Analysis of 8 link Quadruped walking Robot

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***Abstract*— This paper describes design, analysis and simulation studies of quadruped robot made of coplanar single degree of freedom eight link leg mechanism using SOLIDWORKS. Kinematic and stress analysis is performed on the leg mechanism and entire quadruped robot respectively. Foot Path generation, the force analysis on each link, velocity and acceleration plots are analysed.**

Keywords— 8 link leg mechanism; Solid Works; Force analysis; Quadruped model.

I. INTRODUCTION

Legs are the most important needs for humans and most of the land animals to relocate themselves for accomplishing physical work. Animals can overcome obstacles and unevenness in the surface by varying configuration of their leg to adapt to the natural aspect.

In [1], the studies on human walking apparatus describe that the skeletal structure of human beings consists of a structure that is obtainable mechanically. This human leg consists of a driver located at upper part of the leg and its cylindrical in shape. The studies done by researchers gives us information about the walking mechanism and claim then to be quantifiable, foreseeable and repeatable in nature.

For the past two decennia, our inception about robots and their implications in real life have progressed from sci-fi movies to the real-life computer-controlled bionic devices blended into a wide variety of industrial environments.

The construction of four leg robot has been in trend and will continue to do so in the future. Robots are the future of machines as they are being incorporated in every field known to mankind. As automation is being incorporated into every field, and the presence of very few quadruped robots allows us to present a model having eight links that can be on any terrain and environment with good accuracy and efficiency. The model represents a four-legged animal that can climb trees or commute on an unstructured environment enabling it to attach its prey or safeguard its territory. In [2], they have recognised that legged off-road vehicles flaunt preferable adaptability, achieve greater energy efficiency and contribute added congenial movement than traditional tracked or wheeled automobiles during operation on irregular landscape. As seen in many innovations, two-legged robots have less stability compared to quadruped robot and centre of gravity also less in the former compared to latter which benefits during locomotion. These types of bots use an alternating technique to walk.

The charm associated with human-like devices has not suppressed, and individuals still envisage robots as evolving into bionic replicas of humans. Therefore, machine-like replication of walking mechanisms proves to be efficacious in the evolution of humanoids for a varying range of applications.

II. LITERATURE SURVEY

Desai *et al.* (2019) have designed a new walking leg mechanism with 8 links for walking machines and robots and behaviour of this mechanism is studied. Several configurations are proposed in their study.

Eslam S. Elagamy *et al.* (2016) used graphical based design to synthesize a linkage, is not very accurate, the error range can sometimes be unacceptable.

Lovasz *et al.* (2014) gave solution for leg movement which consists of 5 links belts, it is favoured for its harmonious walking motion, where rotary motion acts as input. Walking robotics and gait analysis have extensively implemented Jansen's mechanism.

Shunsuke *et al.* (2013) modelled and improved the geometry of eight link walking mechanism which has a trajectory of foot which is analogous to Jansen's mechanism.

Ghassaei *et al.* (2011) designed and optimized a crank-based leg mechanism and studied the position of driving link in both Jansen's and Klann's mechanism that is approximately at the centre of the structure and is computed upright.

Ashitava Ghosal *et al.* (2010) proposed to establish up to seven precision point synthesis for a function generating four link mechanism. It needs be considered that the complexity of the system increases when the system has to solve non-linear transcendental equations which consist of more than three precision points.

Batayneh *et al.* (2008) designed and implemented the human-like biped walking mechanism and studied open kinematic chains. They are conventionally more versatile and uncomplicated to design, but their immense degrees of freedom (DOF) makes the mechanism more valuable and intricate to control.

Collins *et al.* (2005) mentioned about five degrees of freedom in the design of three-dimensional biped robot that has human-like architecture and gait.

Hirose *et al.* (2000) reviewed several concepts that could be adopted for design of legged vehicles and key objective of design was to maximize the power developed in the system as well as the energy efficiency. Genta and Amati *et al.* (2001), Koyachi *et al.* (1991) and Senta *et al.*, (1995) have mentioned about use of actuator gravitational decoupling technique in several robots that can be exercised not only during the system design but also in the posture during motion which was used by Hirose *et al.* (2000).

Raby *et al.* (1999) made use of the approach in Fig. 1 which is a pliable six-legged robot.

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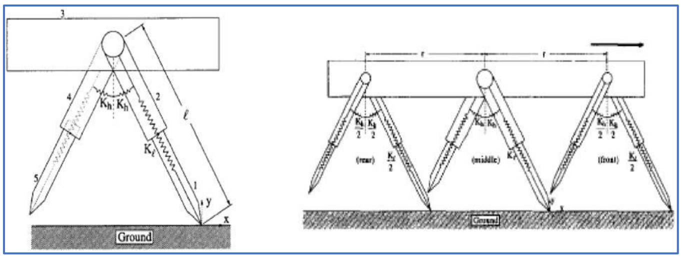


Fig. 1: Biped model with leg and hip compliance (left) and hexapod model with compliant legs (right). Reproduced with kind permission from the IEEE (Raby and Orin, 1999).

Hirose *et al*. (1997) and Yamaguchi *et al.* (1998) have advised that few instances of designing a robot is aided by empirical knowledge of mechanics and physics as an adopted approach. The equipments' design has an aim of minimizing some situation and penalizing the functioning of robot under consideration.

Hirai *et al.* (1998) presented the dimensions, joint locations, ranges of motion and centre of gravity of Honda Humanoid Robot model P2 during its primary phase of development which was analogous to human leg. Later, it was corroborated to cause difficultly in satisfying all the conditions because of which some simplifications were made.

Shieh *et al.* (1996) came up with a two-stage optimization approach for leg mechanism having two degrees of freedom.

Lapshin *et al.* (1995) studied the motion of legged vehicles (having statically stable gaits) along straight path and estimated their energy consumption.

Alexander *et al.* (1990) proposed another technique in which actuators could be used at the location of joints in legs for motion which was based on a biology research for optimising robot architecture. During different stages of locomotion sequence, it is possible to reserve and release kinetic and potential energies of robots' leg's and body using actuators.

Gracia *et al.* (1998) studied mechanical reproduction of walking leg mechanisms. The motion of these mechanisms is helpful in various fields of human prosthetics development, human imitating robots. Developments in research areas of bionics, military services, photography, toys and terrestrial and extra-terrestrial expedition also used their motion.

III. CONSTRUCTION OF 3-D MODEL

The quadruped robot is developed by referring to benchmark studies in [3].

Comparison of the different links to human leg is described in Table 1. The 3 fixed joints are Link 1, Link 4 and Link 6. Binary links are Link 7, Link 3 and Link 5. The foot is attached at Link 2 and the knee joint is located at the connection of Link 2 and Link 5. The model consisting of links was initially constructed on Solid Works and analysed for its movement and path generation. The constructed model is displayed in Fig. 2 and Fig. 3 where all links are designed according to dimensions mentioned in [3]. The orbital motion of ground contact point has a direct relevance with the respective spatial association of length between fixed mounts of the three links of walking mechanism. The dimensions of the various linkages are as below shown tabular column [Table 2 and Table 3]:

[Note: All dimensions are in mm]

Table 1: comparison of mechanism links with human leg

Links of the mechanism	Human leg
Link 1	Crank (neck of hip joint)
Link 2	Leg
Link 3	Connecting rod
Link 4	1st Rocker arm
Link 5	knee arm (Fibula)
Link 6	Ankle
Link 7	2nd rocker arm (thigh)
Fixed point 1	Hip joint
Fixed point 2	Pivot
Fixed point 3	Idler

Table 2: Dimension of Links as in [3]

Link 1	Link 2	Link 3	Link 4	Link 5	Link 6	Link 7
24.2 mm	102.563mm	65.92mm	44.38mm	64.2mm	50mm	44.142mm

Table 3: Values of distance/angle between fixed points in one leg mechanism

Distance between	Dimension
Fixed Point 1 & Fixed Point 2	73.9897 mm
Fixed Point 2 & Fixed Point 3	72.3322 mm
Fixed Point 3 & Fixed Point 1	57.7731 mm
Angle between	Degree
Fixed Point 1 & Fixed Point 2	46.4944°
Fixed Point 2 & Fixed Point 3	68.2633°
Fixed Point 3 & Fixed Point 1	65.2423°

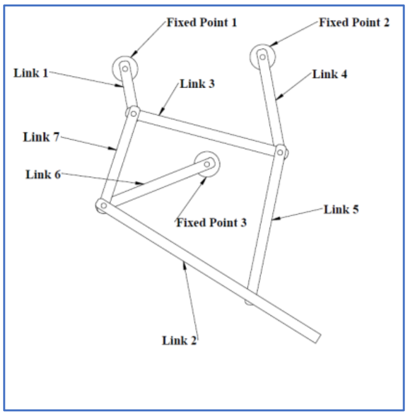


Fig. 2: Annotations of the Linkage model for dimensions and angles

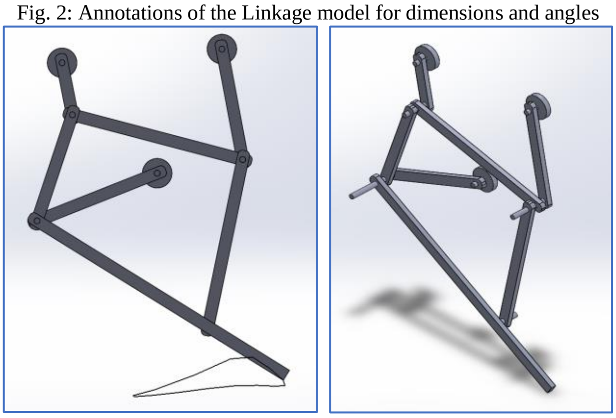


Fig. 3: Linkage model as well as the path generated by the end link

Displacement graph of the model shows that movement of linkage from 0 to 5 seconds along X-axis in Fig. 4.

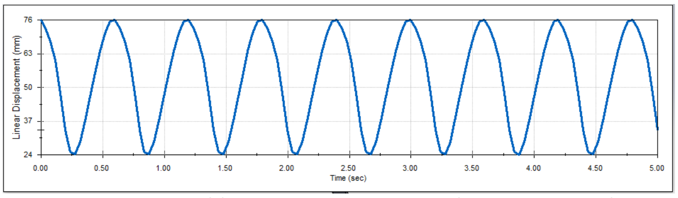


Fig. 4: Displacement of foot with respect to ground for CW rotation of Link 1 with 100 rpm for 5 seconds

IV. ANALYSIS OF QUADRUPED MODEL

Three cases were explored in the studies on the quadruped model; they are:

1) path on a flat surface
2) climbing staircase up and
3) climbing down a staircase

To determine the movement of the leg mechanism in different terrains, for example: along straight path on a smooth surface and climbing up and down a staircase. The factors that are traceability of model in forward and backward motion second is to be sure whether the reversal of mechanism is possible. Four legs of the linkage model along four sides of a model similar to that of four-legged animal. Initially power of 100 rpm was supplied to opposite legs (viz., 1 & 2 are front legs 3 & 4 are rear legs of quadruped as seen in Fig. 5) 1 and 4, also same amount of 100 rpm is alternatively supplied between 1 & 4 and 2 & 3 legs which will move parallel to one another exhibiting the movement of the quadruped bot forward and other two legs are given motion once the initial legs are resting on ground, as seen while walking of human and four legged animals like dog or tiger there is always a leg or two legs which are in ground contact and like this movement of robot happens and parallel movement of opposite legs i.e. Leg 1 and Leg 4 move parallel to one another and Leg 2 and Leg 3 move parallel to each other, and alternately are powered which helps to preserve energy.

A. *Experimental Model*

The first configuration from [3] was selected to determine the precision of leg mechanism and for this mechanism a model was designed using Table 1 and Table 2. The dimensions are Link 1 = 24.2 mm, Link2 = 102.563mm, Link 3 = 65.92mm, Link 4 = 44.38mm, Link 5 = 64.2mm, Link 6 = 50mm, Link 7 = 44.142mm. The dimensions of the frame tabulated in Table 2 which generates a triangular shape with the same angle as mentioned, on which the linkages are mounted called fixed plates of 10 mm diameter on which an extrusion of 5 mm is designed for mounting of linkages. The fixed plates are mounted onto a flat triangular shaped plate which consists of a hole for passing driving rod across the two linkage models to keep them from falling apart. The dimensions of rectangular body onto which the legs are attached is 300 mm long, 150 mm wide and 20mm in height. Using the proposed leg mechanism, a four-legged quadruped was designed as shown in Fig. 5. The quadruped model comprises of a framework on which four legs are mounted. Alternately power is supplied to the legs because, alternate supply of energy enables the robot to always have ground contact and also stability is maintained as seen while walking in human beings where we can see that there is always a leg on ground and helps from falling towards ground, similarly this is seen in four legged animals like a dog or a tiger where at any given point of time two legs are in ground contact. The foot of two opposite legs are always in ground contact while in motion. The model was placed in two paths, one a straight path of 1000 mm length and another as explained in Table 3.

Name of Path	Number of Steps	Run Length in mm	Riser Length in mm
Climbing up the staircase	12 steps	150 mm	13 mm
Climbing down the staircase	12 steps	150 mm	13 mm

Table 3: Dimensions of Staircase

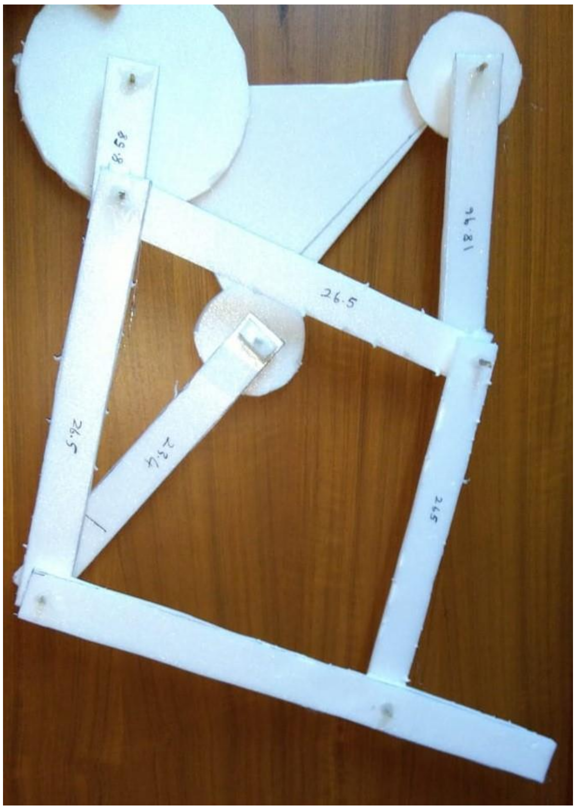
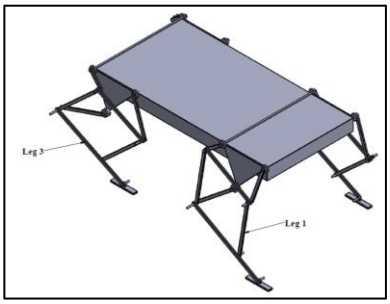


Fig. 17: Linkage model made in Depron sheet



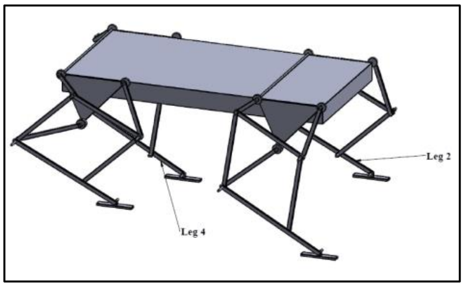


Fig. 5: Quadruped Model

B. Experiment Setup

The quadruped robot was designed based on the dimensions in Table 1 and Table 2, as rectangular cross-section of the links enables sustain bending resistance the links were constructed in rectangular shape but the sharp edges were provided with a 1.5 mm circular fillet and a thickness of 2 mm. The performance analysis of the quadruped model was conducted on two different terrains, one along a straight path and another for climbing a staircase. Opposite Link 1 of the leg mechanism were given constant 100 rpm of Link 1 rotation. A path was traced from the foot of the model. A stress analysis was also performed to determine the factor of safety of the model and to analyse the weight it can carry. The model was analysed on both straight path as well as on staircase using Solid Works. The below figures show the path generated, the experimental setup, graph of acceleration vs time, FOS plot, Von-misses stress plot, Strain plot.

C. Experiment Results

The stride length of foot is 160 mm and stride height are 36 mm. As observed in Fig. 6, the FOS of the model is 1.4, the yield strength exhibited by the model is 3.25e+08 N/m^2, maximum strain of 8.832e-04 ESTRN. The movement of the model is exhibited along a staircase as well as along a straight path. The locomotion of the model along the path at different time is shown in five figures in Fig. 7 and Fig. 9 from starting of the path until the end of path. Von Misses stress of 3.25e+08 N/m^2 is experienced by the model during motion. Variation of velocity and acceleration with respect to time of foot is shown in Plot 3 & 4 and the constant velocity that is supplied to link 1 is shown in Plot 2. The path generated by the model during motion along straight path and along the staircase is shown in Fig. 10. A maximum reaction force of Link 2 with respect to ground 225 N. The weight carried by the robot in these simulations is 20 kilograms. The results obtained by quadruped robot showed that it can have movement in different terrains and shows its capable of motion. Thus, this robot is proposed as a walking leg mechanism which is a practical widget that can be customised to robots, rovers which have wheels and for robots which face difficultly while move in places that are uneven. This robot uses lesser energy for motion as only two legs are initiated at a time and rest two remains stationary where as in a rover all four wheels needs to be supplied with energy for motion. The graphs obtained by the analysis of the designed quadruped robot explains that, from the graph of velocity of Link 1 [Fig. 11], velocity varies during motion along the path due the reaction force that is generated at the foot of model which is shown in Fig. 14. The graph of velocity of Link 2 tells that the greater velocity is required while lifting a leg when compared to while putting it back onto ground due the action of gravity during downward motion and acceleration similarly keeps on varying due to variations while climbing a staircase as seen from Fig. 13.

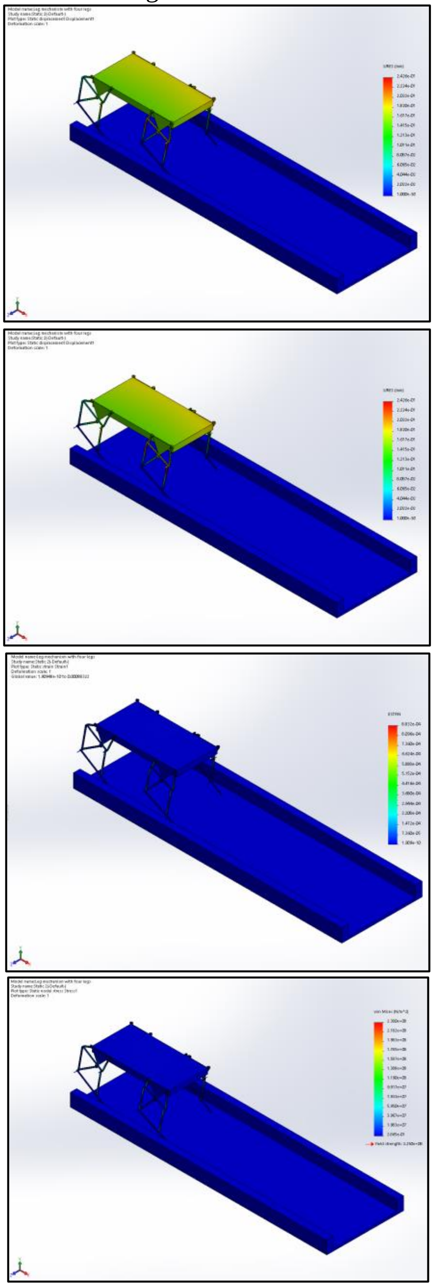
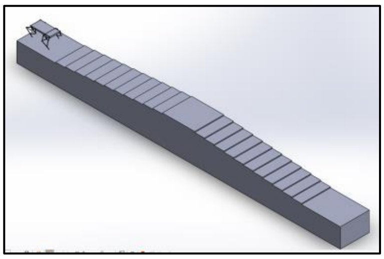


Fig. 6: Displacement, FOS, Strain and Stress of Quadruped robot during straight path motion



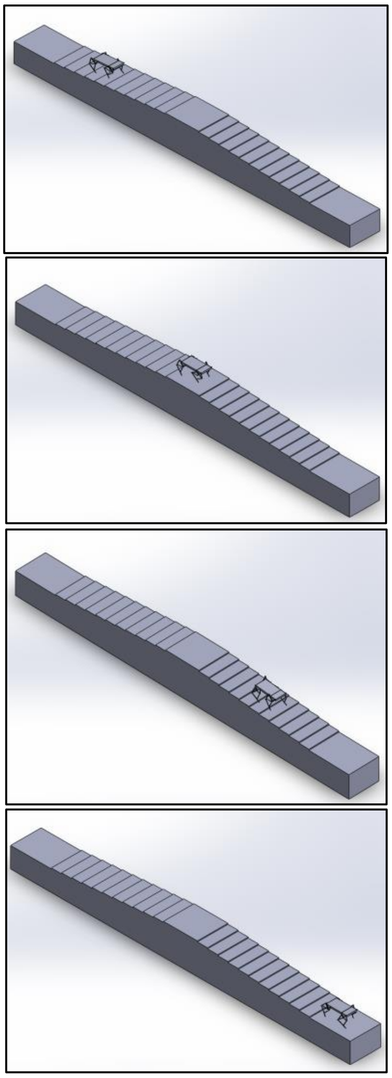


Fig. 7: Quadruped model undergoing simulation of climbing up and down staircase

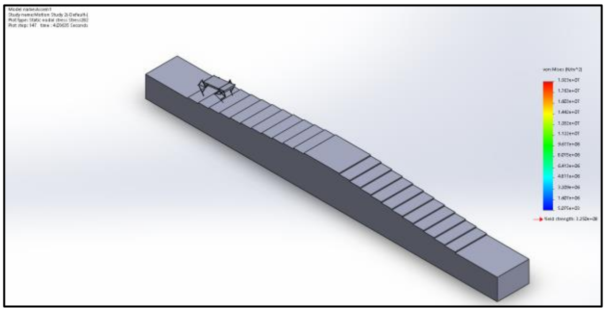
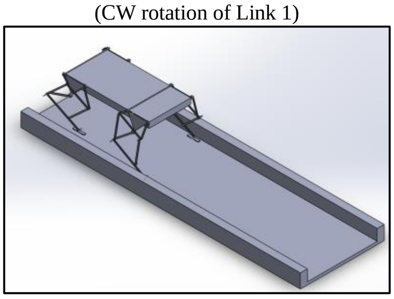


Fig. 8: Motion stress analysis of robot while climbing the staircase (CW rotation of Link 1)



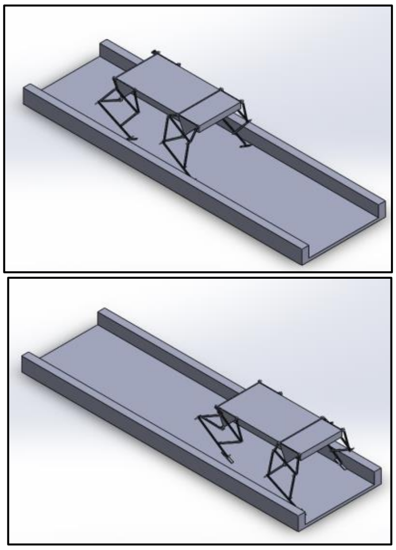


Fig. 9: Quadruped robot walking along a straight path showing the initial, middle and final position (CW rotation of Link 1)

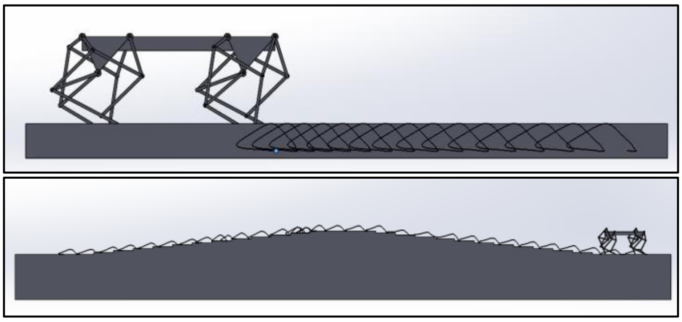


Fig. 10: Show the direction of motion of quadruped from left to right; In the First picture the path is below between two parallel pillars or sidewalks.

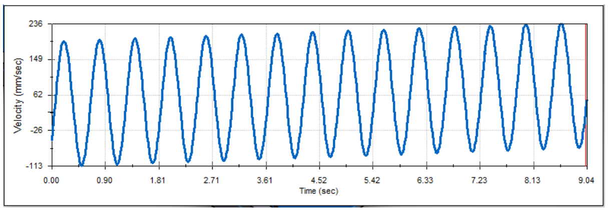


Fig. 11: Velocity vs Time graph for input Link 1

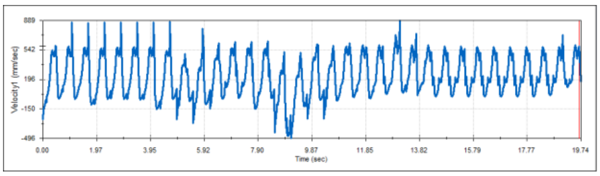


Fig. 12: Linear Velocity vs time graph of Link 2 (Foot)

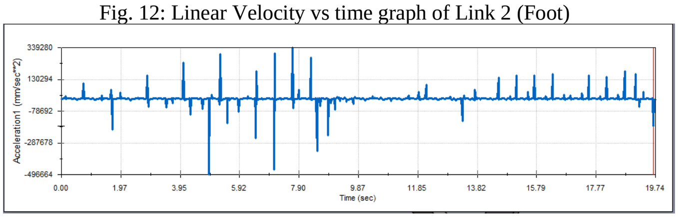


Fig. 13: Linear Acceleration vs time graph of Link 2 (foot), during motion along the staircase

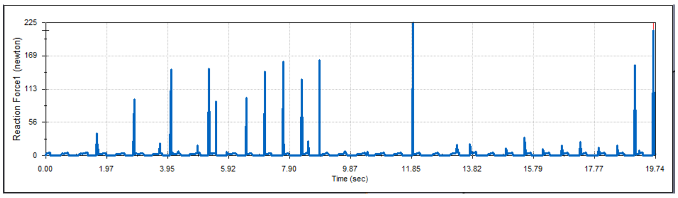


Fig. 14: Reaction Force of Link 2 (foot) with respect to ground

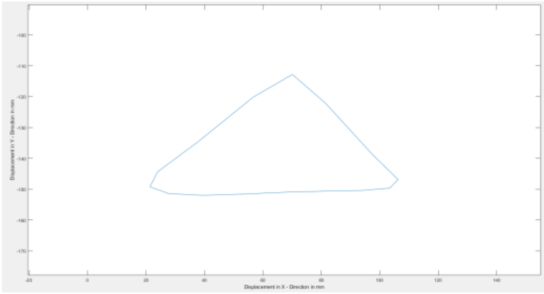


Fig. 15: Path generated by the foot of proposed model

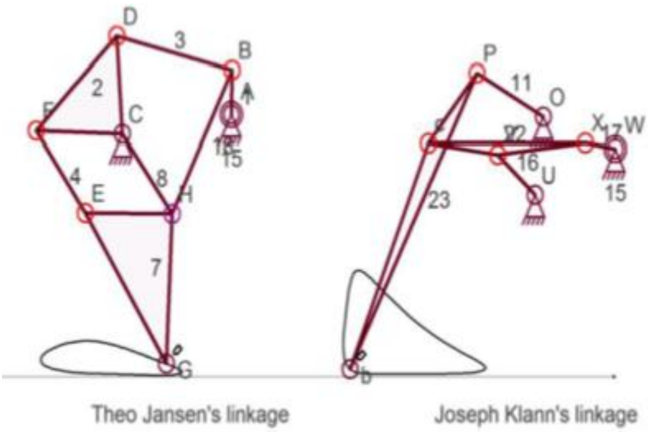


Fig. 16: Path generated by Jansen's and Klann's linkages

V. CONCLUSIONS

We present the simulation studies on an improved quadruped robot having 8 link mechanism in the paper. The walking leg mechanism is installed on a framework consisting of three fixed pivot points which makes it strong and stable.

Walking of the quadruped model is satisfactory along a flat surface, Stair climbing up or down with constant velocity and acceleration period of foot. Stress analysis displays a stable system in handling the reaction forces from the ground which makes suitable to operate in different terrain conditions.

The error percentage in straightness of stride path to stride length of path of the proposed model is 0.011 and that of Jenson's and Klann's linkages are 0.050 and 3.40 which shows that the proposed model has greater efficiency than other two models.

The robot exhibits reversible motion both in forward as well as reverse direction walking at same velocity, similar observation is made in climbing up or down the stair case.

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