International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 05 | May 2020 www.irjet.net p-ISSN: 2395-0072

Six-Legged Robot (HEXAPOD) With Obstacle Avoidance and Autonomous Traversing Capabilities

PRAMOD S V[1], JOEPETER FRANCIS[2], MANASA K S[3], DHANUSH V[4]

[1]*Assistant Professor, Department of Mechanical Engineering, Sapthagiri College of Engineering, Bangalore, Karnataka, India*
[2-4]*Bachelor of Engineering (B.E Final Year) Student, Department of Mechanical Engineering, Sapthagiri college of Engineering, Bangalore, Karnataka, India*

Abstract - *Legged robots have drawn our interests in the past few decades. Conventionally robots were being utilized for automation. They use technology based on computers, electronics, pneumatics, and also hydraulics. When it comes to traversing or locomotion the wheeled and legged robots come into the picture. When it comes to many real-world problems like traversing on uneven terrain, flooded areas, or traversing on debris, wheeled robots fail to perform the required tasks. To overthrow the drawback of these wheeled robots, and to formulate a likewise vigorous and solid solution, we create an all-terrain robot, which uses legs rather than rotating elements. Certainly, a robot with a leg becomes an acceptable entity in many circumstances. It also aids or can replace humans in unsafe environments, inspection in border areas, rescuing people from natural disasters. Leg arrangement has a distinct connection spot with the ground, which is preferred deliberately. The robot is made completely autonomous by the use of artificial intelligence. The hexapod is made using aluminum alloys and so it is highly durable, lightweight, and economical. It is autonomous as the values received from the GPS and Compass sensors are analyzed and using pre-written algorithms, decisions are made, like the path to be taken and ways to avoid obstacles. In addition to this, a thermal imaging camera/infrared camera is attached to the body of the hexapod for live video recording. This video can further be used for analysis, spying, and strategy development.*

Key Words: Hexapod, Legs over wheels, Autonomous, Bio-mimicking, Artificial Intelligence, Surveillance Robot, Multi-Terrain Robot.

1. INTRODUCTION

Hexapod is a six-legged mobile robot in which each leg is programmed and attached to the framework. The movement of the body is controlled by these legs which move to meet expected movements or motion. These robots are suited for terrestrial and space operations. They also combine ingredients related to omnidirectional traversal, irregular geometry, excellent support, entry to various regions along with the fault-tolerant motion. Traversing robots are indeed complex and quite valuable machines consisting of many servo motors, ultrasonic sensors, Arduino board, and few modules related to camera, Wi-Fi, and other supporting hardware.

1.1 Literature Survey

Plenty of analysts and researchers have worked on hexapod or bio mimicking robots, on how to make them useful to humans. Marek Zak and Jaroslav Rozman have explained the need for legged robots in non-human zones. For example, in projects related to military operations and some space missions. They have also created various programs for the system to control the robot using a microcontroller unit. The robot was also tested for walking in rugged terrains and repeatability of movements.

Franco Tedeschi and Giuseppe Carbone have focused on design issues for walking robots while traversing in uneven and steep surfaces. They implemented artificial intelligence systems to the robots to analyze the environment and for traversing on complex surfaces with the help of actuators, sensors, and hardware. They involved kinematic architecture for legs. They focused more on mechanical structures of the robot, power supply, and operational features so that they don't face any issues or constraints in building hexapod.

Adarsh R S and Meher Madhu Dharmana have interpreted the trends of using mobile robots in various applications in the daily life, also other applications like surveillance operations over different terrains; it includes operations such as search and rescue. They have focused more on lightweight, modular, and inexpensive effective traversing machines.

2. DESIGN OF HEXAPOD

Design of Hexapod is divided into the following sections:

1. CAD Model
2. Materials Used and Fabrication Process
3. Electronic Components and Sensors

2.1 CAD Model

Hexapod was designed using Unigraphics software, by carefully considering the following parameters:

1. Light weight
2. Estimated load
3. Easy to manufacture
4. Economical design
5. Less reusable materials
6. Compactness
7. Mechanical flexibility
8. Tough and durable

The draft design of few parts are shown below:

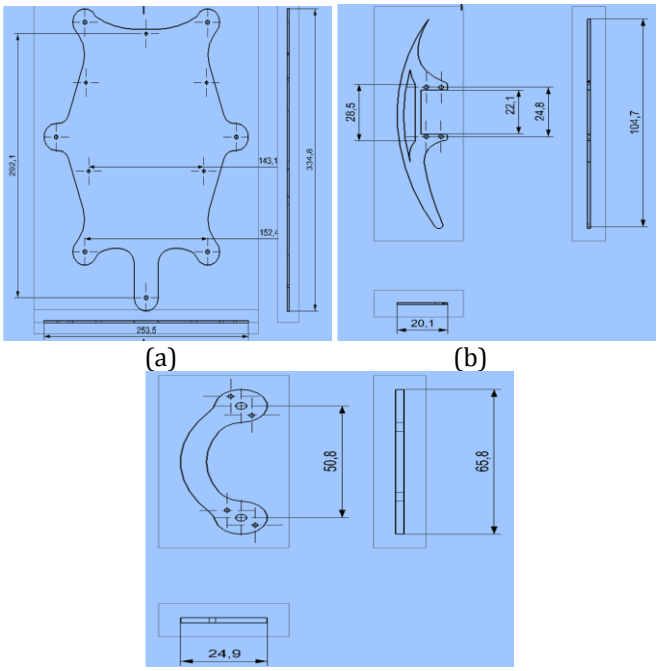


Fig -1: Figure shows **(a)** Draft design of Bottom plate; **(b)** Draft design of Leg; **(c)** Draft design of Connecting link

2.2 Materials Used and Fabrication Process

The Material used in the fabrication of the Hexapod is Aluminum. But why choose Aluminum? Certain properties of a material are given more importance to in the design of Hexapod and when a comparison is brought about between different materials, Aluminum is found to be the optimum material for the design of hexapod.

Material Properties of Aluminum:

$\sigma_{ultimate}$ MPa	E GPa	ρ Kg/m^3
552	72	2801

A Computer Numerical Control (CNC) system is used to remove materials from the Aluminum sheets and obtain the desired shape with the required dimensions.

Specifications:

1. A 3 flute carbide End mill is used. They allow a higher spindle speed.
2. Small diameter cutting tool is used to increase the feed rate and obtain smoother cuts.
3. Lithium grease is used a lubricant.
4. An air blast is used to keep the chips away from the cutter.

Note: Keeping the chips clear of the cutter is important to avoid breakage of the End mill.

2.3 Electronic Components and Sensors

The most important electronic components and their functions are mentioned below:

Wi-Fi Module (NODEMCU)
A single Wi-Fi Module is used which is a self-contained system on chip with an integrated IP protocol that can give access to the microcontroller. The command from the designed app (HEXA) is given to servo shield through the Wi-Fi module. Bluetooth can also be used instead of a Wi-Fi module, but will confine the hexapod to a certain area.

Adafruit 16-Channel 12-bit servo shield
Two Servo shield is used to receive a command signal from the Arduino, amplifies the signal and transmits the electric current to Servo motor. This Servo shield can safely drive up to 16 servos. The PWM controller will drive all 16 channels simultaneously with no additional Arduino processing overhead.

Arduino Uno
An Arduino Uno microcontroller is used; it has 14 digital pins, and 6 analog pins. Out of 12 digital pins, 6 can also be used as PWM inputs. They are used for taking inputs from the sensors, Wi-Fi Module (commands from the app). It processes all the parameters and executes the respective action as per the program written into it.

Servo Motor (MG995)
Eighteen MG995 servo motors are used in this project. These motors are very powerful and have a metal gear. It weighs about 55 grams, and has a stall torque value of 10 kg-cm. Operating voltage is between 4.8 volts – 7.2 volts. Servo motors are connected to servo shield and is powered by external power supply.

[The Arduino Uno board and the Servo shields are powered separately. In addition, ultrasonic sensors, GPS sensor, compass sensor, and Camera module are also used.]

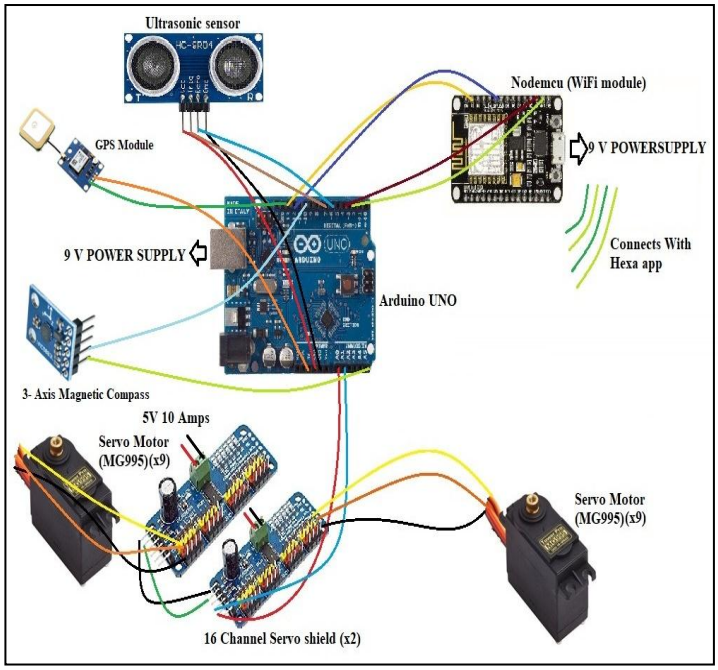


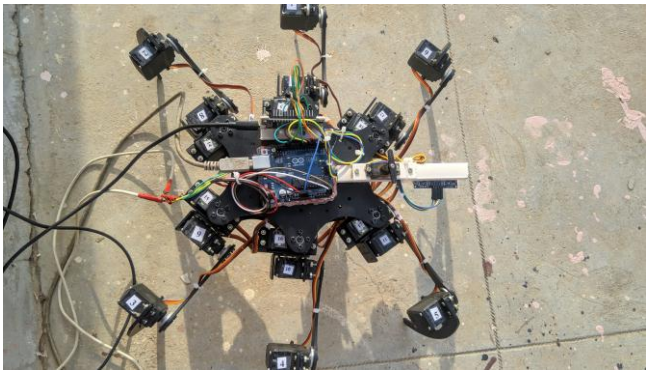
Fig -2: Figure shows the circuit diagram of Hexapod, connecting all the components

3. ASSEMBLY

There are mainly four stages of assembly,

1. The leg and link assembly along with the Servo motor.
2. Attaching the Servo motor to the Servo holders using bearing screws.
3. The sub-assembly of leg, link and the Servo motor are screwed to the base plate through Servo holders.
4. Finally, the top plate is placed completing the body of the Hexapod.

After assembly of the fabricated parts, There are two ultrasonic sensors used, out of which one of the sensor is mounted at the bottom of the base plate, that keeps a track on the distance between the base plate and the ground (when the distance between the base plate and the ground crosses 15cm, the legs automatically move 90^0 upwards making sure the impact is on the base plate and not on the legs, hence protecting legs from any damage). The other ultrasonic sensor is mounted on a servo motor that checks for obstacles ahead of the robot. Also Arduino and NODEMCU is electrically insulated at the bottom to prevent it from coming in contact with the metal body of Hexapod.



(a)

(b)

Fig -3: Figure shows the Hexapod after complete assembly **(a)** TOP VIEW; **(b)** SIDE VIEW

4. WORKING

Before getting into the working of a hexapod, few parameters need to be checked and considered. The parameters are as follows;

1. Working of electronic components and proper wiring (as per the circuit diagram)
2. Proper assembly of the Mechanical parts
3. A proper server for the HEXA Android Application (Movement/Motion control app).

The overall working of Hexapod can be divided into

1. Electronics Element
2. Mechanical Element
3. Software (Programming and app development) Element

4.1 Electronics Element

Once the Servo motors are connected to its respective slots present on the servo shield board, then external DC power is supplied through the battery. All circuits are checked for

correctness. Then it is powered (switched ON). When the user taps on one of the buttons present in the HEXA application, that is either one of forward / backward / left / right, then depending on which action is selected, an electrical impulse from the corresponding GPIO in NODEMCU (Wi-Fi Module) is sent to a digital pin present in the Arduino, which in turn initiates the program for required movement to take place. The same process keeps repeating every time the user taps on one of the buttons present in the HEXA application. Also, the ultrasonic sensor continuously monitors for any obstacle around the hexapod.

4.2 Mechanical Element

Forward and backward motion of the robot happens in three steps, whereas the left and right turn motion happen in three steps. Though the number of steps varies, the principle involved in completing the respective motion or movement is the same.

The basic principle behind the movement of hexapod is that first, it lifts all its legs and moves it one step forward, lifting two legs at a time. But the body of the hexapod remains in the same place, this step is called the preparatory step. Now in the second step, the legs stay firm in its place, whereas the body of the hexapod moves one step forward, in this manner the whole structure of hexapod completes a step. The second step is called the "blending in phase".

How much distance is covered in each step, depends on the surface on which the hexapod is operating. The distance traversed is more on a semi-smooth surface and less comparatively on a rough surface.

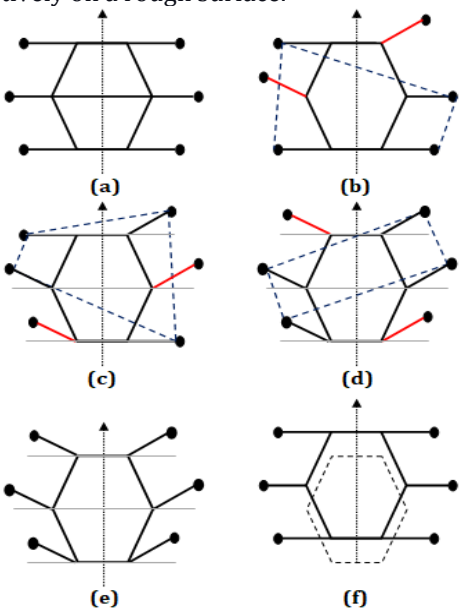


Fig -4: Figure demonstrates the moving mechanism of the Hexapod; **(a)** The initial position; **(b)-(d)** The process of moving two legs at a time; **(e)** The final position before "Blending in phase"; **(f)** Hexapod after "Blending in phase"

4.3 Software (Programming and Application development) Element

To program the hexapod requires knowledge and experience of programming in Arduino IDE and NODEMCU domains. To program the Hexapod, each motor need to be positioned to a particular angle by writing codes, for each and every position that they come across. This was done with the help of the trial and error method, and also by considering the overall stability of the robot.

Also, other factors influencing are the center of gravity, stability, inertia, momentum, and overall load carried by the Hexapod. The body of the hexapod is programmed to be in level with the legs, so as to lower the center of gravity, and in turn, improve the stability of hexapod.

6. TESTING

Subjecting a design to various levels of testing and simulations, before its induction to the real world, is an important step to ensure that the design is safe to use and complies with all the design and safety standards. Similarly the Hexapod Design was also tested for safety. Various safety tests were simulated using NASTRAN software (NX CAD). The tests conducted are test for stress and strain concentration, Factor of safety test (FOS), Displacement Analysis. The testing was performed for individual parts by applying a calculated load and reports were properly analyzed. As a result some improvisations were made into the initial design. Stress Analysis Result for base plate is shown in Fig -5, which indicates the various stress values found on the surface of base plate, when the calculated load is applied on the base plate. Displacement Analysis result is shown in Fig -6 and Factor of Safety (FOS) Analysis result is shown in Fig -7, which indicates that the base plate is safe to use under the applied load. Similarly Analysis reports for other parts of the Hexapod were also obtained and analyzed.

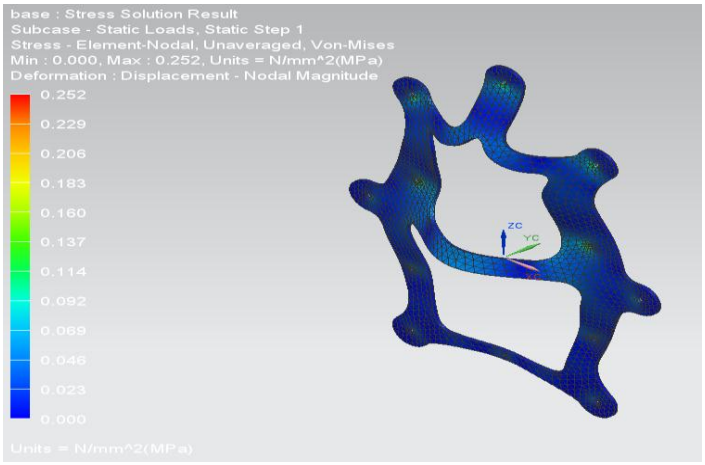


Fig -5: Figure shows the Stress analysis result.

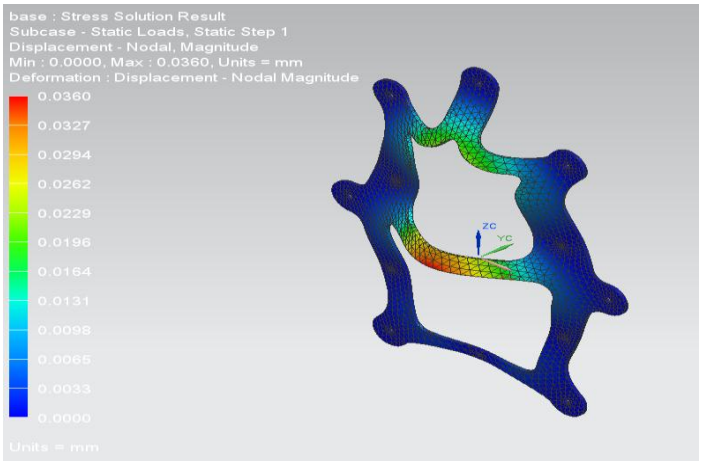


Fig -6: Figure shows the Displacement analysis result.

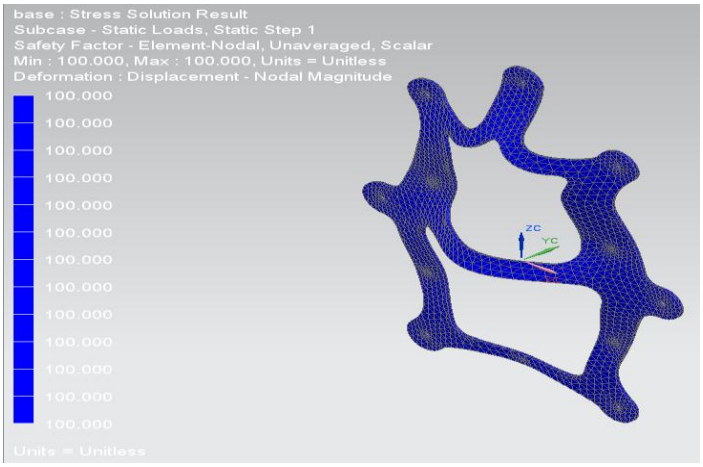
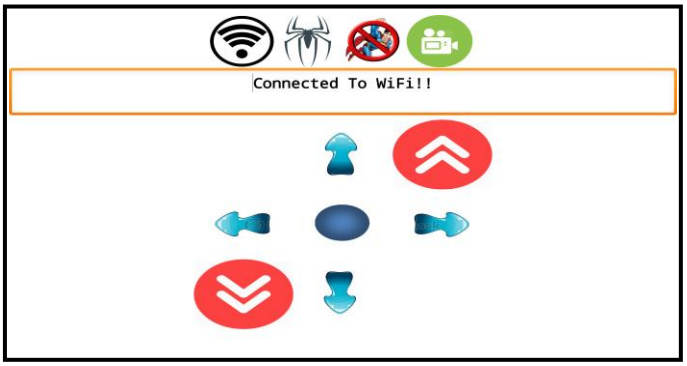


Fig -7: Figure shows the Factor of Safety (FOS) analysis result.

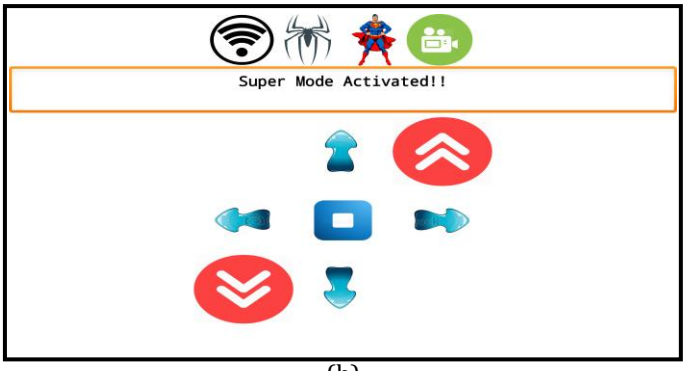
7. HEXA (Hexapod Movement/Motion Control Android Application)

HEXA is an android application developed by us, in order to control various actions performed by the Hexapod. This application was developed using MIT App Inventor, which is an online platform for new and inexperienced Android Application developers. HEXA is connected to NODEMCU (Wi-Fi Module) through a common Wi-Fi network. HEXA is a compact application, and works on all versions of Android including the latest Android 10.

(a)



(a)



(b)

Fig -8: Figure shows various screenshots of HEXA Application

8. APPLICATIONS

1. They can be used in disaster struck zone for search and rescue, in places where human presence is difficult to reach or unsafe such as in earthquake struck zones over debris.

2. Pre-Written Algorithms along with GPS module and Compass sensor makes Hexapod completely autonomous, and hence, in case connection is lost the Hexapod continues to perform the given task, which is very useful in space missions.

3. They can be used for surveillance in harsh environmental conditions such as extreme hot or cold conditions, and therefore can assist various Military forces.

4. Hexapod is an all-terrain compatible Robot, and hence can be used on uneven or irregular surfaces.

5. Hexapod can be used to travel in confined spaces such as vents, as they require very less space to maneuver over.

9. CONCLUSION

Design, Fabrication and testing of a Hexapod is done in this project. Majority of the work focuses on overcoming the disadvantages of wheeled robots and to develop a more

dynamic and a stable solution. Legs are used to create an all-terrain support robot and pre-written algorithms coupled with sensors, make it completely autonomous.

Aluminum sheets are used to make the body of the Hexapod and an android application (HEXA) is designed to manually command and control the robot to perform a specific task. Arduino Uno is used as the main microcontroller, to control the actions and movements of the Hexapod.

Arduino Integrated Development Environment (IDE) cross-platform software is used to program the Hexapod using C programming language. The Hexapod is tested for Stress concentration and Factor of Safety using NASTRAN software (NX CAD).

The Hexapod is designed to work in harsh environmental conditions autonomously without human interference. It can play a vital role in the field of research and security and can dominate during rescue missions.

The Hexapod making costs is around Rs. 20,000, including the fabrication charges, electronic components cost.

In our future work we want to involve in research of controlling Hexapod using GSM module, so that it can be remotely operated from any corner of the world.

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BIOGRAPHIES

Pramod S V, Assistant Professor, Dept. of Mechanical Engineering, Sapthagiri College of Engineering, Bangalore, Karnataka, India

Joepeter Francis, B.E Final Year Student, Dept. of Mechanical Engineering, Sapthagiri College of Engineering, Karnataka, India

Manasa K S, B.E Final Year Student, Dept. of Mechanical Engineering, Sapthagiri College of Engineering, Karnataka, India

Dhanush V, B.E Final Year Student, Dept. of Mechanical Engineering, Sapthagiri College of Engineering, Karnataka, India