

Design, Construction and Performance Test of a Rough Terrain Beetle Robot

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ABSTRACT

Nowadays, robots are moved not only over smooth surfaces with typical wheeled mechanisms but also for verities of applications a robot needs to travel over rough surfaces. It is difficult to move over rough surface using wheeled and tracked robots. So, the idea of a rough terrain robot appears to ease this situation. From the locomotion of insects and animals, researchers got the idea to invent a multilegged robot that can move easily on the rough surface with legs rather than a wheel. A vast improvement has been made in the sector of rough terrain robots since the 1990s. RHex was the most advanced version of the hexapod robot, with better velocity and stability than other rough surface robots. Over time, many improvements have been made in RHex and other hexapod robots. This paper presents a new design of a rough surface robot of beetle shape; also, can be called as an adaptation of RHex robot. This new model of a Six-legged hexapod robot focuses on mechanical simplicity with minimum power consumption. The model of the robot body is designed without any circular parts, which makes it easier to construct the body with laser cutting. This process also reduces construction costs. Acrylic is used for the body construction to reduce the total weight, and the leg is fabricated using a 3D printer. Using a DC gear motor reduces the complexity of the robot rather than a stepper motor or any other motor because of the simplicity of control. Also, the important thing of this rough surface terrain beetle robot is it uses six motors, one for each leg, which helps to move over various rough terrain with the capabilities to produce a lot of applications. Performance test on different surfaces shows that the constructed robot has the capabilities to perform the movement accurately. This robot can achieve forward movement, running, and turning capabilities with a more straightforward control method using the Android Application.

Keywords: Hexapod, Six-legged robot, Rough surface robot, Beetle Robot, Legged robot.



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1. Introduction

Nowadays, service robot has taken a massive role in all sectors. For a robot, moving on a smooth surface is easy, but when it needs to move on a rough surface, then it becomes challenging. Spy robots or typical observing robots are not suitable for moving in rough terrains like hilly tracks, jungles, and rocky areas because of their wheeled mechanisms and the wheel's shape. A rough terrain robot can solve this problem by moving on those surfaces with its different wheel shapes and unique design model.

Legged robots are one of the latest inventions in this rough terrain robot area. They are the imitation of insects and animals because of their mechanical limbs to move on rough terrain [1]. Developing these types of robots creates some difficulties, mainly the navigation of uneven stairs and obstacles in the way of running [2]. To solve these difficulties, scientists found efficient ways to move animals and insects on uneven terrains, leading them to build a six-legged hexapod robot with low-cost operating features [3]. One actuator in each hip of a six-legged hexapod robot can be crucial in traveling on dangerous and unclear terrains. This robot is not only an intelligent autonomous robot but also a cost and energy-efficient one to navigate the broken, obstacle-ridden ground [4].

Subterranean surfaces and environments like artificial tunnels, natural caves, and underground structures are the systems where these legged robots can be efficient for observation and other problems rather than typically wheeled robots. Existing research on robots that are primarily focused on flat terrain, such as HyQ2Max [5], ANYmal [6], MIT

Cheetah 3 [7], and TITAN-XIII [8], works on quadruped and dynamic locomotion, fast speed with high robustness against uneven terrains and disturbance. Besides, Six-legged hexapod robots like RHex, LAUREN V [9], Snake Monster [10], and MAX [11] have worked over uneven terrains because of their broader support polygon, lower center of gravity, statically stable, and quick gaits. Because of their added features, hardware, and weight complexity compared to conventional quadruped robots, hexapod robots increase reliability and velocity in unstable, rocky, and slippery terrain. It is difficult to obtain a wholly uneven or smooth surface in the real world. So, if a robot can do both quick dynamic and fast, steady locomotion in a plane and rough terrain, it will be appropriate for time-critical applications.

The main goal of developing this rough terrain robot is to make a viable solution for moving in both rough and smooth surface with low difficulties. Using Dc motor makes it less costly and simple in programming and controlling along with its ability to produce high torque in each leg. Therefore, in any tough situation, it is reliable to do its task properly.

2. Methodology

Mechanical complexity is a primary source of failure in all robotics applications, and it significantly raises the cost. Mechanical simplicity is emphasized in this design, which increases robustness and also minimize the overall cost. Also, with the thought of real-world application, a tight design parameter on the hardware and software is placed. Simple adjustments to a system designed for nonautonomous

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functioning often make autonomy impossible to implement. These limits also motivate the preference for general simplicity, with a focus on decreasing the number of actuators and relying on sensing as little as possible.

2.1 Robot Body

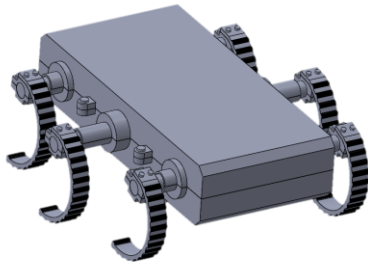


Fig. 1 Model of Rough Surface Terrain Beetle Robot

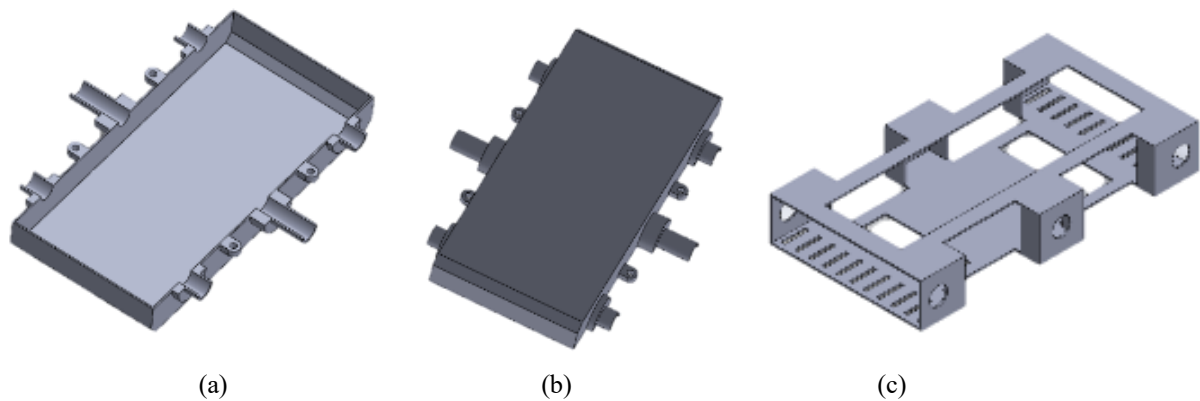


Fig. 2 Robot Body (a) Lower External Body (b) Upper External Body (c) Internal Body

The overall design is so simplified due to two external bodies are in same dimension and design. The middle two shaft cover is slight larger than the other four shaft covers. Because those two shafts are taller than others so that in the time of rotating the shafts do not hit or touch each other and can produce a smooth rotating. Plane part of this bodies is made with the laser cutting of acrylic board and the shaft covers are made using 3D printer and attaching all of them with adhesive.

The short description of the robot is presented in table 1.

Table 1 Robot Specifications.

Properties	Amount	Unit
Robot weight without battery	2.56	Kg
Robot dimension	37.5×15.5×7.95	cm
Average velocity on smooth surface	0.23	m/s
Average velocity on rough surface	0.158	m/s
Maximum working time with 1500 mAh Battery	16.14	min
Robot's capable working environment	Rough, smooth, broken, rocky and obstacle-ridden ground	

The body of the robot is made of acrylic plastic which is very light in weight with a lot of good features. Legs of the robot is fabricated using 3D Printer for the perfect shape and design. Figure 1 shows the model of the rough surface terrain beetle robot with all body parts.

There are two types of main body parts of this robot. One is external body and other is internal body. External body is used as a cover of the robot and protects the robot in all type of environment and save it from damaging. There are upper body and lower body of the external body part which is shown in Fig 2.

The internal body of the robot is used to hold six DC gear motor, microcontroller, motor driver, battery and other components as shown in Fig 2(c). Its dimension is 30×16.7×4.68 cm. This internal body is also made with acrylic. There are some blank spaces in the lower and upper surface which is used as ventilation system. It helps to pass the excess heat with the air flow and make the whole system cooler. Specially the motor and motor driver which creates a lot of heat while running. So, it is very much important to create ventilation system in the internal body.

Main advantage of the model of this rough surface beetle robot is the maximum part of the bodies are plain in shape. So, it is very easy to construct the body using acrylic board. All the body parts are made using laser cutting machine, which reduces the cost of construction than a 3D printer. Laser cutting process is the best way to cut the acrylic board. It gives precise cut and actual dimensions. It is also very much difficult to cut acrylic board with hand tool because acrylic is very much brittle. Even an uneven load during the cutting process can break this board into two or many parts. So, it is safer way to cut the board. Figure 3 represents the cutting process of the acrylic board for the construction of the robot body using the laser cutting process.

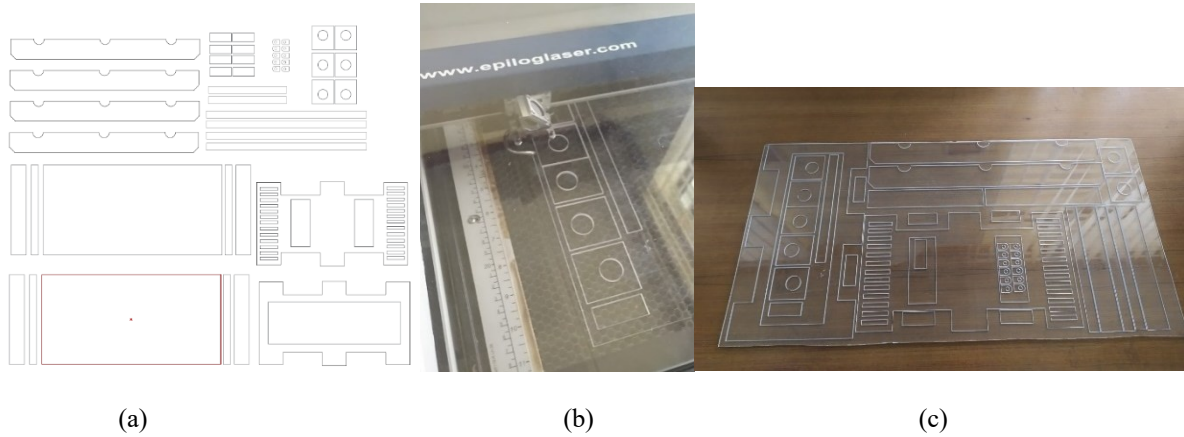


Fig. 3 Body Construction process (a) Illustrator Drawing (b) Laser Cutting of Acrylic Board (c) After the cutting

2.2 Leg of the Robot

There are six round shaped legs for this robot. Every leg is connected with one single motor to rotate separately. Inner side of the leg is smooth but the outer side has some spiked shape to give the friction for the movement on the surface. Diameter of the round shape is 12 cm and the thickness of the leg is 5 mm. So, the leg is stronger and more capable to carry the whole weight of the robot body. Leg joints are used to connect each leg with the motor shaft. These legs are made by using 3D printer. Leg joints are used to connect the leg with the rotating shaft of the motor. There are two parts of leg joint- upper joint and lower joint. Screws and nut bolts are used to connect these parts. Leg is attached with the upper joint. The whole system is connected with a 12V Dc Gear motor. So, each leg can rotate freely and can give the maximum power. Each leg can be controlled separately by the single motor. For these features, the robot can perform various operations just changing the program of the robot. The assembly of a single leg with all the parts like leg, motor joint, extended shaft are presented in Fig 4.

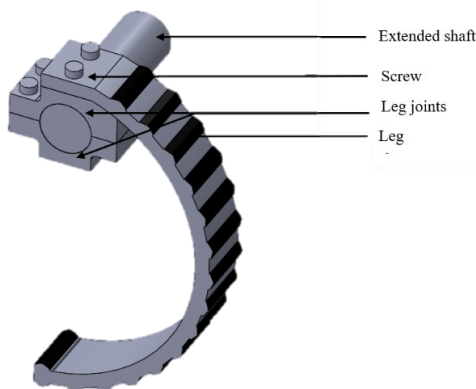


Fig. 4 Assembly of Robot Leg

2.3 Electronics Devices

The electronics devices of the robot can be divided into three parts- mobile controlling, main robot and power section. Mobile app is connected with the Bluetooth module which is also connected with the microcontroller of the robot. The UI of the Mobile app named "Bluetooth RC Controller" is showed in figure 5. This helps to control the robot from a distance of about 100 meters. Six motors are connected with six individual motor driver which all are connected with the microcontroller from where they get the signals.

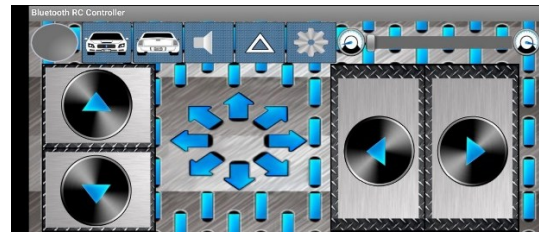


Fig. 5 UI of the Mobile App

Figure 6 represents the electronic system structure and the details of the parts are as follows

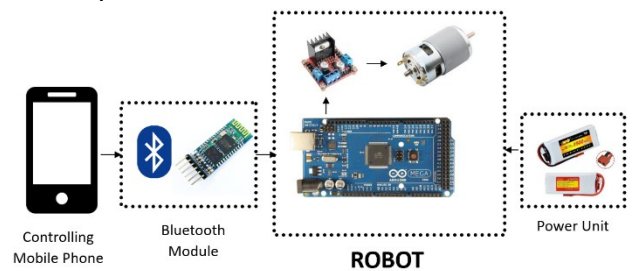


Fig. 6 Electronic parts of the Robot

- **Arduino Mega 2560**
 Input voltage (Recommended) 7-12 V
 Operating voltage 5 V
 Input voltage (Limit) 6-20V
 Digital I/O Pins 54 (15 of it provides PWM output)
 Analog input Pins 16

All of the analog pins on this board can be converted to digital I/O. This board can be used to develop the Arduino mega application. It is possible to use a wide range of sensors on these boards without experiencing any lag in performance.

- **12V DC Gear Motor 100 RPM**

Total Weight of the robot is 24.9 N. Assume the most critical situation on the rough surface, when the robot has to move with its full body weight using one leg while other can't touch the ground-

Then one leg has to carry weight of 24.9 N.

Length of leg's top to bottom which is also the diameter of the circular leg is 10 cm or .10 m

$$\text{So, the maximum required torque, } \tau = F \times r \\ = 24.9 \times .1 = 2.49 \text{ N-m}$$

Here, the rated torque of 37GB 12v DC gear motor is 10 N-m with 100 rpm which is enough for any case.

- DC Motor Driver

Each motor driver can operate two DC motors. This DC motor driver can be operated with the input voltage from 4.5-25V. Highest current flow is 600 mA per motor which means 1.2A in peak.

- HC-05 - Bluetooth Module

Operating Voltage 4V - 6V (+5V preferable)

Operating Current 30 mA

Range <100 m

- Lipo Battery 1500 mAh

It provides 11.1 V with a maximum burst rate of 90C. Its continuous discharge rate is 25C.

Load Current of this robot = 5.57 Amp = 5570 mA

Operating time, $t = \text{Battery Capacity} / \text{Load Current}$
 $= 1500 / 5570$
 $= 0.269 \text{ hr} = 16.14 \text{ minutes}$

3. Working Procedure

For moving forward, all six motors are used to lift the full weight of the body and take it forward. When the legs rotate anti-clockwise, the robot moves forward direction. After half circle rotation, the legs lift the whole body while rotating. The legs again come to its initial position after a full circle rotation and the body comes down in the ground. The

full process is shown in figure 7 graphically. There is a rubber pad under the robot body which works as a shock absorber while the robot touches the ground. The benefit of the process is it doesn't need any encoder or sensor to sense the leg's position which make the robot simpler to use.

Initially high torque is required for the movement of robot. Six 12V DC motor is enough here to do the task.

Here the total mass of the robot is 2.54 Kg and the weight is 24.9 N.

While moving forward or backward, all six motors are used to carry the total weight with six legs. For this, one leg has to carry weight of 4.15 N and required torque for this is 0.415 N-m. For turning left or right, this robot uses three legs. Therefore, it required more torque and the calculated torque is 0.83 N-m for this process.

Sometimes the robot cannot use all of its legs while moving. In some uneven terrains, robot can't make contact with the surface with all of its legs or can't rotate using all the legs. So, it needs to keep in mind that the robot should have the ability to produce that much torque in this situation. For this situation the maximum required torque is 2.49 N-m.

Here, the rated torque of 37GB 12v DC gear motor is 10 N-m. So, it is much more than the required torque of the robot. This excess torque will help to overcome some obstacles in its way of moving and produce a stable moving in the rough terrain.

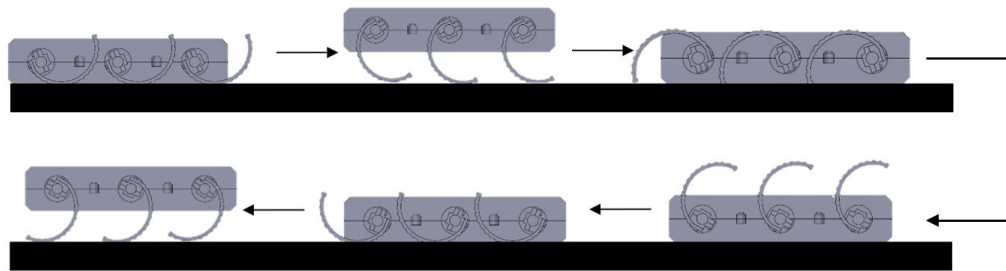


Fig. 7 Forward Movement Process of Rough Surface Terrain Beetle Robot

4. Performance Test and Result Analysis

Rough surface terrain beetle robot has been tested over both rough surface and flat surface. From the test, distance and average velocity is measured over time for three observations. There are some variations in the measured values. So, the comparison between the value in rough surface and flat surface is observed and the result of the performance test is presented below-



Fig. 8 Performance Test on Rough and Flat Surface

4.1 Distance and Average Velocity for Observation 1

Time vs distance diagram of the constructed robot over the rocky and flat surface is showed in Fig 9. This data is taken after every 5 seconds of movement. Here the line is

almost linear for the flat surface. It means that the robot has been run smoothly. It moves 13.83 meter in 60 seconds or 1 min. Where the average movement is 1.15-meter distance in 5 seconds over the flat surface. On the other hand, there are some ups and downs for the rocky surface. The robot passes more distance where the height of pebbles is low and less distance where the pebbles size is bigger.

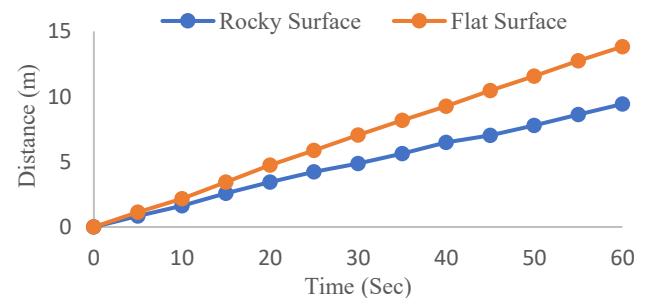


Fig. 9 Time vs Distance diagram for rocky and Flat surface (Observation 1)

The average velocity over time diagram for both rocky surface and flat surface showed in Fig 9. The average velocity in every 5 second is measured by total distanced covered divided by time. For the flat surface the change of velocity is not differ too much because there were no obstacles on the terrain. Sometimes the velocity increases a little due to gravitational force when the beetle robot goes downwards and speed decreases when the robot moves upward. The maximum velocity of the robot is measured 0.26 m/s and the average velocity is 0.235 m/s on the flat surface.

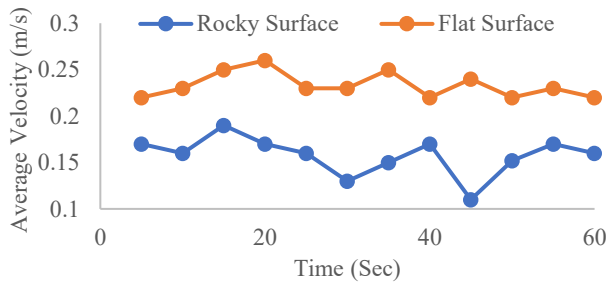


Fig. 10 Time vs Average Velocity Diagram for Rocky and Flat Surface (Observation 1)

On the other hand, for rocky surface the average velocity is less than flat surface. On the rocky surface the robot needs to move with various types of obstacles and pebbles. Sometimes the velocity decreases when the rock's size is slight larger than others and increases when there are less uneven surfaces. For the change of surface, the required torque varies and that is reason of increase or decrease of average velocity. The maximum velocity of the robot is measured 0.19 m/s and the average velocity in 50 seconds is measured 0.156 m/s on rocky surface. In time vs distance figures, the graph looks linear with slight change of value. In time vs velocity graph, the range of the y axis is kept small, that's why the minor change of velocity makes the graph nonlinear.

4.2 Distance and Average Velocity for Observation 2

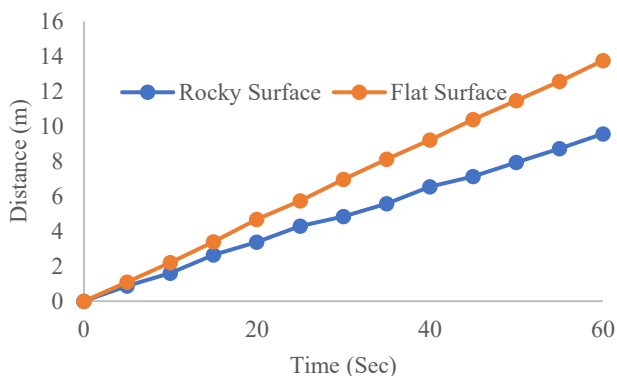


Fig 11: Time vs Distance diagram for rocky and Flat surface (Observation 2)

In observation 2 for flat surface, the total distance covered is 13.76 meter in 60 seconds and for rocky surface it moves 9.57 meter as shown in Fig 10.

From Fig 12, it is shown that the maximum velocity for flat surface is 0.26 m/s where the average velocity is 0.23

m/s. For rocky surface the velocity is also lower than the flat surface. This time the maximum velocity of the robot is measured 0.20 m/s while the average velocity is 0.158 m/s.

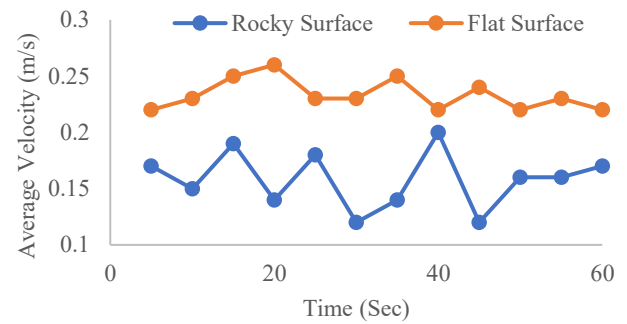


Fig. 12 Time vs Average Velocity diagram for rocky and Flat surface (Observation 2)

4.3 Distance and Average Velocity for Observation 3

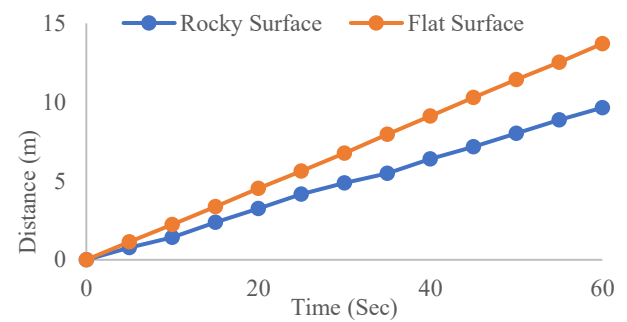


Fig. 13 Time vs Distance diagram for rocky and Flat surface (Observation 3)

Here total distance covered in 60 seconds is 9.65 meters over rocky surface and 13.71 meters over the flat surface for observation 3.

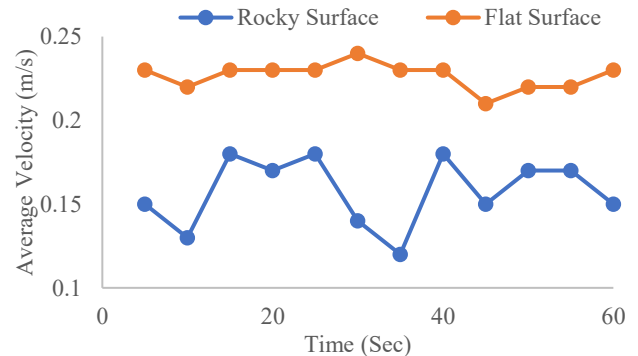


Fig. 14 Time vs Average Velocity diagram for rocky and Flat surface (Observation 3)

Here the maximum velocity for flat surface is 0.24 m/s where the average velocity is 0.227 m/s. For the rocky surface, the maximum velocity is measured 0.18 m/s where the average velocity is 0.157 m/s.

The overall outcome of the rough surface terrain beetle robot is shown in the Table 2. Here the average distance covered per minute and average velocity is presented for rough and flat surface. Rough surface terrain robot is able to run in both rough surface and flat surface. From the performance test it has been seen that the robot run very smoothly over the flat surface and there is a little deviation in the data which is negligible. In average, the robot is able to gain 0.23 m/s velocity on flat surface. While running on the rough surface

like rocky area where the performance test has been done, the robot can't move as fast like flat surface. There are many reasons behind it. Sometimes the unevenness of the surface is more and the robot leg can't make contact with the surface constantly in rough surface. Also, the legs of the robot slip sometimes over pebbles. These factors are reducing robot's

average velocity and the velocity is got 0.158 m/s on rough surface. Though the velocity is not important too much for the hexapod robot because the robot mainly focuses on the reliability to move on rough surface where the wheeled and tracked robots face difficulties.

Table 2 Result of Rough Surface Terrain Beetle Robot on Rocky Surface and Flat Surface

Surface type	Observation	Distance (m/min)	Average Distance Covered (m/min)	Velocity (m/s)	Average Velocity (m/s)
Rocky Surface	1	9.43	9.55	0.156	0.158
	2	9.57		0.160	
	3	9.65		0.157	
Flat Surface	1	13.83	13.77	0.235	0.23
	2	13.76		0.228	
	3	13.71		0.227	

5. Conclusion

A robot was developed in the present research which can move on rough surface easily. This rough surface terrain beetle robot reduces the limitations of wheeled and tracked robot to move in all terrain. It can be concluded that:

- The Performance test of the rough surface terrain beetle robot shows the robot's capability to move in both rough and plain surface.
 - The feature of using each leg freely with single motor helps to perform varieties of application.
 - The development of new model helps to reduce the construction cost and the weight of the robot.
- Overall, this rough surface terrain beetle robot uses the insect's locomotion for a viable solution of rough surface movement with a simplest control procedure.

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