothold | |
| 9 | Screw, Nut etc. | |

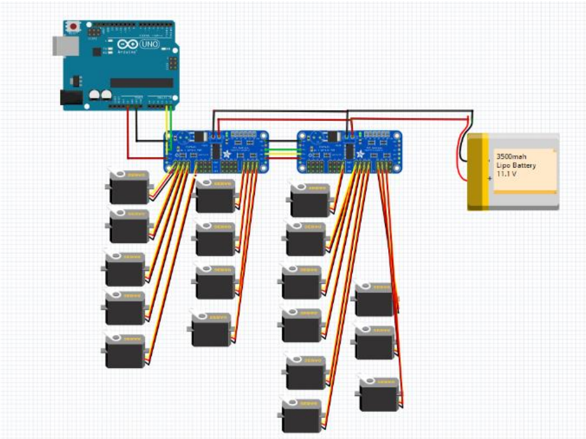

**Fig.1** Electrical Connection of Arachne

2.3 CAD Modeling

The legs were the parts on which the physical movement of the hexapod depended on. They were designed using the SolidWorks 2018 software. The CAD model of one leg of the model is found in Fig.2.

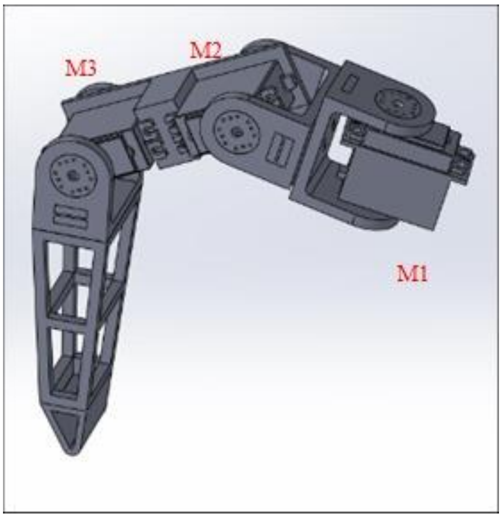


**Fig.2** One leg design with three motors

The full body CAD design and the final manufactured model have been given in Fig.3 and Fig.4, respectively.

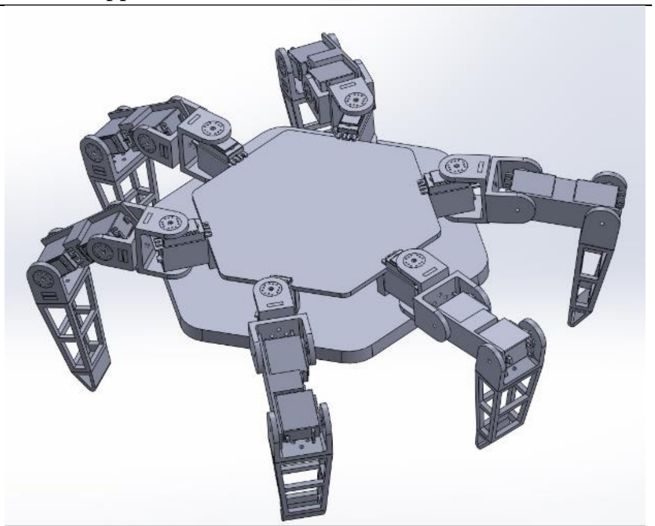

**Fig.3** Full Body Design of the Hexapod

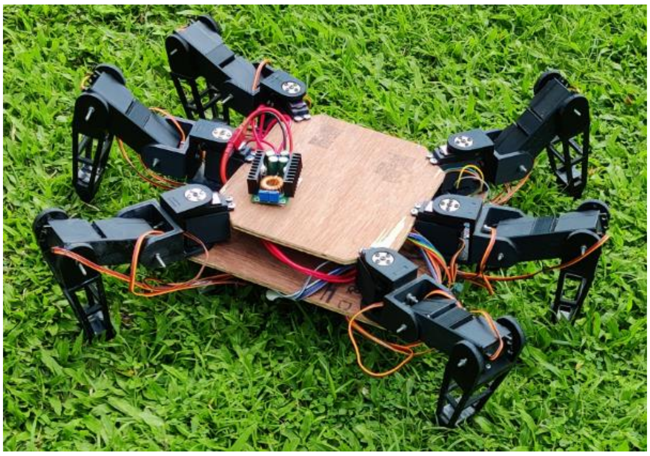

**Fig.4** Final Manufactured Hexapod

**3. Methodology**

3.1 Gait planning

The gait we are discussing about is tripod gait, gives the stability by three legs in such a manner that it resists to fall down due to gravity. So, at any moment there one set of legs either L2-R1-R3 or L1-L3-R2 remains grounded. When they are grounded by creating a couple, the forward motion comes from each set of legs due to rotation of each leg by twice angular path than its initial angular path. And when the other set of legs gets grounded, they also create a couple. That's why this tripod gait can be called as high-speed dynamic tripod gait. Here solid box denotes the grounded position of the leg.

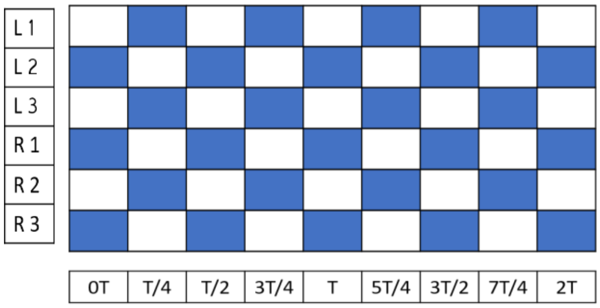


**Fig.5** Time sequence diagram of the robot walking forward in tripod gait

3.2 Torque calculation

There are three motors working on each leg (M1, M2, M3). Motor M1 creates torque along XY plane and allows the bot to move back and forth. Motor M2 allows the leg to move up and down and with motor M3, they carry the body weight of the hexapod.

Let us define distance D1 = distance between M1 and M2 and distance D2 = distance between M2 and M3 Total body weight = 3.5kg. (it includes six legs, plywood, battery etc.)
torque produced by M1 = total body weight/6*(D1+D2)
= (3.5) * (14.0)/6
=8.17 kg-cm

We had used servo motor MG995 180-degree rotation and its rated torque is 10 kg-cm at 4.8V, so it is ok to use.

Motor M2 carries the body weight. So generated torque by M2 will be
= (total body weight/6) * (D2)/2
= (3.5/6) * (8/2)
=2.3 kg-cm

It is assumed that Motor M3 does not create torque as it connected with foot perpendicularly with the ground.

3.3 Power Consumption

To ensure the proper walking mechanism of the hexapod, 18 servos need to be constantly powered on. The electricity consumption of components other than these is negligible compared to them, so only the power consumption by the servo motors will be considered to approximate the power use of the bot.

Total power consumed by each Servo Motor, $P_m = V_m * I_m$ = 5V * 1A = 5W

Power consumed by 18 motors, $P$ = 18 * $P_m$ = 18 * 5W = 90W

Total energy available in battery, $E = V_b * C_b$ = 11.1V * 3500mAh = 38.85 Wh

Battery runtime, $T = E/P$ = 38.85Wh/90W = 0.432h = 25.9min

**4. Result and Discussion**

4.1 Motion Analysis:

In order to understand the movement of the hexapod in question, it is necessary to show its motion from various perspective in both translational and rotational movement. For this, the motion of the body itself and the motion of each foot-end will be shown using different figures.

4.2 Foot-end Trajectory

Movement along x-axis for all Legs

To show the comparative position of all the foot-ends, the variation of their positions along x axis has been plotted in Fig.6. As it can be seen, the L1, R2 and L3 legs started moving from the very beginning at t=0

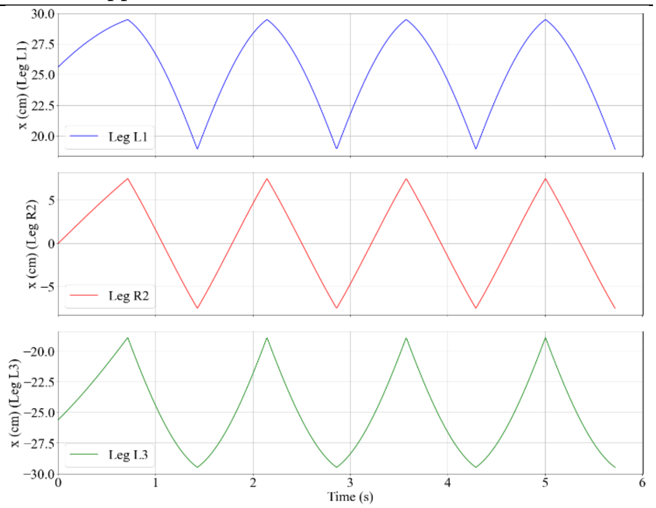


**Fig.6** Variation of position along x-axis for legs L1, R2 and L3 for translational movement

But the other three legs, R1, L2 and R3 were fixed in their position for about 0.7s. After that, they start moving at constant frequency, maintaining an order of forward movement after backward, and so on. This can be seen in Fig. 7.

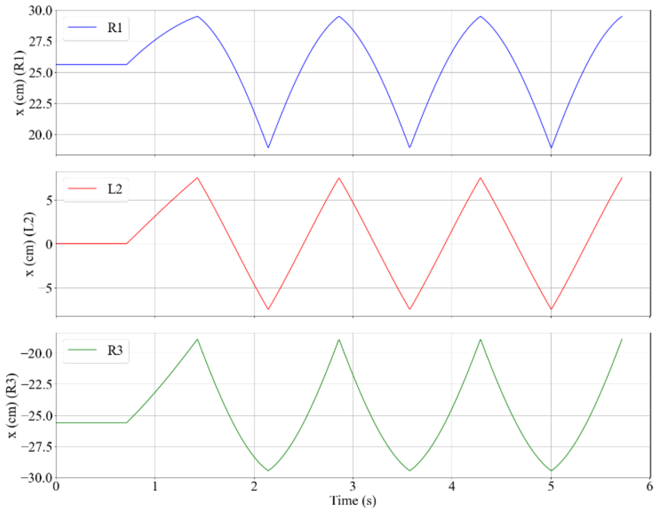


**Fig.7** Variation of position along x-axis for legs R1, L2 and R3 for translational movement

In Fig.8, the variation of position of foot-ends along y axis has been shown. In this case, the middle legs, L2 and R2 show a different pattern compared to other legs. The frequency of movement is found to be double for L2 and R2. On another note, keeping with the same patterns in x variation, the R1, L2 and R3 show an initial period of inactivity, after which consequent forward and backward movements can be seen. The graphs show an inverse pattern in legs from left and right side, signifying that their motions were opposite, as in when a leg on side was moving forward, its counterpart on the right side was going backwards.

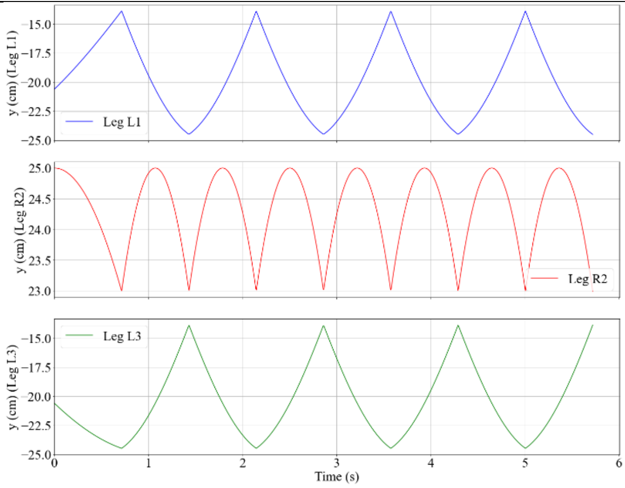


**Fig.8** Variation of position along y-axis for legs L1, R2 and L3 for translational movement

Finally, with Fig.9, the variation of position of the legs have been shown along the z axis. Notably, two plots were enough to show these variation as 3 of the legs followed the same movement patterns at all times. For example, when the leg R1 is at the floor, it means the L2 and R3 are also at the floor. The function of movement itself, was linear, as opposed to sinusoidal; which was the case for x and y axes movement.

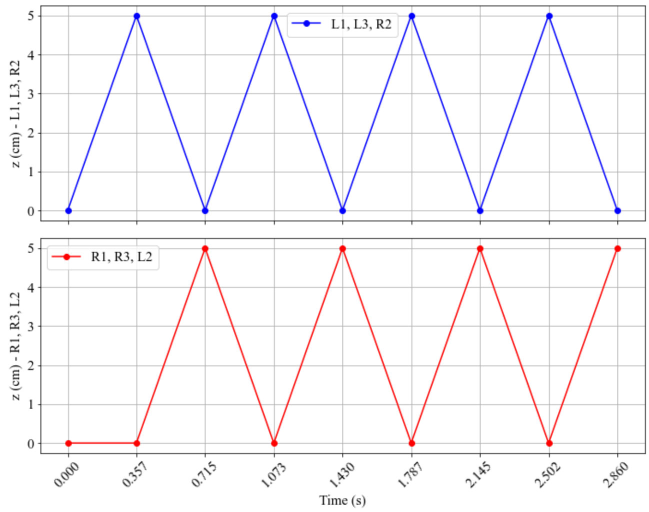


**Fig.9** Variation of position along z-axis for all the legs for translational movement

4.3 Rotary Movement

The hexapod's rotational movement will be discussed in this section. Specifically, the movement pattern for clockwise movement has been shown in the following figures. The rotary movement shows a similar pattern to translational movement, as depicted in Fig.10. The difference is that L1, R2 and L3 show an initial period of inactivity. This is because to turn clockwise, the other set of legs needed to make the first movement. After this, the x-positional graph for translational and rotational movement are identical.

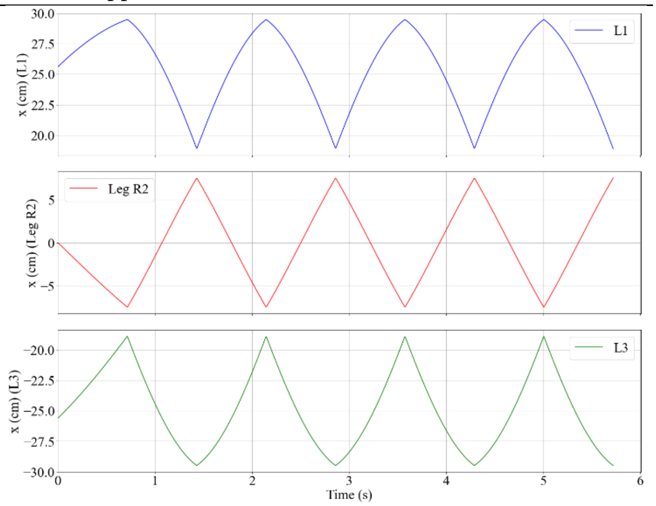


**Fig.10** Variation of position along x-axis for legs L1, R2 and L3 for rotational movement

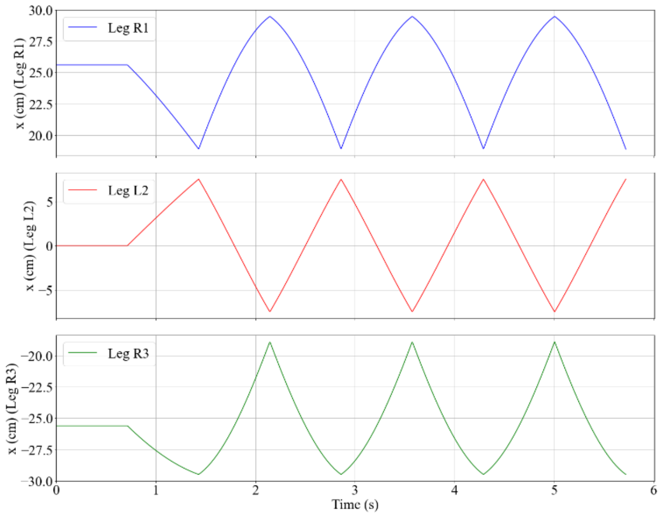


**Fig.11** Variation of position along x-axis for legs R1, L2 and R3 for rotational movement.

For y-axis motion, a similar trend can be seen in figure 11.

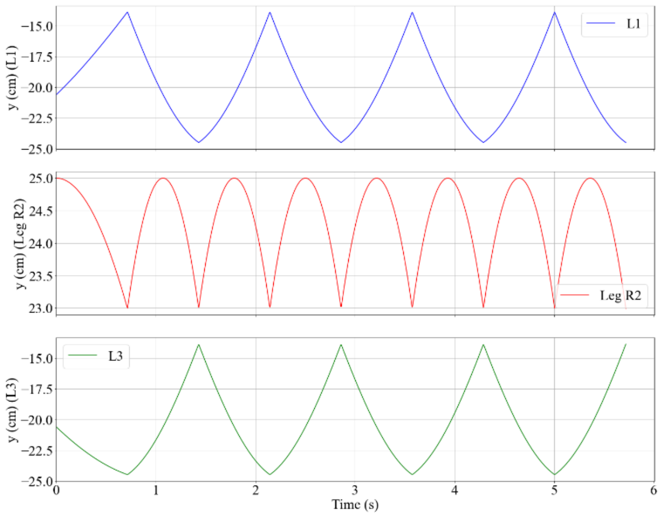


**Fig.12** Variation of position along y-axis for legs L1, R2 and L3 for rotational movement

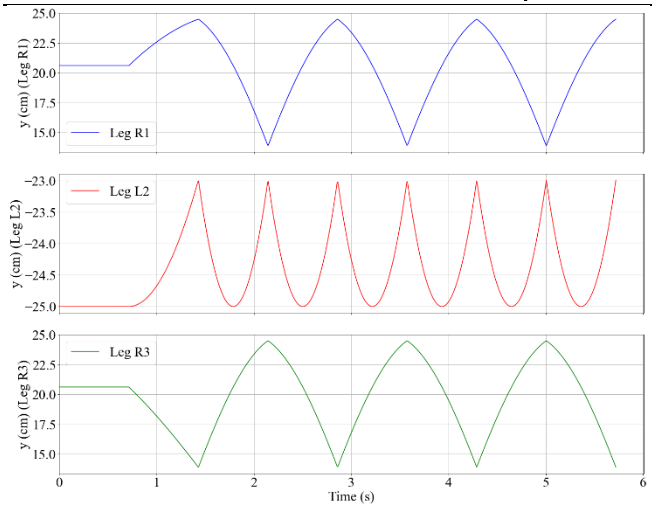


**Fig.13** Variation of position along y-axis for legs R1, L2 and R3 for rotational movement.

The variation of motion along z-axis hasn't been shown here, as it is identical to the same for translational movement.

4.3 Body Motion

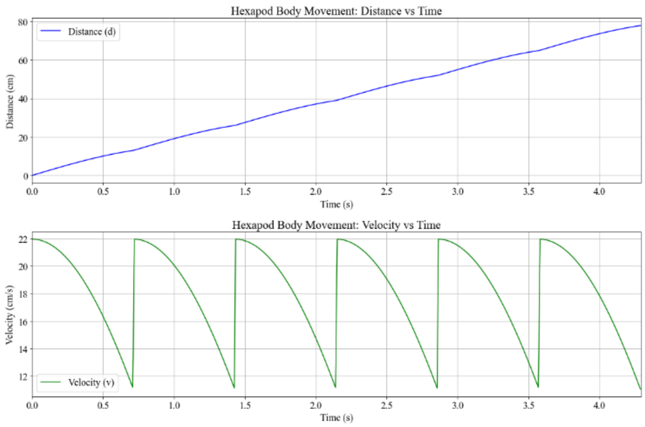


**Fig.14** Variation of position and velocity of the hexapod over time for translational movement.

As the hexapod moves forward, its position varies with time seemingly linearly, but a closer inspection shows a sinusoidal motion. Here, forward movement has been defined as the movement along the x axis. At around 0.7s, there is a break in the continuity of the graph that responds to a stop in motion for the body. This point represents the midpoint of the leg motion's velocity. This is the point where one set of legs stops moving and the other set starts moving. An ideal case has been shown in Fig. 14, so there is no delay visible.

Though the position shows a continuous increase over time, the velocity graph shows a more sinusoidal motion that ranges from around nearly 12 cm/s to 22 cm/s. As time passes, the velocity decreases more steeply, finally reaching the minimal value, and increasing again. This trend persists continuously for velocity of the hexapod over time.

## 5. Conclusion

High speed dynamic tripod gait ensures the stability of the robot running on even or uneven terrains, making it highly adaptable to challenging environments. At any moment during movement, hexapod uses its three legs for motion by creating torque and for carrying body weight.

With some sensing improvements the hexapod can be used for rescue missions, hazardous industrial tasks, and other high-risk applications where human intervention is either dangerous or inefficient.

## 7. Acknowledgement

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