6-LEGGED CRAWLING ROBOT FOR VIRTUAL TELEPRESENCE

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Abstract: In recent times robotics plays an important role in innovation. Robotics combines science, technology, and engineering to build robots. Humans try to construct robots that are structurally similar to that of animals and insects. This allows us to compare and imitate the animal movement and their walking pattern. Inverse kinematics is a method of determining the values that we need to move to a particular position. With this idea, we have developed a 6- legged robot and observed the tripod gait algorithm using inverse kinematics. The hexapod has a camera module attached which helps and video streaming and provides a virtual view in a local network. Additional features like pan and tilt options for the camera module helps the user to get a better view of the surroundings.

Index Terms **- Hexapod, Tripod gait, Legged-robot, Virtual telepresence, Inverse kinematics, Video streaming, Automatic, Arduino, Raspberry Pi.**

I. INTRODUCTION

A robot is a machine that could be programmable by a PC and is equipped for doing an intricate arrangement of activities naturally. Robots can be guided by an external control contraption or the control may be introduced inside. They can be independent or semi-self-sufficient and run from humanoids to modern robots, clinical working robots, and even tiny nanorobots. By mirroring an exact appearance or mechanizing developments, a robot may pass on a feeling of knowledge or thought of its own. Strolling robots recreate human or creature movement, as a trade for wheeled movement.

Legged robots are a kind of portable robot, which utilizes verbalized appendages, for example, leg systems, to give motion. Legged movement makes it conceivable to arrange lopsided surfaces, steps, and different territories that would be hard for a wheeled robot to reach, just as makes less harm natural territory as wheeled robots, which would dissolve it. Numerous legs permit a few unique strides, regardless of whether a leg is harmed, making their developments increasingly helpful in robots moving items. Legged robots are intended for velocity on harsh landscape and require control of leg actuators to look after equalization, sensors to decide foot arrangement, and arranging calculations to decide the course and speed of development. The occasional contact of the legs of the robot with the ground is known as the stride of the walker. Legged robots can be ordered by the number of appendages they use, which decides strides accessible. Many-legged robots will in general be increasingly steady, while fewer legs fit more prominent mobility.

Six-legged robots, or hexapods, are persuaded by a longing for considerably more noteworthy steadiness than bipedal or quadrupedal robots. The structures frequently impersonate the mechanics of creepy crawlies, and their steps might be ordered also. These incorporate wave gait, tripod stride, creep step, swell step. A hexapod robot is a mechanical vehicle that strolls on six legs. Since a robot can be statically steady on at least three legs, a hexapod robot has a lot of adaptability by the way it can move. On the off chance that legs become debilitated, the robot may at present have the option to walk. Besides, not the entirety of the robot's legs is required for strength; different legs are allowed to arrive at new foot arrangements or control a payload. Hexapods might be utilized to test natural speculations about creepy crawly motion, engine control, and neurobiology.

Furthermore, including a camera module to the legged robot helps in obtaining a virtual view of the surroundings. The person can look around from the perspective of the robot. Video streaming from the Raspberry Pi camera can be viewed in any web browser or a smartphone that is present and connected to the same network as that of the Raspberry Pi.

II. LITERATURE SURVEY

2.1 Kinematic and Gait Analysis Implementation of an Experimental Radially Symmetric Six-Legged Walking Robot [1]

As a robot could be steady statically remaining on at least three legs, a six-legged strolling robot can be exceptionally adaptable in developments and perform various missions without managing genuine kinematic and dynamic issues. An exploratory six-legged strolling robot with 18 degrees of opportunity is contemplated and worked in this paper. The kinematic and stride examination details are exhibited by an exploratory hexapod robot. The outcomes show that the robot strolls well as it was recreated.

2.2 A Novel Navigation Algorithm for Hexagonal Hexapod Robot [2]

An epic route calculation is produced for a hexagonal hexapod robot that utilizes the ideal step for movement. This calculation produces close to maximal stroke tripod step for strolling on the ordinary territory. The issue of ideal step age for a six-legged strolling machine, the hexapod, is tended to in this exploration. Cutoff points on the least soundness edge, greatest foot power, foot movement, and impact between neighboring legs are considered for producing the step. The calculation can be utilized with minor changes, for creating an ordinary stride like wave stride for strolling on slanted planes just as steps. We have additionally built up a technique to perform obstruction shirking and territory arrangement in static questionable conditions by utilizing diverse stride of velocity with walk change between tripod step and wave step.

2.3 Locomotion analysis of hexapod robot [3]

In this paper, the movement of symmetric hexapods has been concentrated in detail. We have introduced a complete investigation of hexagonal hexapod walks including ordinary and shortcoming lenient ones. Strides of rectangular and hexagonal six-legged robots have been looked at from a few angles: solidness, adaptation to non-critical failure, landscape versatility, and strolling capacity. To encourage recreations and tests we have given coordinated kinematics of swinging and supporting legs for nonstop walks. Hexagonal hexapod robots have been demonstrated to be more adaptable than rectangular ones. Also, hexagonal hexapods have numerous practical steps. Notwithstanding the surely understand creepy-crawly stride and well-evolved creature step, another blended walk for hexagonal six-legged robots has been proposed in this part which involves a few highlights of both bug and vertebrate strides. But ordered by legs development as referenced above, hexapod robots' strides are arranged by the quantity of supporting legs during strolling, as 3+3 tripod, 4+2 flaw lenient quadruped, and 5+1 individually steps. On record to the presentation of a blended walk, each numbered stride has one more structure. Among three tripod-walk shapes, the steadiest in the blended one. The warm-blooded animal step can arrive at the longest step; while the consistent creepy-crawly walk has the most limited greatest step and least fortunate solidness. Because of their six legs, hexapod robots have excess and adaptation to internal failure. Walks where one leg is lost or two inverse legs are lost have been examined as of late. In this part, we have handled additionally the cases where two neighboring legs or two isolated by an ordinary leg are harmed. Calculations for understanding these two issues lenient steps have been point by point and approved with reenactments.

2.4 Design Issues for Hexapod Walking Robots [4]

Hexapod strolling robots have pulled in extensive consideration for a few decades. Numerous examinations have been done in the research focuses, colleges, and businesses. Be that as it may, just in the ongoing past have productive strolling machines been imagined, planned, and worked with exhibitions that can be reasonable for common sense applications. This paper gives an outline of the best in class on hexapod strolling robots by alluding both to the early plan arrangements and the latest accomplishments. Cautious consideration is given to the principle configuration issues and requirements that impact the specialized liability and activity execution. A structured methodology is illustrated to methodologically plan a hexapod strolling robot. Specifically, the proposed plan methodology considers the fundamental highlights, for example, mechanical structure and leg arrangement, impelling and driving frameworks, payload, movement conditions, and strolling stride. A contextual analysis is depicted to show the adequacy and possibility of the proposed structure system.

2.5 Inverse Kinematic Analysis of a Quadruped Robot [5]

This paper presents a reverse kinematics program of a quadruped robot. The kinematics investigation is a fundamental issue in the controllers and robots. Dynamic and kinematic structures of quadruped robots are intricate contrasted with mechanical and wheeled robots. In this investigation, backward kinematics answers for a quadruped robot with 3 degrees of opportunity on every leg are introduced. Denavit-Hartenberg (D-H) strategy is utilized for the forward kinematic. The reverse kinematic conditions obtained by the geometrical and numerical techniques are coded in MATLAB. Also, hence, a program is obtained that ascertains the legs' joint points comparing to wanted different directions of robot and endpoints of legs. Likewise, the program gives the body directions of the robot in a graphical structure. The rakish places of joints acquired comparing to wanted various directions of robot and endpoints of legs are given in this examination.

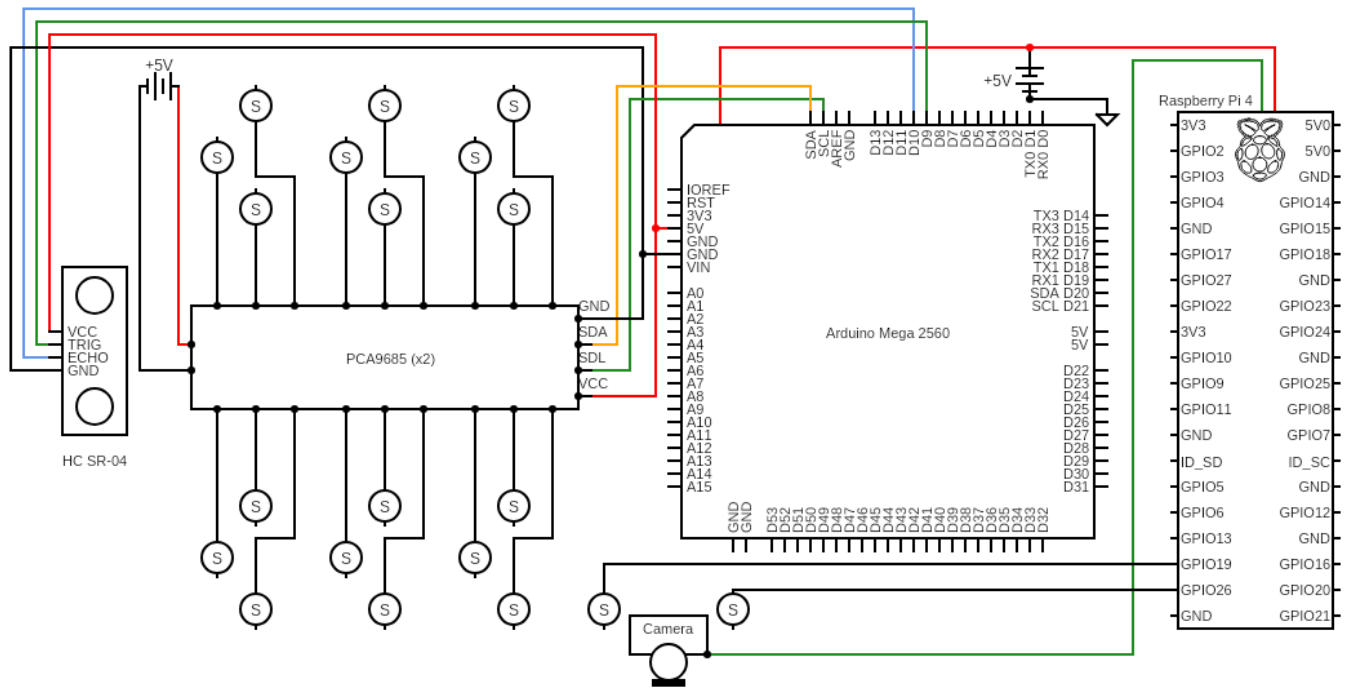**III.** DESIGN AND IMPLEMENTATION

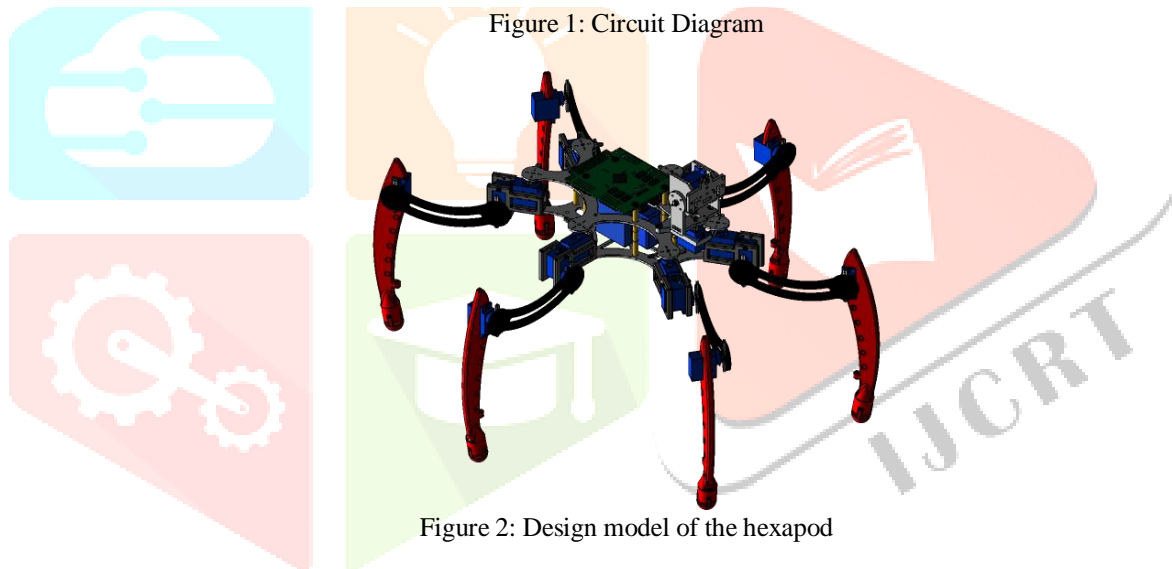Figure 1: Circuit Diagram

Figure 2: Design model of the hexapod

The main controller of the robot is Arduino Mega 2560. It acts as the brain of the robot. The consists of three motors in each leg. One each for coxa, femur, and tibia, respectively. Each leg provides 3 degrees of freedom. From Figure 1, it can be observed that the motors are connected to the PCA9685 board which is a 16-pin servo shield and is in turn connected to the Arduino Mega board. A 5V power supply is used to supply voltage and current. HC SR-04 ultrasonic sensor is connected to the Arduino Mega. An ultrasonic sensor is used to detect obstacles using ultrasonic waves. All these components constitute the working of the robot and the implementation of the gait.

The next component is the camera module. The Raspberry Pi camera is connected to the Raspberry Pi 4. This camera module is used for video streaming. Raspberry Pi uses the Apache server by default in its operations and working. The user gets the virtual view of the surroundings captured by the robot. RPi Cam web interface is used to stream the video on the web browser. MQTT acts as an agent in the interface. The user has control over the movement of the camera module. Pan and tilt options are provided for sideways and upward motion of the camera.

3.1 Hardware Components

1. **Arduino Mega 2560**

The Arduino Mega 2560 is a microcontroller board dependent on the ATmega 2560. It has 54 advanced info/yield pins (of which 15 can be utilized as PWM yields), 16 simple sources of info, 4 UARTs (equipment sequential ports), a 16 MHz gem oscillator, a USB association, a force jack, an ICSP header, and a reset button. It contains everything expected to help the microcontroller; essentially interface it to a PC with a USB link or force it with an AC-to-DC connector or battery to begin. The Mega 2560 board is perfect with most shields intended for the Uno and the previous sheets Duemilanove or Diecimila.

Figure 3: Arduino Mega 2560

2. Raspberry Pi 4

Raspberry Pi 4 Model B was discharged in June 2019[2] with a 1.5 GHz 64-piece quad-center ARM Cortex-A72 processor, on-board 802.11ac Wi-Fi, Bluetooth 5, full gigabit Ethernet (throughput not constrained), two USB 2.0 ports, two USB 3.0 ports, and double screen support using a couple of smaller-scale (HDMI Type D) ports for up to 4K goals. The Pi 4 is likewise controlled utilizing a USB-C port, empowering extra capacity to be given to downstream peripherals when utilized with a proper PSU. The underlying Raspberry Pi 4 board hosts a plan imperfection where third-gathering re-checked USB links, for example, those utilized on Apple MacBooks, erroneously recognize it and decline to give power.
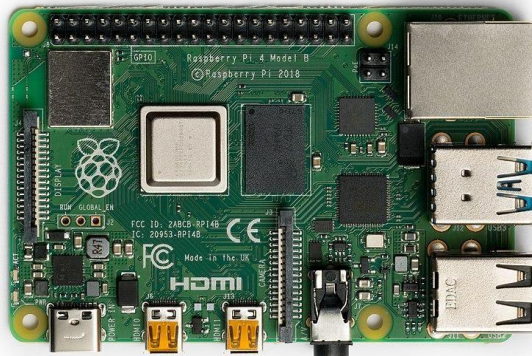

Figure 4: Raspberry Pi 4

3. Raspberry Pi Camera Module (Sony IMX219 – 8MP)

The Arducam 8MP Sony IMX219 Camera Module w/CS focal point 2718 (Raspberry Pi) is an 8MP Raspberry Pi good camera dependent on the equivalent Sony IMX219 picture sensor. It's equipped for 3280 x 2464 pixels static pictures, and furthermore bolsters 1080p30, 720p60 and 640x480p90 video. It appends to Pi by the devoted standard CSI interface. It is beneficial for Raspberry Pi's official cameras to satisfy the requests for various focal point mounts, the field of view (FOV), and profundity of the field (DOF) just as the mechanized IR cut a channel for both sunlight and night vision**.**

Figure 5: Raspberry Pi Camera Module

4. Tower Pro MG90S Servo Motors

MG90S Metal Gear Mini Servo is little and lightweight with high yield power, this small servo is ideal for RC Airplane, Helicopter, Quadcopter or Robot. This servo has a metal apparatus for included strength and durability. The servo can turn roughly 180 degrees (90 toward every path) and works simply like the standard sorts however smaller.

Figure 6: Tower Pro MG90S Micro Servo

5. Ultrasonic Sensor (HC – SR04)

An ultrasonic sensor is an instrument that gauges the separation to an item utilizing ultrasonic sound waves. An ultrasonic sensor utilizes a transducer to send and get ultrasonic heartbeats that hand-off back data about an item's vicinity. High-recurrence sound waves reflect from limits to create particular reverberation designs.
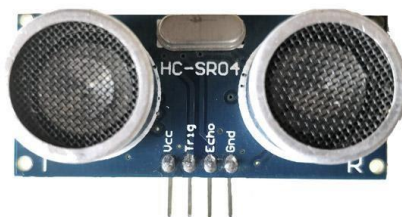

Figure 7: Tower Pro MG90S Micro Servo

3.2 Inverse Kinematics

In PC liveliness and mechanical technology, inverse kinematics is the scientific procedure of figuring the variable joint boundaries expected to put the finish of a kinematic chain, for example, a robot controller or activity character's skeleton, in a given position and direction comparative with the beginning of the chain. Given joint boundaries, the position and direction of the chain's end, for example, the hand of the character or robot, can ordinarily be determined legitimately utilizing different uses of trigonometric recipes, a procedure known as forwarding kinematics. Be that as it may, the opposite activity is, as a rule, substantially more challenging. Inverse kinematics is likewise used to recuperate the developments of an item on the planet from some other information, for example, a film of those developments, or a film of the world as observed by a camera which is itself making those developments. This happens, for instance, where a human entertainer's recorded developments are to be copied by a vivified character.

For a 3DOF hexapod, trigonometric equations make it easier to implement the inverse kinematics method.
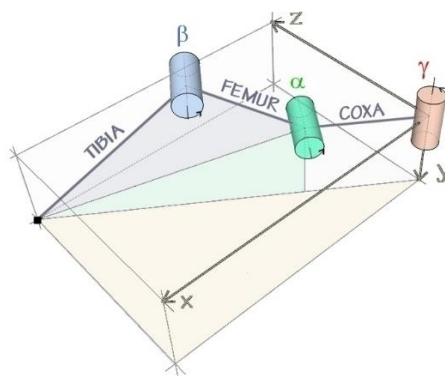

Figure 8: Orientation of leg in the coordinate system

Figure 7 shows how the leg parts namely coxa, femur, and tibia are oriented in the coordinate system. They form the angles α, β, and 	. By calculating these individual angles, it helps us to move the leg to the required position.
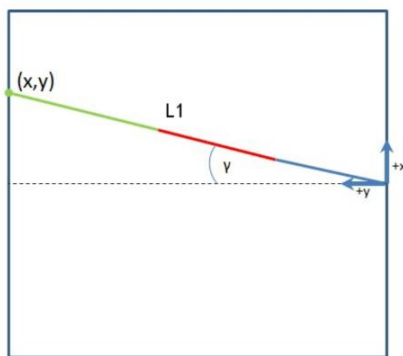
Figure 9: Leg in the x-y plane

To calculate the angle ⬚, let's consider the leg orientation in the x-y plane. From figure 8, the angle gamma would be:

$$\frac{x}{y} = \tan(\gamma)$$

$$\rightarrow \gamma = \tan^{-1}\left(\frac{x}{y}\right)$$

Now that we have the angle gamma, the other two angles can be calculated in the y-z plane.
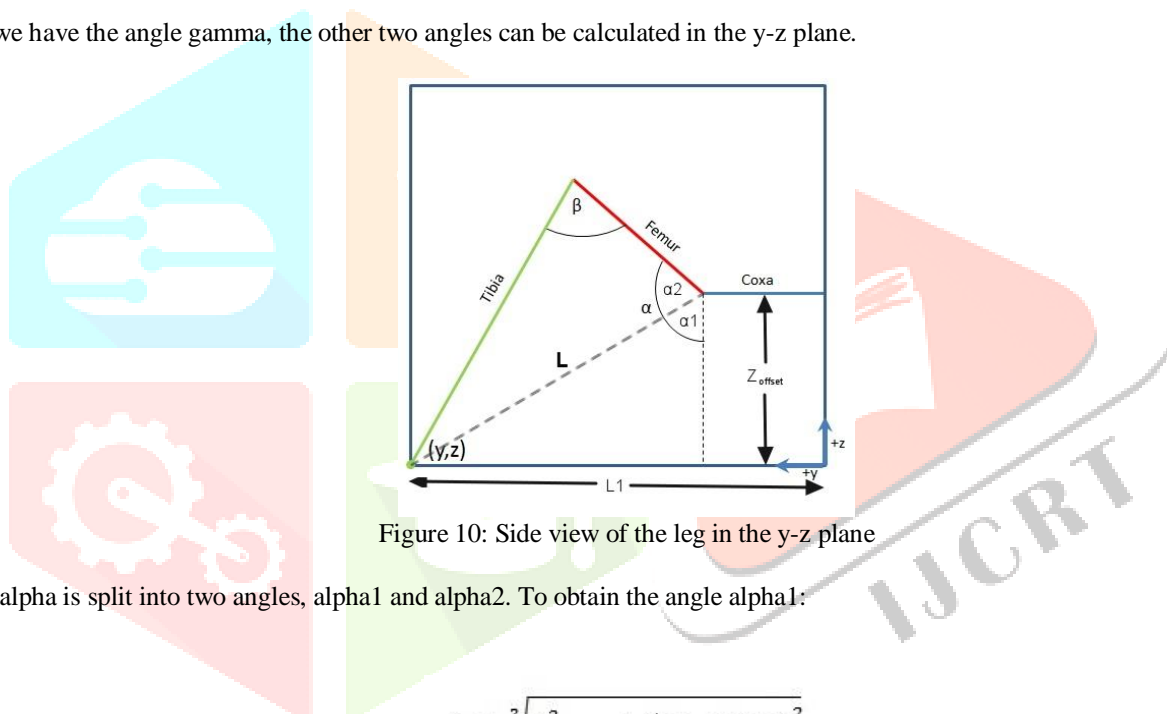

Figure 10: Side view of the leg in the y-z plane

The angle alpha is split into two angles, alpha1 and alpha2. To obtain the angle alpha1:

$$L = \sqrt[2]{z_{offset}^2 + (L1 - coxa)^2}$$

$$\alpha_1 = \cos^{-1}\left(\frac{z_{offset}}{L}\right)$$

To calculate angles alpha and beta, we make use of Cosine rule:

Cosine Rule

$$a^2 = b^2 + c^2 - 2bc \cos A$$
$$b^2 = a^2 + c^2 - 2ac \cos B$$
$$c^2 = b^2 + a^2 - 2ab \cos C$$

Which one to use depends whether the unknown is a length or an angle

The formula can be rearranged to:

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$

$$\cos B = \frac{a^2 + c^2 - b^2}{2ac}$$

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab}$$

By using Cosine rule, we get:

$$Tibia^2 = Femur^2 + L^2 - 2(Femur)(L)\cos(\alpha_2)$$

$$\rightarrow \alpha_2 = \cos^{-1}\frac{Tibia^2 - Femur^2 - L^2}{-2(Femur)(L)}$$

Alpha is given by,

$$\alpha = \alpha_1 + \alpha_2$$

$$\alpha = \cos^{-1}\left(\frac{Z_{offset}}{L}\right) + \cos^{-1}\frac{Tibia^2 - Femur^2 - L^2}{-2(Femur)(L)}$$

Finally, the angle beta obtained would be:

$$L^2 = Tibia^2 + Femur^2 - 2(Tibia)(Femur)\cos(\beta)$$

$$\rightarrow \beta = \cos^{-1}\frac{L^2 - Tibia^2 - Femur^2}{-2(Tibia)(Femur)}$$

3.3 Walking Gait

Gait is a periodic pattern of motion that aids the locomotion of the system through a sequence of steps, where each step includes lift-off and touch-down of the legs. There are three main gaits used by a hexapod robot: Tripod Gait, Ripple Gait, and Wave gait. Ant any instance, the system should ensure that at least three legs are in contact with the ground to ensure the stability of the system.

Tripod Gait Algorithm

The tripod gait of a hexapod robot is the most commonly implemented. It comprises a two-step cycle. In the first step, three legs of the system (which are not all on one side of the robot) lift and begin to swing forward, while the other three legs keep contact with the ground and help propel the robot. In the next step, the three legs make ground contact and the other set of three legs begin to swing forward. Thus, the hexapod moves forward with three legs on the ground at all times. The footfall pattern of Tripod gait is shown in Figure 11.
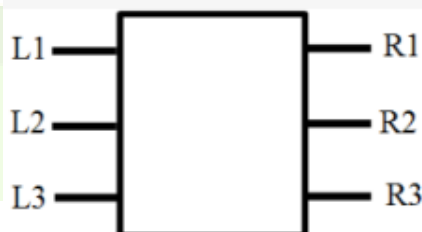

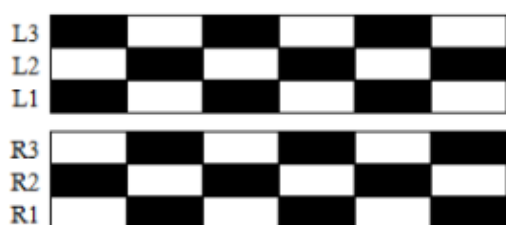Figure 10: Figure depicting the leg positions of the robot

Figure 11: Tripod gait

3.4 Camera Module

RPi Cam Web Interface may be a web interface for the Raspberry Pi Camera module. It tends to be utilized for a wide assortment of uses including observation, DVR recording and time pass photography. It is exceptionally configurable and can be reached out with the utilization of large-scale content. It tends to be opened on any program (cell phones included) and contains the accompanying highlights:

- View, stop, and restart a live-see with low idleness and high framerate. Full sensor zone accessible.
- Control camera settings like brilliance, differentiate, and live.
- Record full-HD recordings and spare them on the SD-card stuffed into mp4 holder while the live-see proceeds.
- Do coordinated or consistent video recording with parting into fixed-length fragments.
- Take single or numerous (time-lapse) full-resolution pictures and spare them on the SD-card (live-review hangs on for a short second).
- Review, download, and erase the spared recordings and pictures, compress download for numerous documents.
- Trigger catches by movement location utilizing inside or outside discovery forms.
- Trigger catches by many booking prospects.
- Roundabout cushion to catch activities paving the way to movement identification.
- Control Pan-Tilt or Pi-Light.
- Shutdown/Reboot your Pi from the web interface
- Show comments (e.g. timestamp) on live-see and taken pictures/recordings.
- Supports choice from 2 cameras when utilized with a process module.

The captured video is streamed in MJPEG format. Motion JPEG is a format in which each video frame is compressed into a separate JPEG image. This format is used by digital cameras, webcams, and IP cameras. This format can be viewed using web browsers and supported by plat station console.

3.5 Simulation using CoppeliaSim Pro

CoppeliaSim is a robotic simulator software that is controlled using an embedded script, a plugin, or a custom solution. The controllers can be written in any language like Java, C, C++, Python, Lua, Matlab, etc. An integration Lua script makes this software very versatile providing great functionalities to the user.

The main features of CoppeliaSim are:

- Different programming approaches
- Powerful APIs
- Remote API
- Inverse/ Forward kinematics
- Collision detection
- Cross-platform
- Full-featured scene hierarchy
- Integrated edit modes
- Full interaction
- Motion library

The simulator is customizable. An embedded script can be used to customize a simulation of any given scene or model by writing Lua scripts which are very easy and flexible. Two major types of embedded scripts supported by CoppliaSim:

- Simulation scripts: These scripts are executed during the simulation and help to customize the simulation model. The main simulation takes place via the main script and models or robots are controlled via child scripts.
- Customization scripts: These scripts can be executed when the simulation is not running and is used to customize a simulation scene.

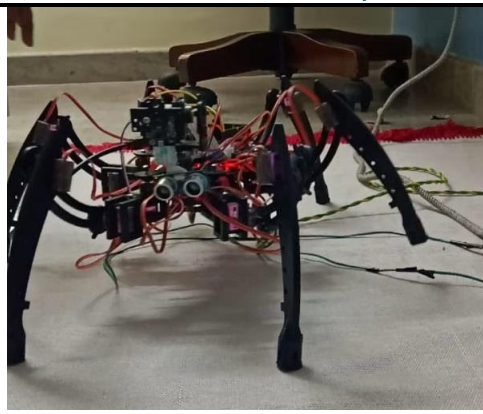## IV. TESTING AND RESULTS

Figure 12: Model of hexapod

Figure 13: Robot during gait implementation

Figure 12 and 13 shows the hexapod's walking implementation. The robot moves using tripod gait in flat terrain and surfaces. The robot gets its stability with three legs that are in the stance phase and the other three legs are in the swing phase.
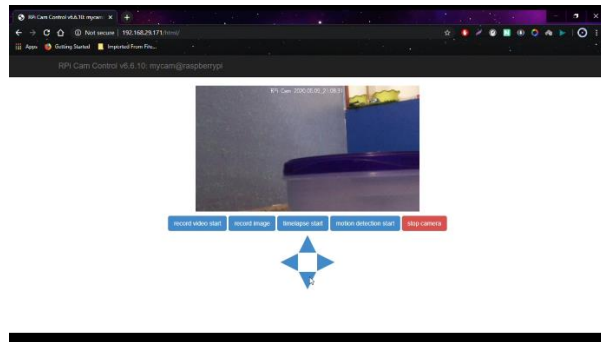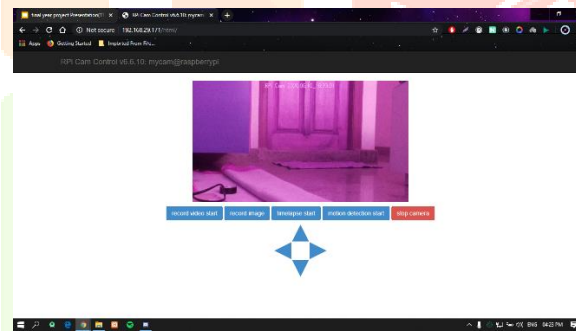

Figure 14: Pan tilt of the camera module

Figure 15: Video streaming on the web browser

Figures 14 and 15 represent the streaming of video using the Raspberry Pi camera module. The streaming can be viewed in the web browser using the local network. The browser has four buttons for pan and tilt options of the camera. The movement of the camera ranges between 170° in both the axes. Additional features like Image record, time-lapse record are also provided to the user.
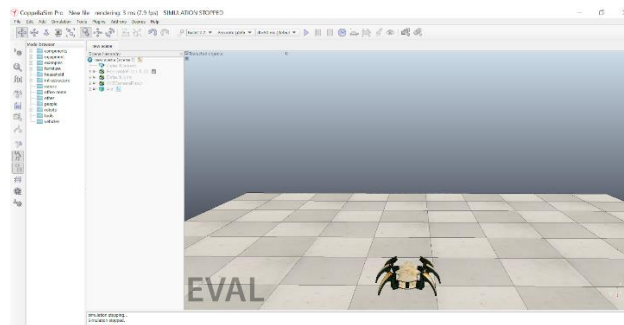

Figure 16: Hexapod simulation using CoppleiaSim

Figure 16 shows the implementation of a hexapod model using simulation software. The simulation implements inverse kinematics and dynamics.

Table 1: Result tabulation

Length of Coxa (in cm)	3
Length of Femur (in cm)	9
Length of Tibia (in cm)	15
Diagonal length (in cm)	49
Weight of the robot (in g)	521
The dimension of robot l*b*h (in cm)	39*39*20.3
Speed of robot's waking (cm/sec)	4
Speed of walking in simulation (cm/sec)	4.97
Camera module pan-tilt angle range	170°

Table 1 shows the final results obtained from the project experimentation.

V. CONCLUSION

In this paper, a hexapod robot uses inverse kinematics and the tripod gait algorithm is implemented. The camera module attached to the robot helps in video streaming and helps in ground surveillance applications. The hexapod is easy to maintain static stability on three or more legs. The robot's structure provides robustness to fault tolerance. An ultrasonic sensor helps in identifying obstacles and the robot moves automatically.

VI. FUTURE ENHANCEMENTS

In the future, the robot can be implemented using various other gait patterns like wave gait and ripple gait. The stability of the robot model can be improved by choosing a better robot body so that smooth movements can be achieved. The robot's model can be extended with furthermore sensors like for detection sensors and laser sensors to make the robot move in all terrains. The surveillance which is limited to the local network can be extended. The user can be given a choice for the robot's movement by using a joystick or an application.

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