ICMIEE22-058

Design and Motion Analysis of Four-Legged Walking Robot using Theo Jansen Mechanism

Meftahul Mahmud[1] , Md. Ashraful Islam[2,]*
[1,2]Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT

This paper analyzes the Theo Jansen mechanism for providing a walking mechanism in terrain areas where wheel-based vehicular systems are less efficient and sometimes ineffective. This project aims to design a simple four-legged walking bot using the Theo Jansen mechanism and to analyze the mechanism's motion for different lengths of the links. This mechanism uses 11 links of certain length ratios in order to imitate the walking motion of a leg. After analyzing the mechanism, a four-legged robot was designed with two legs on each side of a body connected to motors. The four-legged robot can be used as a simple and cost-efficient replacement for surveying terrain areas replacing wheeled vehicles and drones.

Keywords: Theo Jansen's Mechanism, Design, Motion

1. Introduction

Wheeled vehicles often struggle to roam uneven terrain areas, whereas animals with legs can roam these areas much more conveniently. In sandy and snowy areas, automobiles also slip and often cannot move. That's why a leg mechanism can be used in vehicular systems to use in terrain areas [1].

Theo Jansen's mechanism consists of 11 links connected with each other [2]. These 11 links together produce a walking motion and work as a leg. Multiple legs can be used in a robot to mimic the walking motion of an animal. By using more legs, smoother walking motion can be obtained.

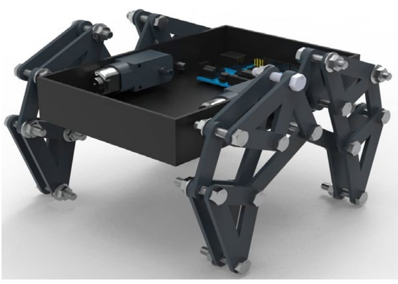

Fig.1 CAD model of a four-legged walking robot using Theo Jansen Mechanism.

2. Methodology

The standard dimensions of all the links of the Theo Jansen mechanism are shown in the figure below.

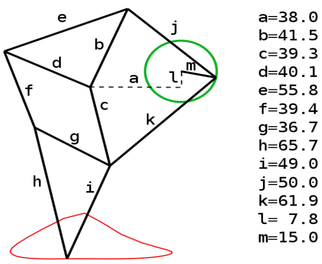

Fig.2 Theo Jansen mechanism link lengths [3].

The length of all the links of the mechanism can be scaled up or down according to the need. The proportion of the lengths of the links needs to be maintained to get the ideal foot tip trajectory. But the desired foot tip trajectory is not the same in all situations. For example, the stride height required for travelling in rocky areas or climbing stairs is more than that required for travelling in snowy or sandy areas. So, it is a huge advantage of this mechanism that the length of the links can be modified a little to get the desired foot tip trajectory [4].

In each configuration, the length of only one link was changed, keeping the length of all the other links the same as the basic length. The table below shows the modified lengths of the links for different configurations.

Table 1 Modified link length for each configuration.

Configuration no.	Changed link	Base length (mm)	New length (mm)
2	j	50	52
3	k	61.9	62.4
4	i	49	52
5	h	65.7	68.7
6	f	39.4	40.5
7	e	55.8	58
8	b	41.5	42.5
9	d	40.1	42
10	g	36.7	39

"Configuration no. 1" is not shown in the table because the length of all the links of the mechanism was kept the same as the basic length. The CAD models of different configurations were made in Solidworks. Then the motion of the foot tip of each configuration was simulated using the Solidworks Motion Study tool.

* Corresponding author. Tel.: +88-01786285393
E-mail addresses: md.islam@me.kuet.ac.bd

3. Design

Each link of the mechanism was made in Solidworks except link' a' and 'l' because the physical presence of these two links is not necessary for the mechanism to work. The length of 'a' and 'l' are required only to define the position of the link 'm' with respect to all the other links [5]. The end of link 'm' connected with 'l' is fixed, and the other end of link 'm' connected with link 'j' and 'k' moves in a circle. The connecting point of links 'b', 'd' and 'c' is also fixed. So, when the link 'm' rotates, it moves all the other links of the mechanism.

Each of the links was first made in Solidworks, maintaining the exact proportion of the lengths as different parts. Then all the parts were assembled. Among these links, 'b', 'd', and 'e' was made as a single part instead of three different parts. Links 'g', 'h' and 'i' were made as a single part as well. As a result, we get a Modified Theo Jansen mechanism. It was found that there is only a slight difference between the conventional Theo Jansen mechanism and the modified Theo Jansen mechanism [6]. It was also found that the Modified Theo Jansen mechanism provides better stability with a slight increase in input power.

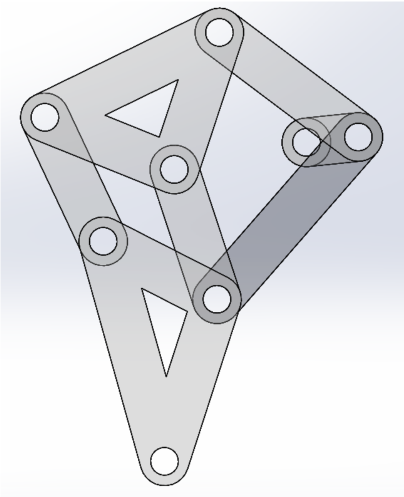

Fig.3 Design of Theo Jansen Mechanism

4. Motion Analysis

The foot tip trajectory of each configuration was simulated in Solidworks Motion Study. The motion of the conventional Theo Jansen mechanism or "configuration 1" is shown in the figure below.

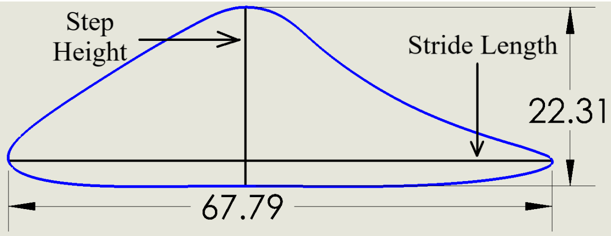

Fig.4 Trajectory of configuration 1

This is the ideal trajectory of the mechanism [7]. We can see from the figure that the Stride length [8] of the foot is 67.79 mm, and the stride height is 22.31 mm.

The trajectories of all the other configurations are shown in the figures below. The trajectory of "configuration 1" is drawn with a blue dashed line, and all the other configurations are drawn with a solid red line. The figures compare each configuration with "configuration 1" to better understand the motion.

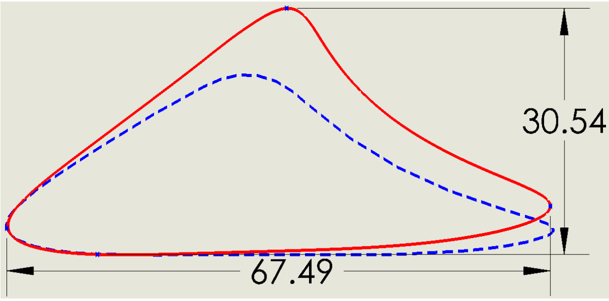

Fig.5 Trajectory of configuration 2

The figure shows that the stride height of "configuration 2" is much higher than that of "configuration 1", but the stride length remains unchanged. The foot starts to lift from the surface a little earlier than "configuration 1".

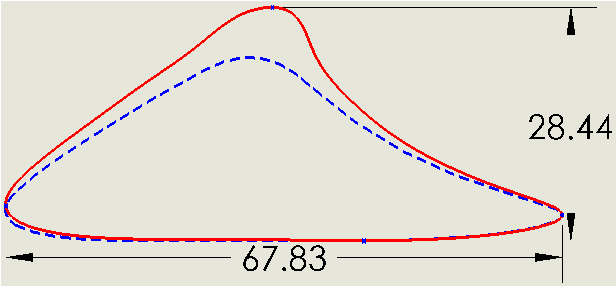

Fig.6 Trajectory of configuration 3

The stride height of "configuration 3" is also much higher than that of "configuration 1". The stride length remains unchanged in this case as well. The foot starts to lift from the surface almost at the same time as "configuration 1".

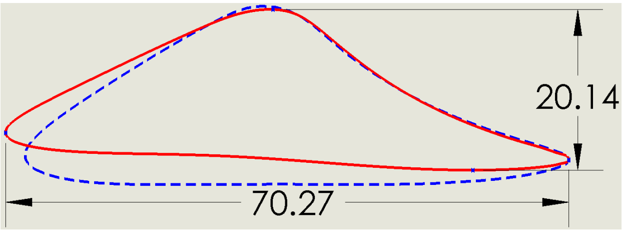

Fig.7 Trajectory of configuration 4

The stride length of "configuration 4" is a little more than "configuration 1", but the stride height is much less. It can also be seen that the foot stays in contact with the surface for a very small amount of time.

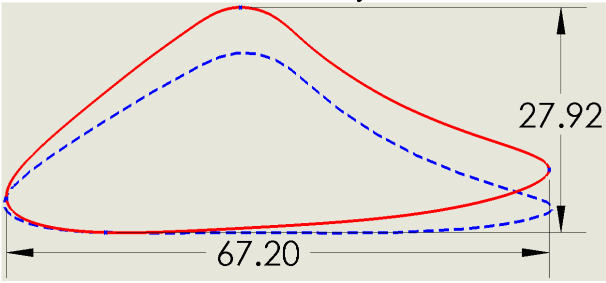

Fig.8 Trajectory of configuration 5

"Configuration 5" gives more stride height than "configuration 1" keeping the stride length same. The foot starts to lift a little earlier as well.

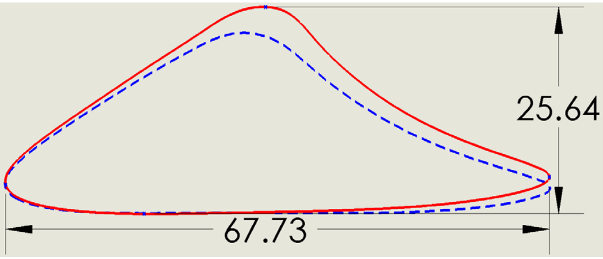

Fig.9 Trajectory of configuration 6

The stride length for "configuration 6" is the same as "configuration 1", but the stride height is a little more. The foot stays in contact with the surface for almost the same amount of time period as well.

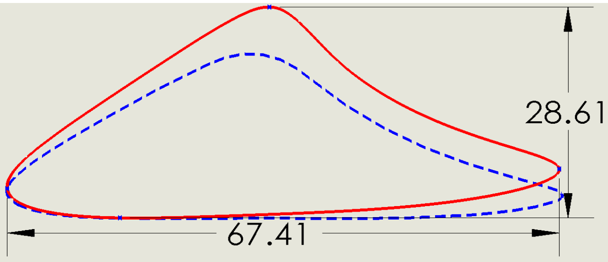

Fig.10 Trajectory of configuration 7

The stride height for "configuration 7" is much higher than for "configuration 1". The stride length is almost the same. The foot starts to lift from the surface a little early as well.

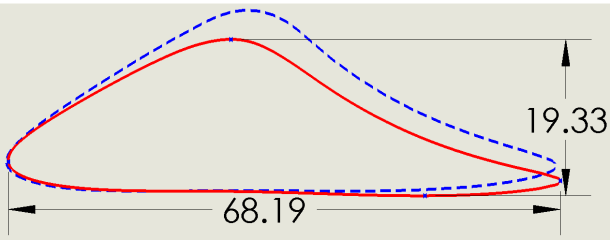

Fig.11 Trajectory of configuration 8

The stride height for "configuration 8" is less than that of "configuration 1". The stride length is slightly more than "configuration 1". The contact time of the foot with the surface is also almost the same.

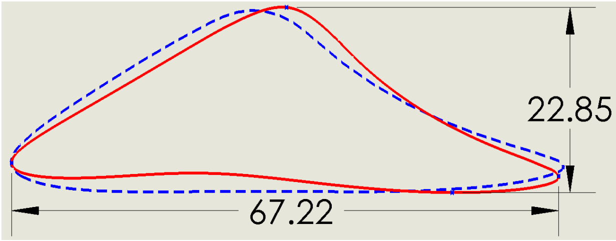

Fig.12 Trajectory of configuration 9

"Configuration 9" has almost the same stride height and stride length as "configuration 1". But the contact with the surface is not smooth in this case.

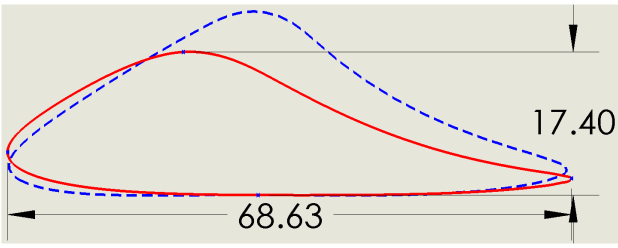

Fig.13 Trajectory of configuration 10

The stride height of "configuration 10" is much less than that of "configuration 1". The stride length is slightly longer. The contact period of the foot with the surface is almost the same in both cases.

5. Torque Analysis:

The torque required for rotating the central link 'm' at a constant angular velocity of 30 rpm for each configuration was also analyzed using the Solidworks Motion Analysis tool. For this analysis, ABS plastic was chosen as the material for the links.

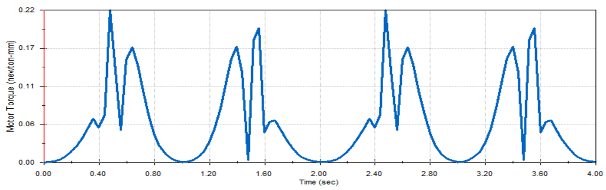

Fig.14 Torque analysis of configuration 1

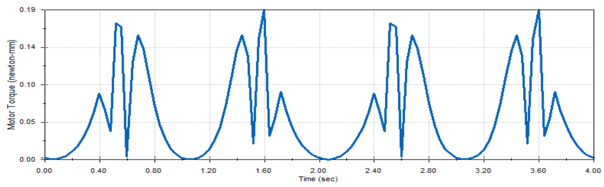

Fig.15 Torque analysis of configuration 2

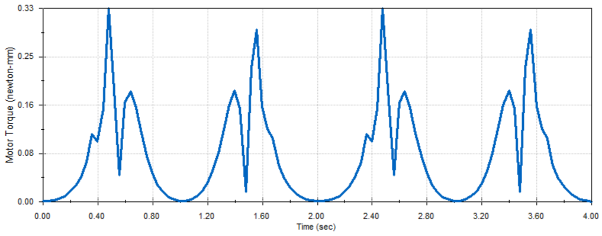

Fig.16 Torque analysis of configuration 3

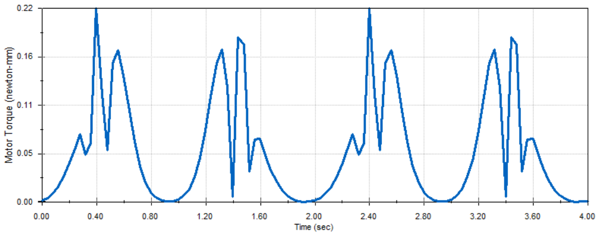

Fig.17 Torque analysis of configuration 4

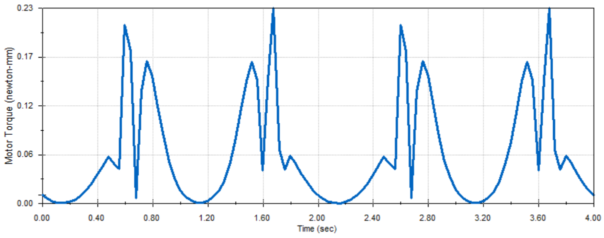

Fig.18 Torque analysis of configuration 5

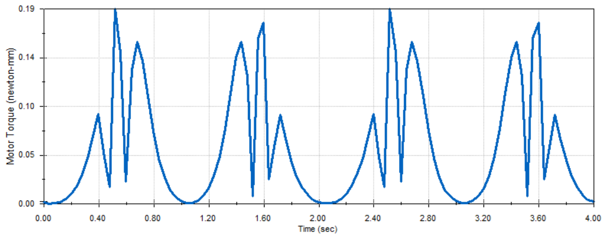

Fig.19 Torque analysis of configuration 6

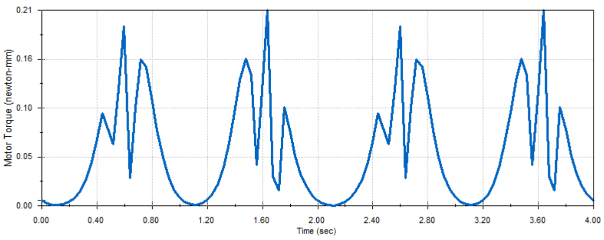

Fig.20 Torque analysis of configuration 7

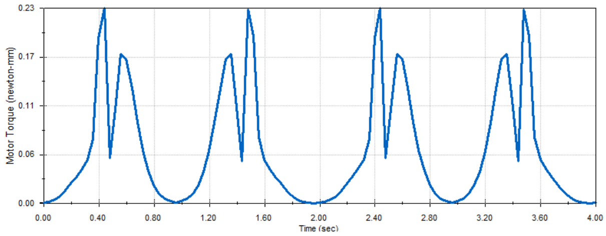

Fig.21 Torque analysis of configuration 8

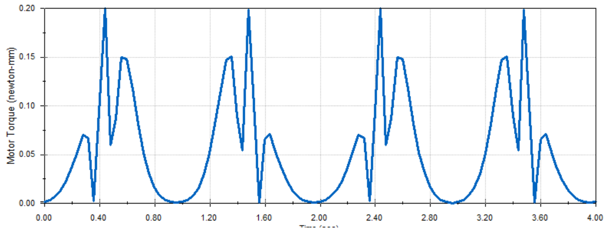

Fig.22 Torque analysis of configuration 9

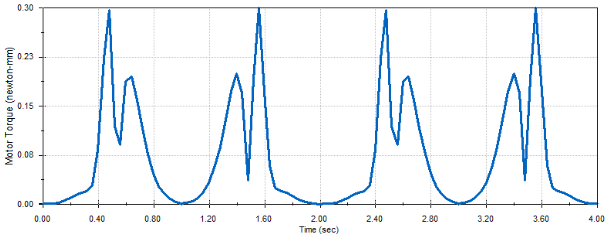

Fig.23 Torque analysis of configuration 10

6. Results and Discussion

The step height and stride length are shown in Table 2.

Table 2 Step height and stride length for different configurations.

Configuration no.	Step Height	Stride Length
1	22.31	67.79
2	30.54	67.49
3	28.44	67.83
4	20.14	70.27
5	27.92	67.2
6	25.64	67.73
7	28.61	67.41
8	19.33	68.19
9	22.85	67.22
10	17.4	68.63

The values from the table are plotted in a graph to understand the impact of changing the link lengths on the leg mechanism's stride length and step height.

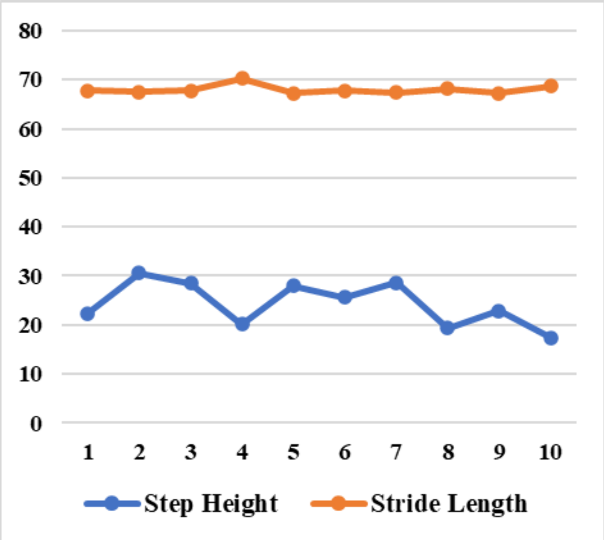

Fig.24 Configuration no. v/s step height and stride length

From the graph, we can observe that the stride length almost does not change at all for different configurations. The change of stride length is only noticeable for configuration 4. So, in order to gain more stride length, increasing the length of link 'i' is the best option. Other than that, changing the length of any other link of the mechanism doesn't significantly affect the stride length of the leg.

On the other hand, the step height changes quite drastically compared to the stride length in different configurations. The impact of changing the length of the links can be better observed from the table below.

Table 3 Step height and stride length for different configurations.

Modified link	Change in link lengths	Change in step height
j	4%	36.89%
k	0.81%	27.48%
i	6.12%	9.73%
h	4.57%	25.15%
f	2.79%	14.93%
e	3.94%	28.24%
b	2.41%	13.36%
d	4.74%	2.42%
g	6.27%	22.01%

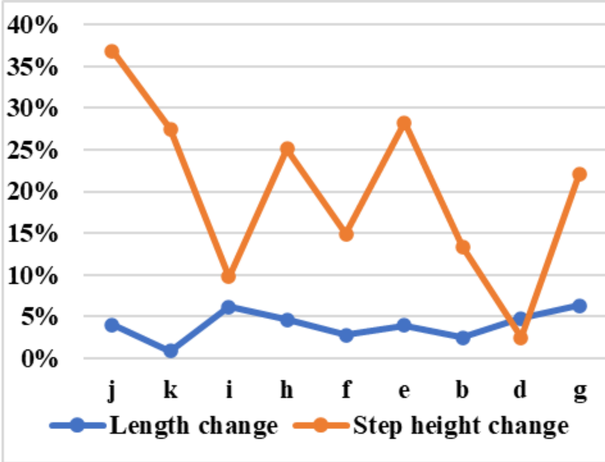

Fig.25 Length change v/s Step height change

Changing the length of each of the links had quite an effect on the step height of the mechanism except for link 'd'. Increasing the length of link 'd' by 4.74% only caused a 2.42% increase in step height. Changing the length of link 'i' also had very little effect on the step height compared to the other links.

Table 4 Torque required to rotate link 'm' for different configurations.

Configuration no.	Torque (N-mm)
1	0.22
2	0.19
3	0.33
4	0.22
5	0.23
6	0.19
7	0.21
8	0.23
9	0.20
10	0.30

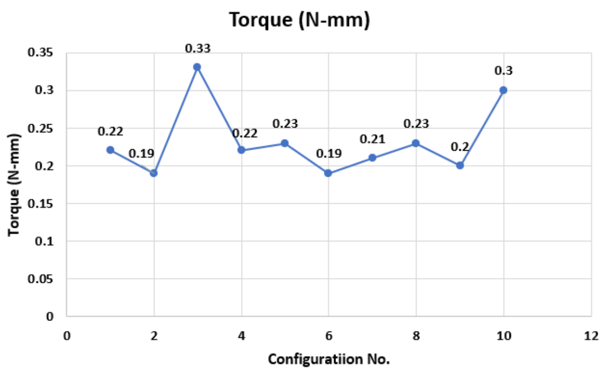

Fig.26 Configuration No. v/s Torque required

The graph shows that configuration 3 requires the most torque, and configurations 2 and 6 require the least amount of torque.

6. Conclusion

By comparing the foot tip trajectories of all the configurations, the Theo Jansen mechanism can be modified according to the need. Among all the configurations, 1, 3, 8 and 10 have the best balance because the foot stays in contact with the surface for the longest period in these configurations. The main purpose of this mechanism is to travel on rough terrain areas and overcome obstacles [9]. So, the legs need to be very well-balanced. Adding more legs can improve the stability of these legged robots [10]. To roam on rocky areas, the legs may need more step height. Increasing the length of links 'j' and 'k' is the best option for increasing step height. It is shown in Table 3 that increasing the length of link 'k' by only a small amount can increase the step height by a lot. In Figure 5 it is also shown that increasing the link 'k' length keeps the leg well balanced. So, increasing the length of link 'k' is the best approach to increase the step height because it maintains the balance of the leg mechanism.

In this study, the length of one link was changed in each configuration. In future, it can be observed how changing multiple link lengths at once can affect the path of the leg of this mechanism. Trying different combinations by changing the link lengths can open the door to many possibilities of exploring terrain areas with legged robots.

7. Acknowledgement

I would like to express my gratitude to Professor Dr. Md. Ashraful Islam sir for his invaluable suggestions and encouragement throughout the whole process of this research work. It would not have been possible to complete this work without his sincere guidance.

8. References

[1] Mrunal S. Sahastrabuddhe, Ravina R. Pathak, Bhushansingh N. Patil, Rishikesh R. Mane, Prof. Miss.Sana Shaikh, Prof. A.M.Dharme, Design and Fabrication of Mechanical Walking Robot using "Theo Jansen Mechanism", JETIR, vol. 6, pp. 277-282, 2019.

[2] Somak Sengupta, Pramod Bhatia, Study of Applications of Jansen's Mechanism in Robot, International Journal of Advance Research and Innovation, vol. 5, pp. 354-357, 2017.

[3] Swadhin Patnaik, Analysis of Theo Jansen Mechanism (Strandbeest) And Its Comparative Advantages Over Wheel Based Mine Escavation System, IOSR Journal of Engineering, vol. 05, pp. 43-52, 2015.

[4] Shunsuke Nansai, Nicolas Rojas, Mohan Rajesh Elara, Ricardo Sosa and Masami Iwase, On a Jansen leg with multiple gait patterns for reconfigurable walking platforms, 2015.

[5] Lalit Patnaik, Loganathan Umanand, Kinematics and dynamics of Jansen leg mechanism: A bond graph approach, pp. 160-169, 2015.

[6] Keval Bhavsar, Dharmik Gohel, Pranav Darji, Jitendra Modi and Umang Parmar, Kinematic Analysis of Theo Jansen Mechanism-Based Eight-Leg Robot, 2020.

[7] Mehrdad Mohsenizadeh, Jenny Zhou, Kinematic Analysis and Simulation of Theo Jansen Mechanism, 2015.

[8] Mohit R. Patle, Mayur S. Mehekare, Ranjit Y. Bisen, Prof. U.N.Shette, Analysis of Stride Length and Step Height of Theo Jansen Leg Motion, International Journal of Innovative Research in Science, Engineering and Technology, vol. 06, pp. 4184-4189, 2017.

[9] Yash Punde, Yugandhar Dhande, Amit Chopde, Sumedh Bagade, Design and Linkage Analysis of Theo Jansen Mechanism, International Journal of Engineering Research & Technology, vol. 9, pp. 259-263, 2020.

[10] S.N. Teli, Rohan Agarwal, Devang Bagul, Pushkar Badawane, Riddhesh Bandre, Design and Fabrication of Multi Legged Robot, International Research Journal of Engineering and Technology, vol. 6, pp. 1019-1028, 2019.