TuijinJishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No.4 (2023),

Design and Optimization of All-Terrain Walking Robot

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Abstract

The ability of the All-Terrain robot to walk on various terrains motivates many researchers to explore the structural design strategies and control methods of the system.They are effective in rough terrains. The legs of the robot with more than 1-dof is found to be more effective, however it is very complicated to design and control.

The present work involves development of an optimized quadruped robot. The legs of robots are based on Klann's mechanism, which has been optimized to follow a set trajectory with timings. The legs enable the quadruped robot to cross on various terrains with the least time possible. The simulation of Klann's mechanism has been carried out considering concerned parameters such as torque, force, time and speed. The robot feet are designed based on fractal geometry to have maximum contact surface, to help in balancing on rough terrain. Based on results obtained the robot leg exhibits good stability with non-uniform terrain

Keywords:*All-Terrain robot,Klann's mechanism,fractal geometry,optimization.*

1. Introduction

Legged robots have been explored by researchers extensively due to its ability to work in an extensive range of terrains.The legged robots are broadly classified based on the degrees of freedom (DOF) it possesses. There are multi-degrees of freedom legged robots and single degrees of freedom legged robots. The multi degrees of freedom legged robots require more actuators for the motion and its complexity is more in terms of mechanical design and control scheme. Hence 1 DOF legged robots play an important role [1].

The present work involves designing and optimizing various aspects of an all-terrain walking robot.This primarily involves optimization of Klann's mechanism to maximize step height and step length of the foot trajectory and the design and optimization of the feet for adaptation to various terrain.

2.Optimization and Analysis of Klann's Mechanism

2.1.Introduction

Optimization of Klann's mechanism is carried out using SAM software by ARTAS - Engineering Software.It is a versatile software capable of modeling,optimization and analysis of mechanism.

2.2.Optimization parameters

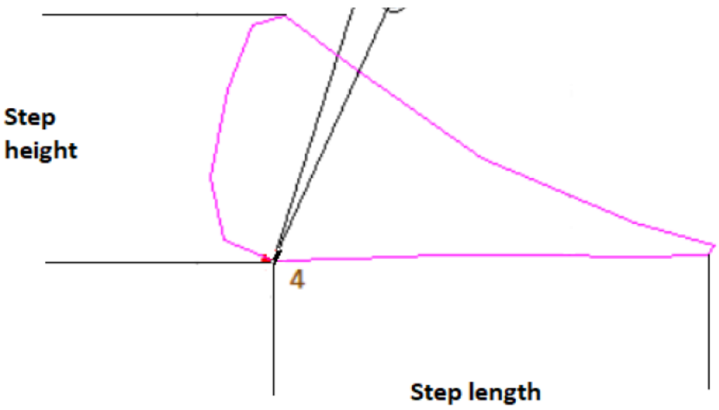


Figure 1. Foot Locus

The foot locus has two primary components Step height and Step length.Step height determines the ability of the mechanism to overcome terrain variations and obstacles.Step length determines the length of the step which along with time determines the speed of the robot.

The ratio of step height to the height of the mechanism when the foot is on the ground determines the size of the robot which in-turn contributes to mobility in cramped spaces.Similarly the ratio of step length to length of the mechanism also contributes to the ability of the robot to turn in cramped spaces.

The time spent pushing the robot forward must be equal to the rest of the time to prevent reduction of speed to keep the balance.

2.3.Optimization procedure

The SAM user interface provides the necessary tools required for optimization of planar mechanisms. Here are the steps followed:

1. Modeling the Klann's mechanism to be optimized using SAM software's GUI.
2. Referencing a file which defines the foot locus required and path timings associated with it.
3. Defining the input parameters.

a. This can be done by selecting the required node and clicking on optimizationparameters and drawing a rectangle to define the range positions for said node

b. It is taken care not to allow the range of the nodes to exceed the height and lengthof the mechanism as this will only result in a bigger mechanism which is not of much use.

4. selecting the objective performance number: The option selected was Maximum (other options were minimum,range,absolute maximum, average among others)
5. Running the optimization

The optimization process in SAM is based on a two-step approach, consisting of exploration of the design space and optimization of a specific solution.First, the entire parameter space is explored globally using a combination of a pure Monte-Carlo technique and a so-called Evolutionary Algorithm, which is an optimization technique derived from Genetic Optimization.This local search can be either based on a Simplex technique or on Evolutionary Algorithm with a smaller parameter range centered around the selected solution.

2.4.Optimization result

Figure 2.Optimized Klann's Mechanism

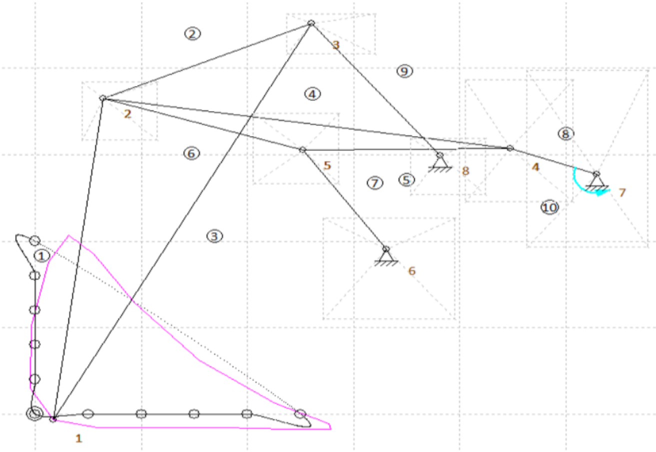


Table 1. Optimized Klann's mechanisms link lengths

Link number	Link Length(mm)
1	187
2	107.25
3	259
4	169.3
5	98
6	98.62
7	69.65
8	43.3
9	97.6

Table 2. Optimized Klann's Mechanism fixed support parameters

Joint no. for the support triangle	distance between them (mm)	angle with horizontal axis (degree)
6&7	127.44	29.703

7&8	82.76	-1.646
6&8	71.24	66.891

The optimized klann's mechanism has achieved both a reasonably high step height to mechanism height as well as step length to mechanism length while maintaining a reasonably low variation along the vertical axis as the mechanism proceeds through the step length phase.

2.5.Analysis of forces on mechanism

The mass at each node was analyzed by first finding the mass at each node of a link using the formula for center of gravity by coordinate system method and then adding mass from other links connected to the node

Table 3. Mass acting at each node of the mechanism

Node number	Mass(gm)
1	27.49
2	33.36
3	27.365
4	8.935
5	6.675
6	3.475
7	5.935
8	6.085
total	119.32

The weight of the mechanism is distributed among the nodes.It is assumed that the entire weight of the mechanism is 4 Kg and carried by the mechanism during the step height phase.

The force due at the step height phase is given by:

$$F=m*a \quad (1)$$

where**,**

F=Force

m=Mass of robot-mass of a leg

a= Acceleration due to gravity ($9.8 m/s^2$)

F=(4-(119.32/1000))*9.8=38.03N

The force needed to move the robot forward during the step length phase is given by the equation:

F=m*a (2)

where,

F=Force

m=Mass of robot - mass of a leg

(the maximum speed of the robot is constrained at 0.15m/s, which is to be achieved instantaneously. Hence time to reach this speed is assumed to be 1 sec).

Therefore, a= desired acceleration (0.15m/s^2 in this case)

F=(4-(119.32/1000))*0.15=0.58N

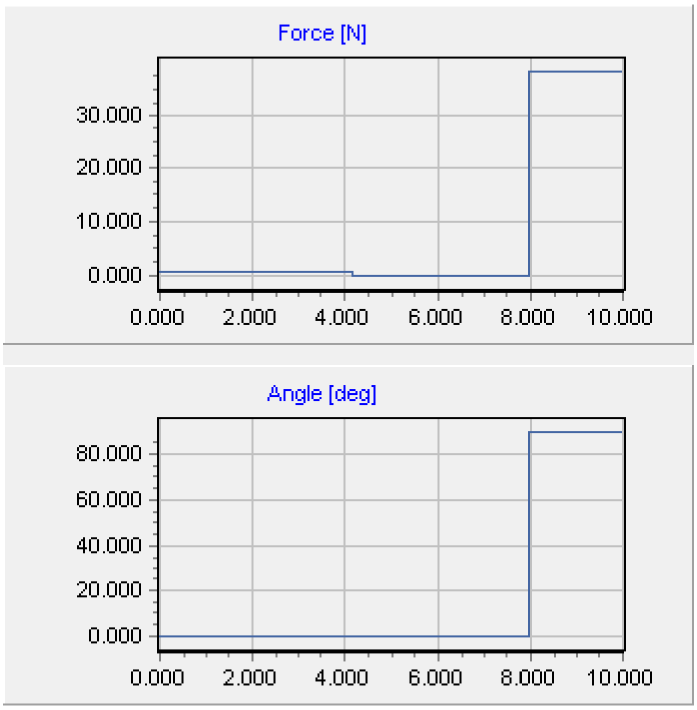


Figure 3.Force and input angle combination for foot node

2.6.Analysis results

2.6.1. Position analysis: In the below image the red line represents the x coordinates of the foot node and the purple line represents the y coordinates of the foot node .it can be seen that step length starts at 0s and ends at 4.617s and step height starts at 7.981s and ends at 10s therefore the amount of time spent pushing the robot forward is almost equal to the amount of time the foot node sends in the air and pushing the robot upward.This is advantageous to us because the 0.383s barely makes a difference in speed when the mechanism is coordinating with other legs.If the difference was significant the other legs would have had to wait to prevent the robot from losing balance thereby reducing speed.

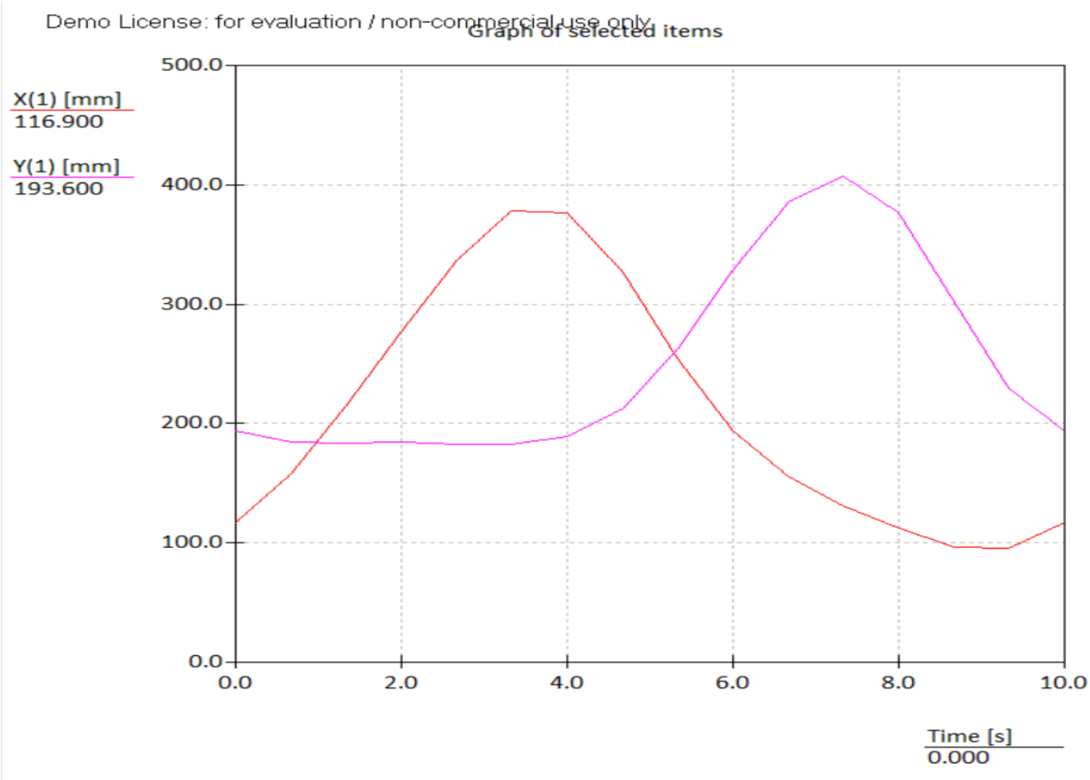


Figure 4.displacement of foot node with respect to time

2.6.2. Velocity analysis: The velocity can be calculated by the distance moved during the step length divided by time consumed for the process.

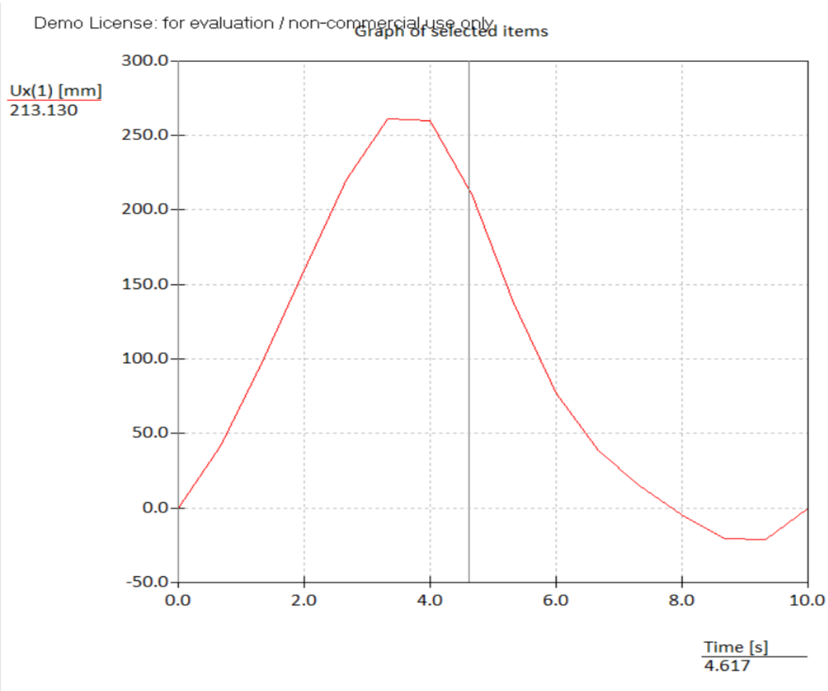


Figure 5.position of x component of foot node with respect to time

From figure 5, we can infer that the step length which begins at 0s and ends at 4.617 seconds will provide a net x displacement of 106.65 mm in a span of 4.617 seconds this results in a velocity of 23.1 mm/s which is reasonably fast for a robot of height of around 225mm..**6.3. Power analysis:**Figure 6 shows the power consumed with respect to time.

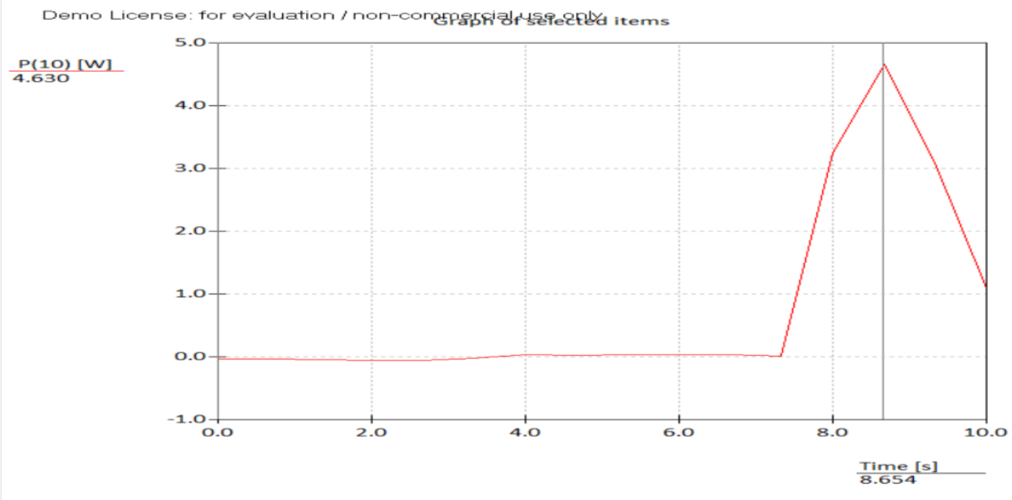


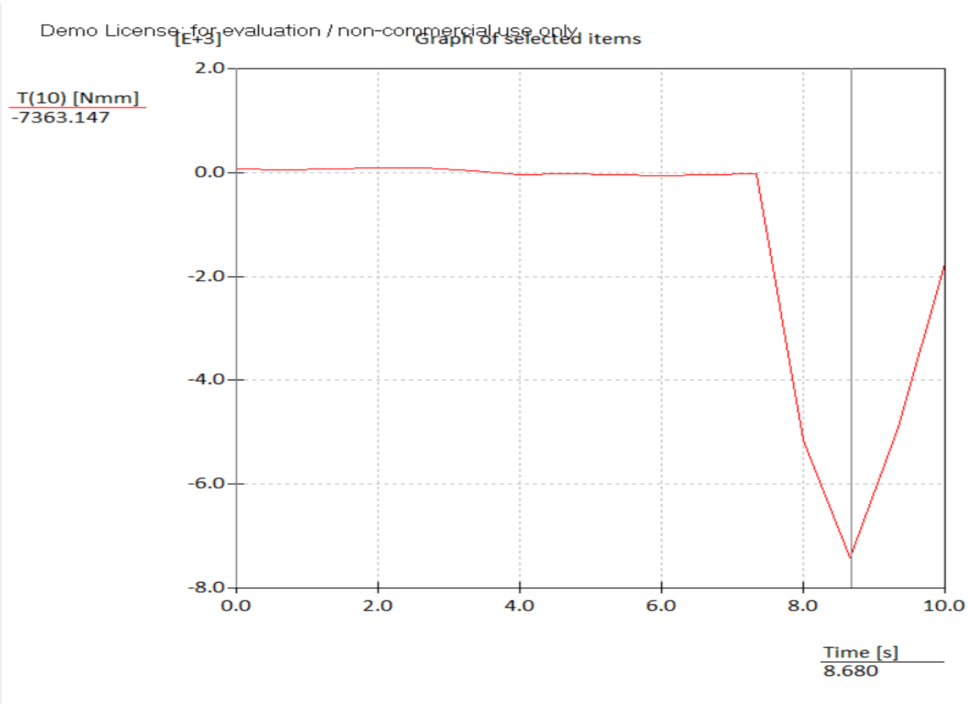
Figure 6.Power with respect to time

From figure 6, we can see that the peak power consumed is 4.630 at 8.654s.and the average power consumed per cycle is around 7.077 W

2.6.4. Torque analysis: Figure 7 shows the torque consumed with respect to time.

The peak Torque required by the mechanism is -7363.147 Nmm.The negative sign is to indicate that the crank is spun in clockwise direction.

Figure 7.Torque with respect to time



3.Design and Analysis of Foot

3.1.Objectives of Design of Foot

The most important factors to consider while designing a foot are:

1. Pressure distribution on ground
2. Providing higher friction to avoid slippage

Numerous terrains are not stable enough to withstand the application of a higher magnitude of pressure. Therefore, it is necessary to reduce the pressure exerted on the ground .This can be achieved by two methods:

1. reduction in weight
2. increase in contact surface area

Since the weight of the robot is negligibly dependent on weight of the feet the only factor that can be used to decrease pressure is the increase of contact surface area.

3.2.Concept for Design of Foot

To achieve a higher contact surface area, the concept of self-similar fractals has been used. A fractal is a geometric shape containing detailed structure at arbitrarily small scales, the exhibition of similar patterns at increasingly smaller scales is called self-similarity. In theory self-similar 2D fractals have infinite perimeter.

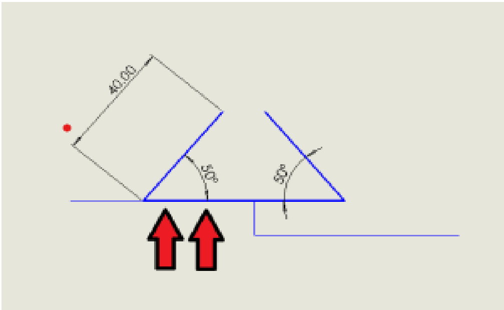


Figure 8.Feet design with no joint

Feet designed with no movement at the joint produces tremendous pressure on the terrain.

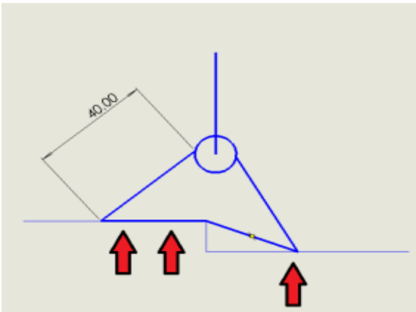


Figure 9.Feet design with joint

Due to the addition of a joint at the feet,it can be observed that there is a reduction in pressure on the terrain.

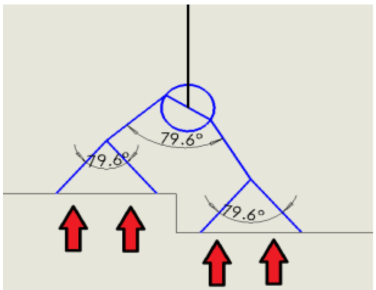


Figure 10.Feet design with fractal joints

Due to the addition of a second layer of links in the feet similar to the first layer, there is much more surface area which helps reduce pressure on the terrain.

3.3. Design of Foot

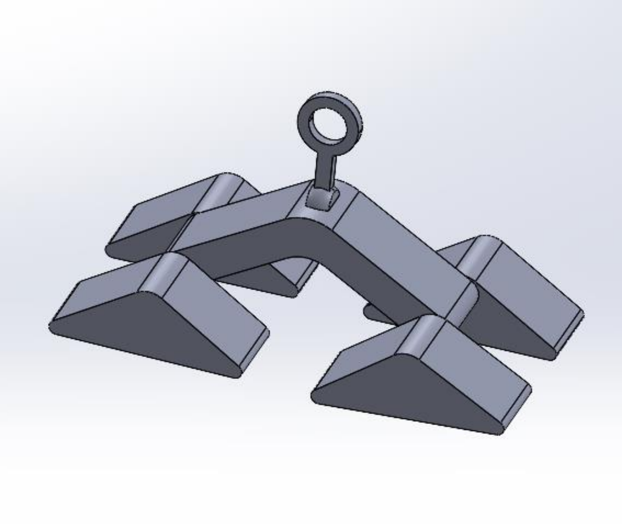


Figure 11.Feet design with fractal joints

The feet is created in Solidworks which has two levels of links, the primary link and four secondary links.It also houses a cylindrical joint which allows for a restricted freedom of movement perpendicular to the application of fractal mechanism of the feet which facilitate the increase of contact surface area.

3.4.Analysis of foot

3.4.1.Procedure: The assembly of feet and ground is imported to Ansys from Solidworks. The kinematic analysis of the feet is performed by using transient structural analysis features of Ansys workbench. The material of the feet is set to structural steel while the ground is set to concrete. The ground is fixed and the primary joint is set as a force member.

The following parameters were used in analysis of foot:

Weight of the robot: 4kg.

Minimum load the leg should handle= 20N.

The load is applied at the primary joint as shown in figure 12.

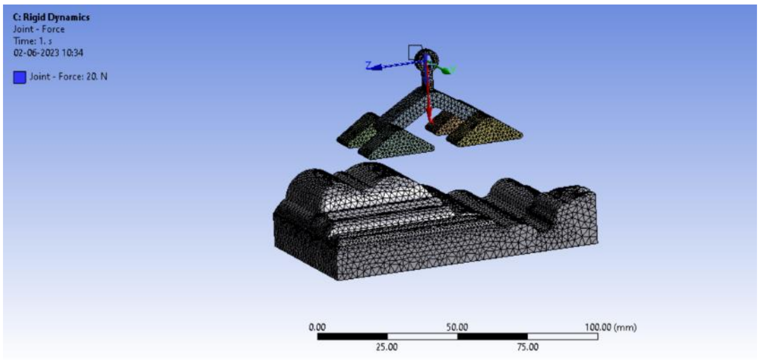


Figure 12.Initial condition for Feet analysis(configuration 1)

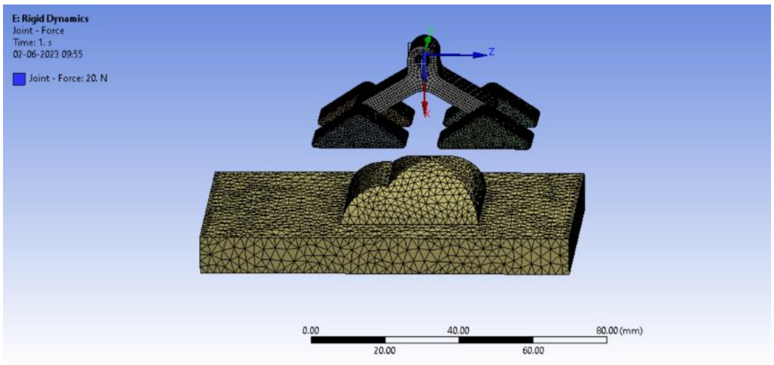


Figure 13.Initial condition for Feet analysis(configuration 2)

3.4.1.Result: The following are the results for the kinematic analysis of the above configurations

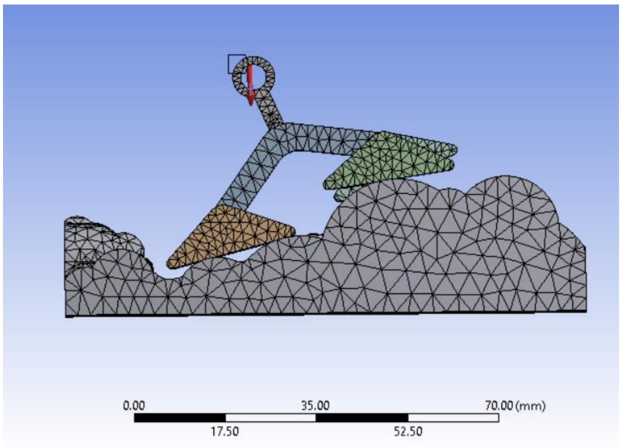


Figure 14.Result for Feet analysis(configuration 1)

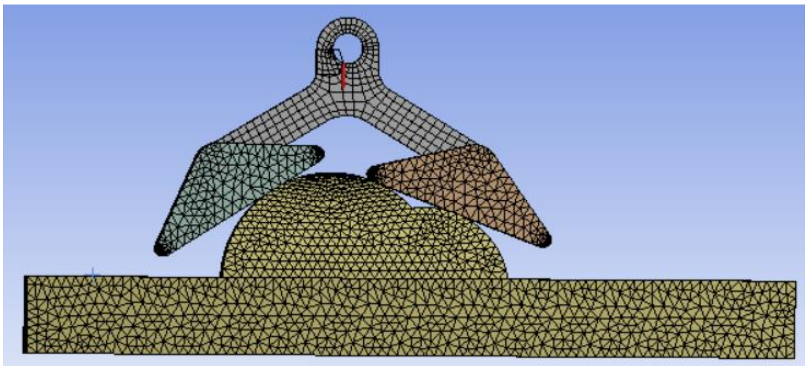


Figure 15.Result for Feet analysis(configuration 2)

Thus we can conclude that the feet are adaptable to an extensive number of terrains.

4.Analysis of Complete Leg Assembly

After completing assembly of Klann’s mechanism and feet, Finite Element Analysis is performed with the help of Ansys Workbench.

The material is chosen to be stainless steel, whose tensile strength is 505MPa; shear strength is 500MPa;modulus of elasticity is 200GPa;modulus of rigidity is 77.2GPa and Poisson's ratio is 0.27.

The force of 20N is considered at the feet surface acting upwards and the triangular plate is kept fixed, the analysis is performed and results are obtained which are:

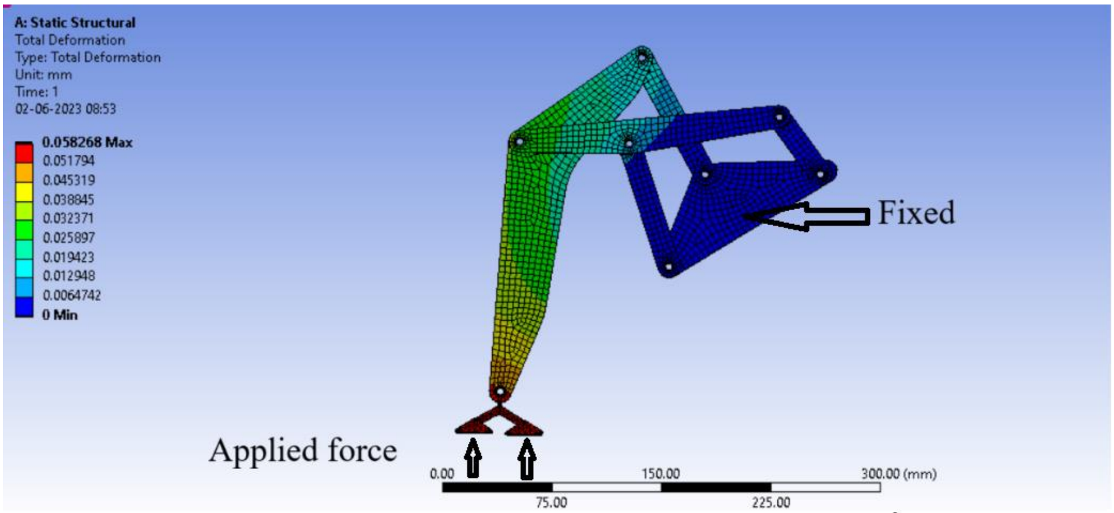


Figure 16.Result of deformation analysis performed on Leg Assembly

The maximum deformation is 0.058268mm, which is shown by the feet.

TuijinJishu/Journal of Propulsion Technology
ISSN: 1001-4055
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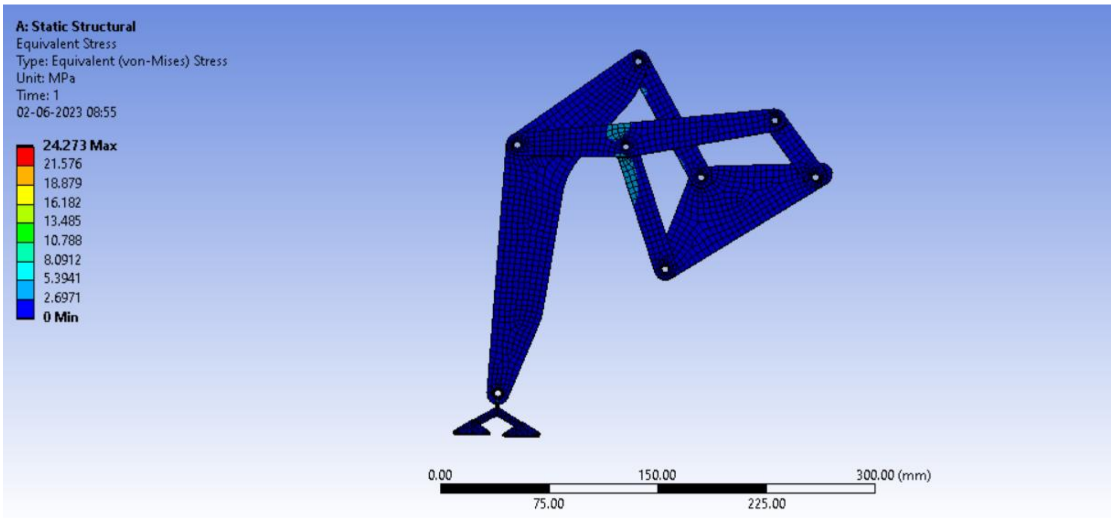

Figure 17.Result of Stress analysis performed on Leg Assembly

The maximum stress obtained is 24.273N/mm².

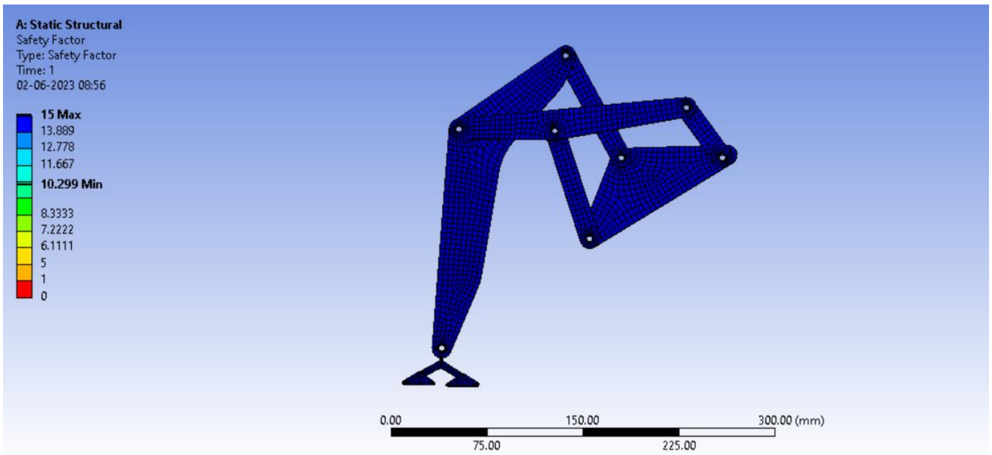

Figure 18.Result of F.O.S analysis performed on Leg Assembly

The minimum F.O.S obtained is about 10.299.

5.Design of Robot

The complete robot is designed based on the calculated data in Solidworks and is assembled. The robot has four legs and a body which consists of space for a motor, controller and a circuit. The size of the robot is about cat size for optimal maneuverability and speed. The length is 30 cm, and width is 10 cm. The picture of the assembly is as shown below:

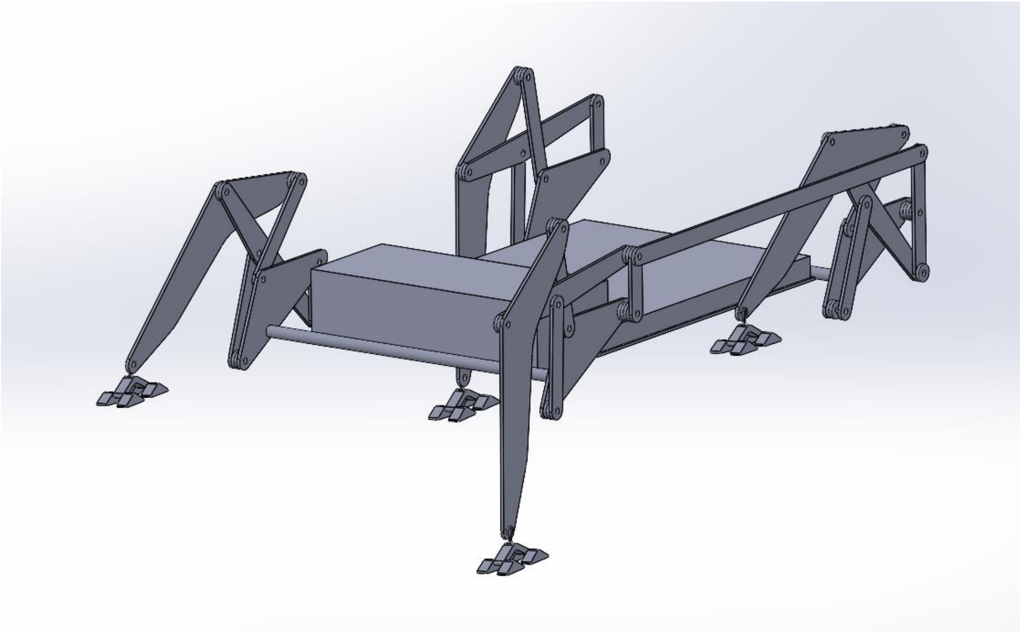

Figure 19.Isometric view of robot

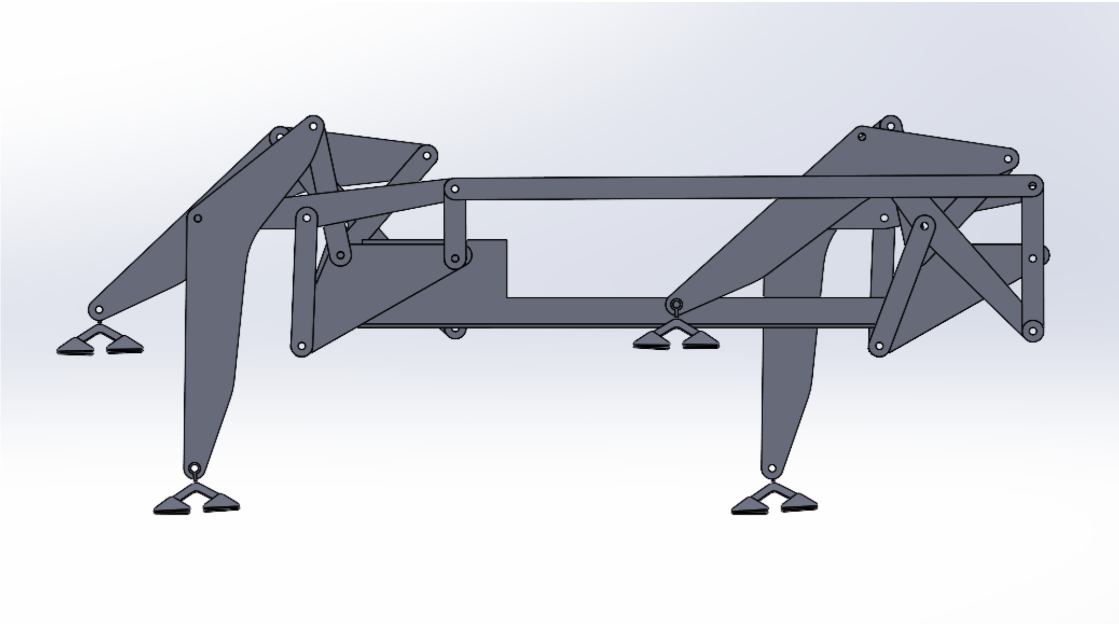

Figure 20.Side view of robot

In this design,the front and back limbs are attached to each other by a parallel four bar mechanism which maintains a phase difference of 180 degrees.The front limbs themselves are arranged with a 180 degree phase shift.This arrangement enables diagonally opposite limbs to function in tandem thus enabling forward movement while maintaining balance.

6.Conclusion

The performance of the solution obtained can be summarized as follows:

1. The proposed leg mechanism solution has a large step height comparable to the robot height,(step height is 48% of robot height) that enables the robot to travel in various terrains.
2. Greater speed for each individual terrain has not been achieved.
3. Feet are designed for greater contact surface area to help in increasing the grip.
4. The feet operate on fractals which help to walk on the terrain even in the presence of small debris or uneven surface. This is quintessential for the robots adaptability.
5. The robot is designed considering the good factor of safety which comes out to be 10 for stainless steel and still has an optimal weight of 4kg.
6. The leg assembly has a Factor of Safety of about 10.299 .Hence it can be concluded that the robot is capable of carrying a significantly greater load and also allows for topology to reduce weight and material used.

The robot design has potential in various sectors,such as search and rescue, extraterrestrial land mapping and sample collection, remote goods transport and other sectors.

7.Future Scope

The proposed design lacks in the following areas

1. Ability to turn
2. alteration of gait speed of each limb individually
3. Remote adjustment of leg mechanism to suit terrain
4. addition of sensing and data transfer elements
5. application of artificial intelligence to adapt to various terrains

These are 5 important elements which have the scope to be further developed

8.References

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