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Development of Hexapod Robot with Computer Vision

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Abstract: Nowadays many robotic systems are developed with lot of innovation, seeking to get flexibility and efficiency of biological systems.

Hexapod Robot is the best example for such robots, it is a six-legged robot whose walking movements try to imitate the movements of the insects, it has two sets of three legs alternatively which is used to walk, this will provide stability, flexibility and mobility to travel on irregular surfaces. With these attributes the hexapod robots can be used to explore irregular surfaces, inhospitable places, or places which are difficult for humans to access.

This paper involves the development of hexapod robot with digital image processing implemented on Raspberry Pi, to study in the areas of robotic systems with legged locomotion and robotic vision.

This paper is an integration of a robotic system and an embedded system of digital image processing, programmed in high level language using Python. It is equipped with a camera to capture real time video and uses a distance sensor that allow the robot to detect obstacles. The Robot is Self-Stabilizing and can detect corners. The robot has 3 degrees of freedom in each six legs thus making a 18 DOF robotic movement. The use of multiple degrees of freedom at the joints of the legs allows the legged robots to change their movement direction without slippage.

Additionally, it is possible to change the height from the ground, introducing a damping and a decoupling between the terrain irregularities and the body of the robot servo motors.

Keywords: Hexapod, Raspberry Pi, Computer vision, Object detection, Yolo, Servo Motor, OpevCV.

I. INTRODUCTION

Currently there are many situations where humans are unable to explore or complete certain task such as finding a missing person in a building collapse, exploring a cave that has lack of oxygen and finding a missing person in the forest which is difficult for humans to search for more than 24hrs. A hexapod robot is a vehicle that walks on six legs. Since this robot can be stable on three or more legs, a hexapod robot has great deal of flexibility in how it can move. Many six-legged robots are biologically inspired by hexapod walking style, these biologically inspired robot largely depends on the insect species used as model (i.e., spider) insects are used as model because their nervous systems are simpler than any other animals. Insect's gaits are mainly obtained by two approaches they are centralized and decentralized control architectures. Centralized architecture will control specific movements of all legs, whereas in decentralized architecture, the six legs are connected in a parallel network and the neighboring legs interact with each other to obtain a walking style. The first hexapod robot was built at the University of Rome in 1972 as a computer-controlled walking machine with electric drives. Later in the mid of 70's, at the Russian Academy of Science in Moscow. The robots with legged locomotion have a higher mobility than the wheeled vehicle in natural terrains. This work aims in development of mobile robotic system with legged locomotion, hexapod type with 3 degrees of freedom in each leg, Tripod Gait walking mode, with ultrasonic distance sensor and monocular vision sensor using computer vision embedded in Raspberry Pi.

II. LITRATURE SURVEY

To build this project many designs of hexapod were studied like controlling of the hexapod using servo-controller. We have gone through many theories and pre-requisites regarding the dynamics and motion of the robot. The movements of different robots and working of joints, were studied. From some of the papers we have learnt about the rotation, orthogonal twisting, revolution, linear joints of different kinds of legged robots are studied. The control method that are used significantly reduces the workload on MCU so it can communicate efficiently with the external devices. Hexapods legs are distributed radially around the body for the efficient construction.

There are more number researches related to Hexapod robot at present .

Alexander Brincalepe Campo [1] described about Hexapod robot which has image processing implemented on Raspberry Pi and explained about the Servo motor axis in the angular position corresponding to the input signal generated by Pulse Width Modulation (PWM) andtold Raspberry Pi is the best for computer vision.

TolgaKarakurt [4] described about of Six-Legged Robot and its Evolving Walking Algorithm. And explained in detail about Calculated distance value depends on the acoustic wave motion utilized. And Each legs of the robot has 3 DOF and same mechanical system.

Imran Uddin [2] said in Multitasking Hexapod Robot,that Each limbs takes 3 servo motors for motion. And the payload of hexapod robot depends on the torque of servo motors.

Object Detection on Raspberry Pi this paper tells us Open CV library is the best. Kok Wai Chan [5] described about Adaptive Intelligent Spider Robot they have explained bout the sequence of leg movements is predefined.

M. S. M. Aras [7] said in Development of Hexapod Robot with Manoeuvrable Wheel this are necessary to use it is hard to denie the usage of this robots because there are lot of natural disasters occurring across the world. The purpose to use Hexapod robot are it can also be used in this situation where it is difficult for humans access it can also be controlled remotely by human. Some robots can also be prepared to move autonomously Hexapod robot is one of a kind this robots can be used in this type of situation because it has good flexibility and stability to walk on any type of surface. Since these types of robots have more than one legs, robots can be programmed to walk around and do other types of activity such as crawling, quadruped and alternating tripod. many variety of designs are developed with different advantages and functions. In this paper, manoeuvrable wheel is used to develop hexapod. manoeuvrable wheel is used to make movement easy on either inclined surface or on flat surface. On flat surfaces manoeuvrable wheel is used for movement while it is on incline surface, the legs are used to climb. The decisions can be made by the robot to use either legs or wheels. This decision is completely based on sensors and algorithm developed at the controller and this is implemented on the robot.

Nihat Yilmaz [4] described Six-Legged Spider design and Walking Algorithm evolution. This paper has developed a Hexapod robot which can perform operations such as search and rescue operations in places which are difficult to access. Different algorithmsare designed for different walking styles. Environmental conditions can also affect Hexapod robot so these conditions are minimized. The risk of accidents are reduced. Many investigation related to the possibility of problems that may occur such as accident, battery life is large. Robot is controlledvia communication port oncomputer. The six legged robots are inspired by the spider mechanism. The robotsperformance are measured according to the movement on irregular surface.

Prof. D. S. Pipalia [14] said on Object Detection & Tracking System are done either locally or remotely with Rotating Camera for recognizing a protest that is undertaking of restriction of articles in an information picture. The meaning of a "question" shift. It can be a solitary occurrence or an entire class of articles. Complaint identification is a technique to distinguish a protest in a video or a photo outline. The question can be anything that is of enthusiasm for further investigation. Many strategies have been created to recognize a moving article utilizing a dynamic camera. Generally using static camera the articles are recognized by using foundation subtraction.

III. OVERVIEW ABOUT INVERSE KINEMATICS

The kinematic modeling of the robot can be divided into two steps: the forward kinematics and the inverse kinematics. In the forward kinematics, knowing the geometry of the robot legs, it is possible to develop a matrix mathematical model that, with the angles of each joint, calculates the position of the end of the leg that touches the ground (known as the terminal element). In the inverse kinematics, the forward kinematic matrix model is manipulated and results in a model that, with a future position of the terminal element, calculates the combination of the joint angles that would lead the terminal element to the new position. In an extrapolation, it is possible to calculate trajectories to move the robot.

For the development of the mathematical model of the forward kinematics was used the Denavit-Hartemberg method. In this method, each joint is assigned to a cartesian coordinate system (xi, yi, zi), which are related by DenavitHartemberg parameters (ai, αi , di , θi) in order to reference the position of the terminal element in the robot geometric center. In the Figure 1 it is possible to observe the design of the partially assembled robot, the coordinate systems assigned to each vertex, and the definition of the displacement vector, which is the vector between the current point and the future point of the terminal element. The index of Denavit-Hartemberg parameters starts at zero in the center of the robot and is incremented on each joint toward the terminal element.

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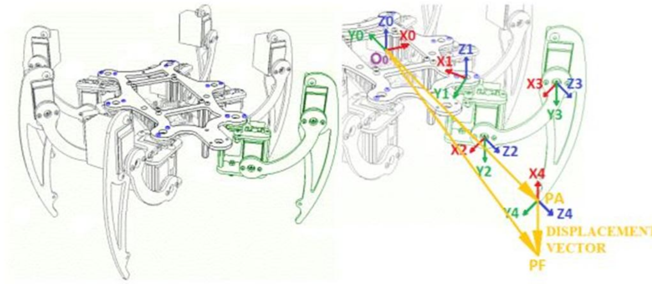

Fig 1:Hexapod Robot coordinate systems and displacement vector.

The Denavit-Hartemberg parameters represent:

ai – distance between the zi-1 and zi axes measured over the xi axis;

αi – angle between the zi-1 and zi axes measured in a normal plane to xi axis. The direction of angle is given by the right hand rule in the xi axis;

di – distance between the origin Oi-1 and the xi axis intersection with the zi-1 axis measured over the zi-1 axis;

θi – angle between the xi-1 and xi axes measured in a normal plane to zi-1 axis. The direction of angle is given by the right hand rule in the zi-1 axis.

The application of this method in a structure such as the legs of the robot, where all the joints are revolution joints, resulting in constant parameters ai , αi , di e θ0 and just θ2, θ3 e θ4 variables, which are the angles of the joints. The parameters of each joint are used to define Homogeneous Transformation Matrix (Fig. 2a) that represents the transformation of the coordinate system i to the coordinate system i-1. The four homogeneous transformation matrices are multiplied to generate the Global Homogeneous Transformation Matrix (Fig. 2b) which provides the forward kinematics of a robot leg and represents the transformation of the terminal element coordinate system to the base coordinate system.

$$A_i = \begin{bmatrix} \cos\theta_i & -\cos\alpha_i \mathrm{sen}\theta_i & \mathrm{sen}\alpha_i \mathrm{sen}\theta_i & a_i\cos\theta_i \\ \mathrm{sen}\theta_i & \cos\alpha_i\cos\theta_i & -\mathrm{sen}\alpha_i\cos\theta_i & a_i\mathrm{sen}\theta_i \\ 0 & \mathrm{sen}\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Fig 2.a Homogeneous Transformation Matrix

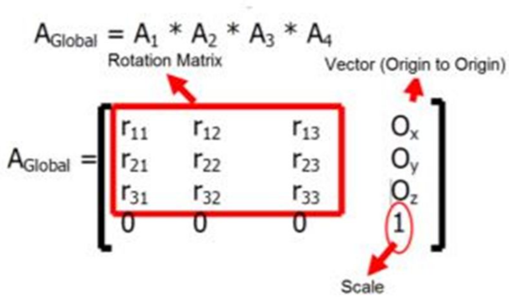

Fig 2.b Global Homogeneous Transformation Matrix

So, with the angles of each joint (θ2, θ3 e θ4), it is possible to calculate the coordinates Ox, Oy e Oz, that determinethe position of the terminal element in the base coordinate system, which is in the center of the robot. TheRotation Matrix shownrepresents the rotation of the terminal element coordinate system in relation to the basecoordinate system and has not been used in this project.

In the inverse kinematics, the vector composed by the terms Ox, Oy e Oz of the global homogeneous transformation matrix is manipulated to obtain the joint angles required for the terminal element moves to a certain position in the base coordinate system.

The Taylor series, truncated at the first derivative, results in the Eq. (1):

$$FP(k) = CP(k) + \frac{d[CP(k)]}{dk} . \Delta k \qquad (1)$$

The term PF is the projection of the future point on the base coordinate system and is obtained by multiplying the future point in the terminal composed of the terms Ox, Oy e Oz. Because it is a three-dimensional function, the derivative is replaced by a Jacobian matrix J(θk-1) which is formed by the first order partial derivatives of the vector function defined by Ox, Oy e Oz, in relation to θ2, θ3 e θ4. The term Δk is the variation of the angles θ2, θ3 e θ4 and also the variable of interest of the equation. Replacing the terms and isolating the variable of interest, results in the equation of inverse kinematics of a hexapod robot leg:

$$[\Delta\theta_i] = [J(\theta_{k-1})^{-1}]. [FP(\theta_i) - CP(\theta_{i-1})] \qquad (2)$$

Finally the joint angles required for the terminal element moves to the future point are obtained performing the addition θi-1 + Δθi. The complete process can be visualized in Fig. 3.

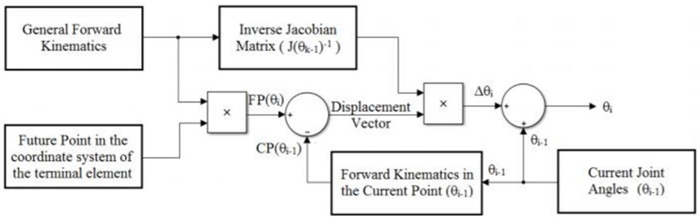

Fig 3 Inverse Kinematics

This process is performed at each point of a discretized parabolic trajectory of the robot leg. The use of a parabolic trajectory was set because it is one of the most used trajectory formats in legged robots.

IV. BLOCK DIAGRAM

1) Block diagram of working model is as follows: -

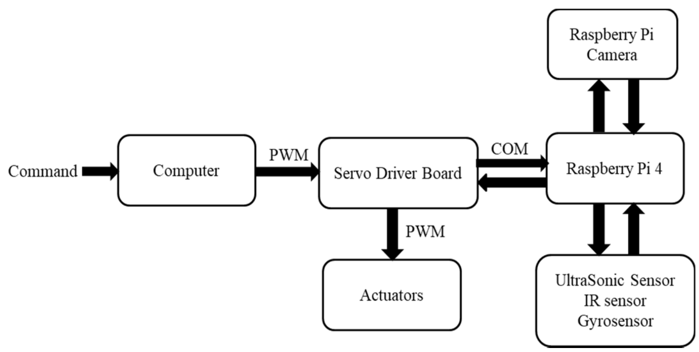

Fig 4 Block Diagram

A servo controller board which received the PWM as its input and interfaces with the Raspberry Pi and all the actuators. The change in the PWM value is indicated to the servo motors for corrections. The raspberry pi provides any error voltage based on the data collected by its on-board sensors.There are few on board sensors such as the ultra-sonic sensors, IR sensors, gyro sensors which helps in the robot navigation.

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2) Block Diagram for object detection is as follows: -

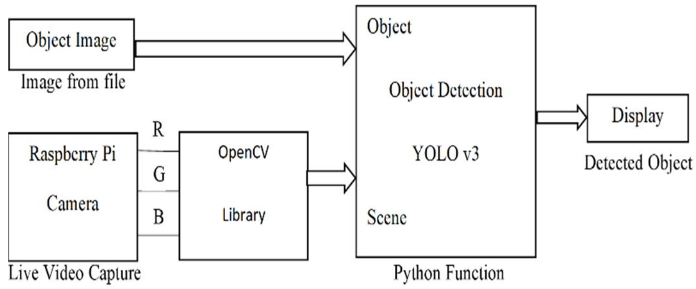

Fig 5 Block Diagram of Detecting object

Object image is the pre-defined object data set which is used to model the YOLO v3 object detection algorithm. 80 different objects are pre-defined using their image data and set is fed to the training model.

V. DESIGN METHODOLOGY

Hexapod walking robots have been one of the robots that has changed the pace in technology through several years. Many studies have been carried out in the prospect oftheir development in research centers, universities. However, only in the recent past have efficient walking machines been conceived, designed, and built with performancesthat can be suitable for practical applications. This project gives an overview of the stateof the art on hexapod walking robots and its limitations. Careful attention is given to themain design issues and constraints that influence the technical feasibility and operationperformance. A design procedure is outlined to systematically design a hexapod walking robot. In particular, the proposed design procedure considers themain features, such as mechanical structure and leg configuration, actuating and drivingsystems, payload, motion conditions, and walking gait. As in general legged robots 12 servos, 2 in each leg cannot stabilize the hexapodand efficiently is largely decreased. Hence 18 servos are used.

As the number of servomotors used for the hexapod are 18, and due to the lack of18 PWM pins in the controller board and external source or a method must be required to runall the 18 servos.

A. Hardware Requirements

The hardware components used for this project are as follows:

1) Two 18650 lithium batteries.
2) Raspberry Pi 4B with 2GB ram.
3) 32 channel servo controller driver board (LSC-32V 1.3).
4) Wireless Transmitter and Receiver.
5) 3mm aluminum alloy material for robot shell.
6) Ultrasonic Sensor (HC-SR04).
7) IR Sensor module (IRLL014TRPBF-BE3)
8) Raspberry camera 5 MP.
9) Gyro Sensor (MPU6050).
10) MG996R servo package (18 nos).
11) S90 Servo package (2 nos).

B. Software Requirements

The software required for this project are as follows:

1) Raspbian Pi Noob operating system.
2) Python 3 with Libraries required – Open CV, NumPy.
3) Object recognition data set - YOLO V3.
4) Lobot Servo Controller software.

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VI. WORKING METHODOLOGY

Fig 6 Hexapod Body

A. Servo Working

Most of the hobby servo motors operates from 4.8v to 6.5v. Higher the voltage higher the torque.Some of the hobby servo motors can rotate from 0 to 180 degree and some from 0 to 360 degree.The gears in the motors are subjected to wear and tear, for stronger and long running motors we can use metal gears.

We have used mg996r motor which has 2.5kg/cm torque, which means that the motor can pull a weight of 2.5kg when it is suspended at a distance of 1cm.

Servo are controlled by sending an electrical pulse of variable width also called as Pulse Width Modulation (PWM)

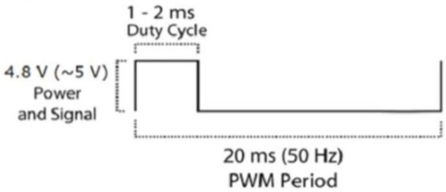

Fig 7 Pulse Width Modulation.

Out of which the On-Time can vary from 1ms to 2ms. When the on-time is 1ms the motor will be in 0° and when 1.5ms the motor will be 90°.

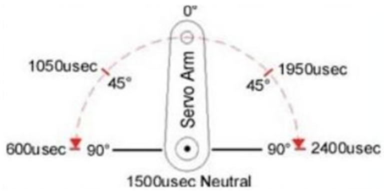

Fig 8 Robotic servo arm

We are using a 32-channel servo controller driver board which can control up to 32 servo motors at the same time.

It can be controlled using either by using a software on a pc, or UART communication (TTL serial port) of MCU to send commands and control the steering Instructions can also be downloaded on the controller board.

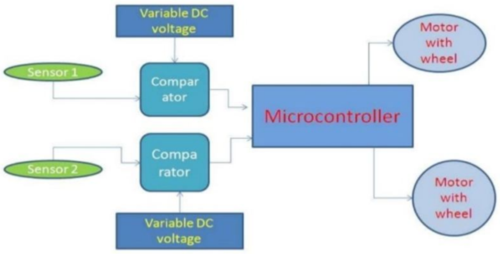

Fig 10 Block Diagram for edge detection

The sensors are mounted at front end of the robot at both left and right side. The sensors are designed to detect the light reflecting from the platform on which it is moving and at the edge, sensors don't get this light. The robot starts moving on platform and until it is on the platform it is receiving the reflected light and robot keeps moving. As soon as it reaches the edge (say left edge), the left sensor won't receive the light and the comparator sends logic 0 to the microcontroller for the left sensor. On getting this condition the microcontroller make the robot to turn right by turning only the left motor ON and making the right-side motor OFF. Reverse will happen if the right sensor detects the edge.
In this way the robot keeps moving on the platform and doesn't fall by avoiding the edges.

B. Object Detection

OpenCV-Python is a library of Python bindings designed to solve computer vision problems. OpenCV is open source and released under the BSD 3-Clause License. It is free for commercial use. The data obtained from the camera model is preprocessed using the OpenCV python library. It converts the image format from RGB to BGR as OpenCV reads all the images in BGR format only for processing the data obtained. This library helps in reducing the size if the obtained images for processing.

The Yolo v3 (You Only Look Once, Version 3) is a real-time object detection algorithm that identifies specific objects in videos, live feeds, or images.

YOLO is a Convolutional Neural Network (CNN) for doing object detection. CNNs are classifier-based systems that can process input images as structured arrays of data and identify patterns between them. YOLO has the advantage of being much faster than other networks and still maintains accuracy.

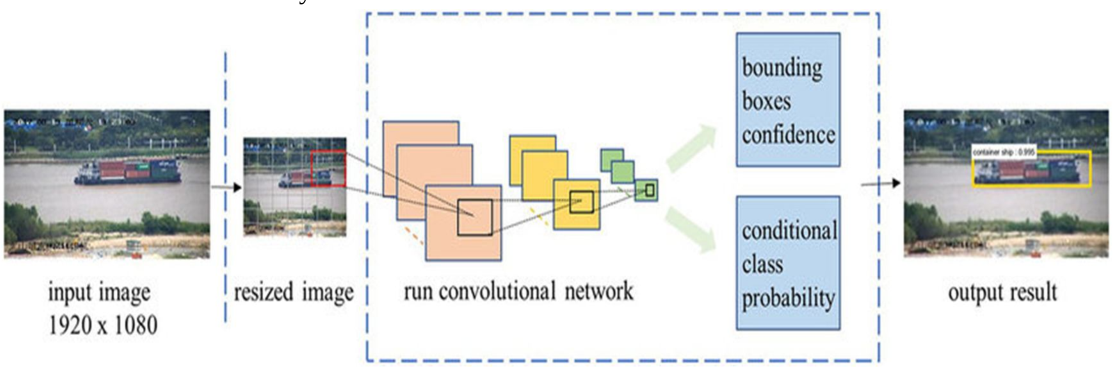

Fig 11 Convolution Neural Networks

This model takes input from the already trained object detection model and the real time input images and tries to find if there are any objects present. If it finds any object, then it will produce a bounding box around the object and displays the name of the object identified.

Fig 12 Output obtained using Yolo v3 model

C. Servo Controller Software

Lobot servo controller software is used to control the servos by interfacing the controller board with the computer using USB cable. All the PWM values are fed using this software by creating an action group.

This action group can be downloaded onto the servo controller board and can be operated wirelessly.

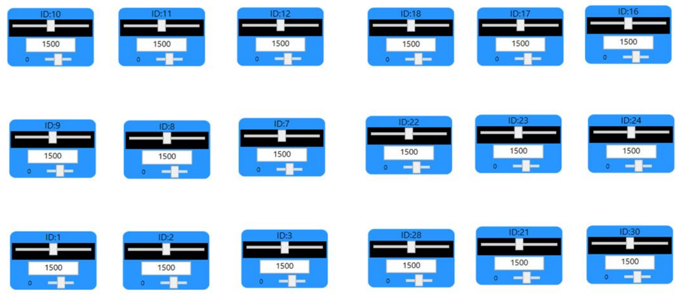

Fig 13 Layout for Hexapod control

Example for giving values to move forward: -

#1 P1700 #2 P2000 #3 P1500 #7 P1500 #8 P1500 #9 P1700 #10 P1700 #11 P2000 #12 P1500 #16 P1300 #17 P1500 #18 P1500 #21 P1500 #22 P1500 #23 P1000 #24 P1300 #28 P1500 #30 P1300 **// Lift legs 12,22,3**

#1 P1700 #2 P2000 #3 P1800 #7 P1500 #8 P1500 #9 P1700 #10 P1700 #11 P2000 #12 P1800 #16 P1300 #17 P1500 #18 P1500 #21 P1500 #22 P1200 #23 P1000 #24 P1300 #28 P1500 #30 P1300 **// Move forward 12,22,3**

#1 P1700 #2 P1500 #3 P1800 #7 P1500 #8 P1500 #9 P1700 #10 P1700 #11 P1500 #12 P1800 #16 P1300 #17 P1500 #18 P1500 #21 P1500 #22 P1200 #23 P1500 #24 P1300 #28 P1500 #30 P1300 **// Put down legs 12,22,3**

#1 P1700 #2 P1500 #3 P1500 #7 P1500 #8 P2000 #9 P1700 #10 P1700 #11 P1500 #12 P1500 #16 P1300 #17 P1000 #18 P1500 #21 P1000 #22 P1500 #23 P1500 #24 P1300 #28 P1500 #30 P1300 **//Lift next legs 7,18,28 and set earlier legs 12,22,3 to initial position**

#1 P1700 #2 P1500 #3 P1500 #7 P1800 #8 P2000 #9 P1700 #10 P1700 #11 P1500 #12 P1500 #16 P1300 #17 P1000 #18 P1200 #21 P1000 #22 P1500 #23 P1500 #24 P1300 #28 P1200 #30 P1300 **// Move forward 7,12,28**

#1 P1700 #2 P1500 #3 P1500 #7 P1800 #8 P1500 #9 P1700 #10 P1700 #11 P1500 #12 P1500 #16 P1300 #17 P1500 #18 P1200 #21 P1500 #22 P1500 #23 P1500 #24 P1300 #28 P1200 #30 P1300 **// Put down 7,12,28**

By connecting the RF transmitter to the servo control board, we can control our Hexapod robot with wireless remote.

A 2.4ghz wireless Play Station 2 style controller works perfectly with our robot control board. They have a range of 10 meters, which is powered by 2AAA batteries. It has two analog joysticks and 16 buttons available for robot control. Dual vibration motors are also provided inbuilt for feedback. Action group mode is the default mode. In this mode, every button of the handle corresponds to one action group. We can download action group to servo controller and make servo controller execute one certain action group.

VII. RESULT ANALYSIS

The result of implementation is shown from fig. 14and fig. 15, which contains the Hexapod model build. The prediction made by the algorithm to detect objects is accurate, the distance is measured through the sensor to prevent any collision is working perfectly with edge detection and self-balancing.

Fig 14 Hexapod Robot

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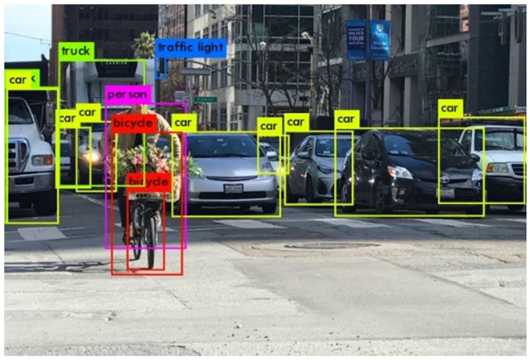

Fig 15 Reference Image used for object detection.

VIII. APPLICATIONS

Hexapod Robots majorly can be suitable for:

1) Providing stability, flexibility in movement and mobility on irregular surfaces like in Military and Défense applications.
2) Space and Aerospace applications providing easy movements and real time video transmission**.**
3) Natural Disasters where humans are inaccessible.

IX. ADVANTAGES

1) Hexapod robots have large number of advantages compared to wheeled and quadruped robots. They even have large number of real life applications, from walking cross dangerous surface to carrying out search and rescue operations in hazardous and unpredictable disaster zones.
2) Wheeled robots are faster on flat surfaces than legged robots, hexapods are the fastest among legged robots because they have the exact number of legs for walking. The studies on speed have shown that using larger number of legs does not increase the walking speed of robot.
3) Hexapods are more superior than wheeled robots because wheeled robots need pre-constructed, flat and continuous surface. Hexapod robots can travel on uneven surface, step over obstacles and even choose footholds to maximise stability.
4) Having maneuverable legs allow the hexapod to turn around on the spot either clockwise or anticlockwise
5) When it comes to stability of robots multi-legged robots have less stability compared to hexapod because they have a higher degree of stability as they can have 5 legs in contact with the ground during walking.
6) Hexapods are robust in nature, because leg faults and loss can be managed by changing the walking mechanism of the robot.
7) It is also possible to use one or more extra legs as a hand to perform other tasks.
8) The center of mass, of the robot stays consistently within the tripod created by the leg moments

Because of these benefits from the hexapod robot, these robots are becoming more and more common day by day, and it is very exciting to see what modifications might come to these type of robots in the future to improve and develop their form and function.

X. FUTURE WORK

A. Developing an autonomous control.
B. Improve the performance with stronger servo motors.
C. Reduce energy consumption.
D. Increasing movements and speed of the robot.
E. Increase stability by adding grippers the legs.
F. More precision camera for advanced computer vision.

XI. CONCLUSION

This paper encourages us to develop a legged robot rather than a wheeled robot. The model which is designed in this project is based on the structure of six legged insect(spider) and its movements. This hexapod model is designed mainly for places such as the after effects of the war and places where humans cannot go. The model also has an ability to avoid obstacle and survey.

The robot is designed to have improved performance and stability compared to the other legged robots. Experiments and tests are made on this types of robots to improve the overall performance of the robot and the future test's and experiments will be more concentrated on the energy consumption, movement and speed of the robot.

XII. ACKNOWLEDGEMENT

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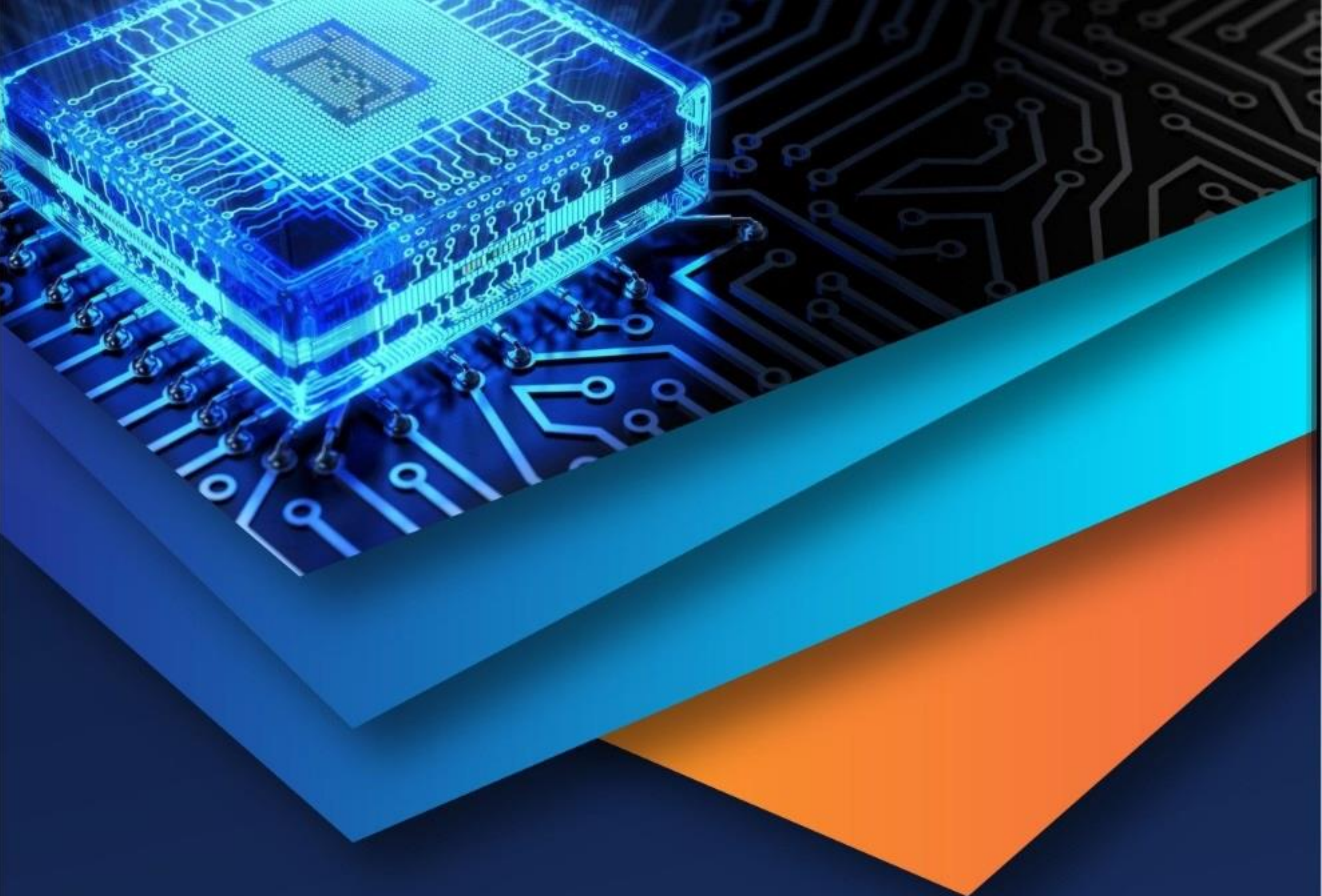

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