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Developing A Hexapod Walking Machine

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ABSTRACT:

This project deals with the walking machines. A brief history and the evolution of the walking machines which are classified based on their legs, different walking mechanisms exists out of which Theo Jansen's walking mechanism was considered as it has single degree of freedom, walking mechanism is theoretically simple and efficient. Vigorous endeavours were encountered in applying the mechanism and toiled in enhancing various parameters to redefine the stability of the model and improving the total efficiency of the model using an optimization technique which is Genetic Algorithm.

The first part of this thesis deals with the basic introduction of the walking machines. Like the classification operation and advantages of the walking machines. The criteria's for the adaption of Theo Jansen mechanism Over The Other mechanism are discussed. Secondly the problems encountered in the application of the mechanism to the prototype design, the implementation of the Genetic Algorithm and the code to optimize the mechanism were discussed with sample results are showcased. Thirdly Justification of the results that were obtained from the genetic algorithm is done using CAD software solid works. The various design parameters like the stresses developed due to various forces applied on the mechanism while walking are analyzed the stresses and strains on each link are evaluated Velocity and acceleration plots for each joint and legs are also plotted. A Prototype was developed to validate the Kinetic and kinematics models of the walking mechanism and the practical constraints that are encountered were discussed in the final part of the thesis. The thesis concludes by discussing the various aspects that need to be considered for the future prototypes based on the Theo Jansen mechanism and the core idea of building a scalable machine which can be used like a transport walking machine in rugged and harsh conditions.

Key words: Walking Mechanism, Legged Locomotion, optimization of Link Geometry, fitness factor, etc

I.INTRODUCTION

Many animals in nature have adopted legs for various environmental conditions. Centipedes, spiders, cockroaches, cats, camels, kangaroos, and human are among those, either with different number of legs or with different kind of walking. It is understandable that people turned their attention to those walking animals, after it was recognized that the human invented wheeled and tracked systems did not satisfy all the needs. In this sense, legged systems have a peculiarity of imitating the nature.

This imitation is obvious in structural similarity between legged robots and imitated animals; however, for today the imitation is not limited to structural design. Today researchers are trying to understand the underlying biological principles of walking in animals, namely the operational and control structures .In biological sciences and robotics applications the most important item is the plan and coordination of leg movements. Movement is a fundamental distinguishing feature of animal life. The locomotion over a surface by means of limbs or legs can be defined as walking whatever is the number of limbs or legs that are used different ways of walking have been achieved by the evolutionary process in nature.

It introduces more flexibility and terrain adaptability at the cost of low speed and increased control complexity. In order to develop dynamic model and control algorithm of legged robots, it is important to have good models describing the kinematic behavior of the complex multi-legged robotic mechanism as walking machines are increasingly gaining importance in space for planetary exploration, where the terrain is rugged thus reducing the expensive and dangerous extra vehicular Activities by Astronauts. Walking machines find wide range of applications like in military logistic support where there are no highways.

II. OBJECTIVE OF THE WORK

The primary goal of this thesis is to create a suitable theoretical framework to justify the design choices for a new type of walking machine.

There are two further secondary aims. The first of these is to validate the mathematical model. The second is to use this design opportunity to develop methods to automate complex parameter related designs. These methods, once developed, could be later extended to optimize other aspects of the design.

III. WALKING MECHANICSM AND MACHINES

Hexapods

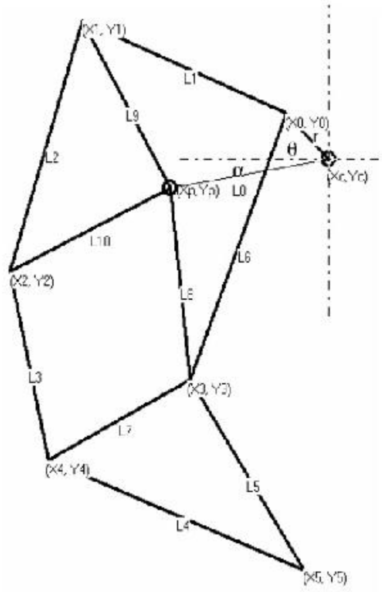
Six legs are the minimum required to ensure static balancing with leg mechanisms with a symmetrical duty cycle, that is, where the return part of the cycle is the same duration as the walking part. Three legs can be in the walking phase of their cycle, while the additional three legs are moving along their return trajectory. This configuration has the twin advantages that it requires no balance control system, and the leg mechanism's movement can be more easily achieved due to the relative similarity between walking and return phases.

The triangular shape of the support polygon for each tripod means that a rigid legged walker will be completely fixed in space once the legs are in contact with the ground. There would be no rocking, and the orientation of the walker body can be determined completely from knowledge of the terrain, which may vary from planar. Rough terrain can be tolerated with a symmetric gait. Hexapods are a common and popular configuration amongst research groups, as the elimination of balance control simplifies the design of the machine significantly. The main problem with hexapodal walkers is the complexity of the additional legs. In electrically controlled and individually actuated legs, this overhead may be considerable.

IV. DESIGN CRITERIA

Applying the principle of parsimony (also known as the "KIS" (Keep It Simple) principle or Occam's razor) makes the criteria for an envisaged walking machine much clearer. This principle is not mentioned facetiously, but as a conscious reminder that complexity is what has kept most walking machines confined to laboratories. The KIS philosophy will need to be applied continuously during design and development of such a machine. In this light, the criteria which the prospective walking machine should meet are:

- Static balance, so that no balance control system is required.
- Active Propulsion, as powered legs will extend the navigable terrain immensely.
- Minimal Power Consumption.
- Minimum number of prime movers, to simplify implementation and maintenance of the machine. If a single prime mover can be used, the control system for the prime mover can be greatly simplified.
- The Prime mover should preferably required a rotary motion rather than linear motion, as rotary prime movers are varied, simple and can be easily portable, particularly internal combustion engines and electric motors. Hydraulic or Pneumatic linear actuators require more sophisticated systems and still require a rotary prime mover to be portable.
- Deterministic foot trajectory, to eliminate the need for ground sensing, impact control and leg kinematic control systems.
- A slow return mechanism to reduce dynamic loads in the leg's return stroke.
- A stiff mechanism, to ensure that body movement is controlled by leg position.
- Variable foot size to enable the machine management/interface with the surrounding area.
- Hinged legs or legs with knees, so waling vehicle body can be maintained in the same horizontal plane, minimizing changes in the potential energy.
- A scalable design to allow testing and validation on reduced scale for the prototype that can be applied for a full sized vehicle.



Considering the sketch of the linkage shown in Figure, it is possible to derive the motion of the foot point, (x_5, y_5), as a function of the crank angle θ. This requires knowledge of the lengths of the links, which can be represented as a vector.

$$L = [l_0, l_1, l_2, l_3, l_4, l_5, l_6, l_7, l_8, l_9, l_{10}] \quad \text{..Eqn 1}$$

Where l_0 represents the distance between the crank shaft and the fixed pivot, and the other subscripts represent lengths of the links as named in Figure.

The crank radius is taken as a constant, r, rotating about the crank centre point (x_c, y_c). The fixed pin position is given by (x_p, y_p), and is inclined by angle α to the horizontal. The fixed pin coordinates (x_p, y_p) are given by:

$$x_p = x_c + \left(l_0 \times \sin(\alpha)\right) \quad \text{….Eqn 2}$$

$$y_p = y_c + \left(l_0 \times \cos(\alpha)\right)$$

…Eqn 3

The positions of the various nodes of the linkage can be represented as a vector of points

$$N=\left[(x_0,y_0),(x_1,y_1),(x_2,y_2),(x_3,y_3),(x_4,y_4),(x_5,y_5)\right]$$

…Eqn 4

Considering Node 0, we can write the following equations.

$$x_0 = x_c + \left(r \times \sin\bar{\ }\right) \quad \text{……Eqn 5}$$

$$y_0 = y_c + \left(r \times \cos\bar{\ }\right) \quad \text{…..Eqn 6}$$

The position of Node 1 is determined by the intersection of the arcs made by Link 1 around (x_0, y_0) and the arc of Link 9 around point (x_p, y_p).

$$\left(x_1 - x_0\right)^2 + \left(y_1 - y_0\right)^2 = \left(l_1\right)^2 \quad \text{..Eq 7}$$

$$\left(x_1 - x_p\right)^2 + \left(y_1 - y_p\right)^2 = \left(l_9\right)^2 \quad \text{..Eqn8}$$

Simplifying equation 7

$$x_1 = x_0 \pm \sqrt{\left(l_1\right)^2 - \left(y_1 - y_2\right)^2}$$

…Eqn 9

Simplifying equation 8

$$x_1 = x_p \pm \sqrt{\left(l_9\right)^2 - \left(y_1 - y_p\right)^2} \quad \text{…..Eqn 10}$$

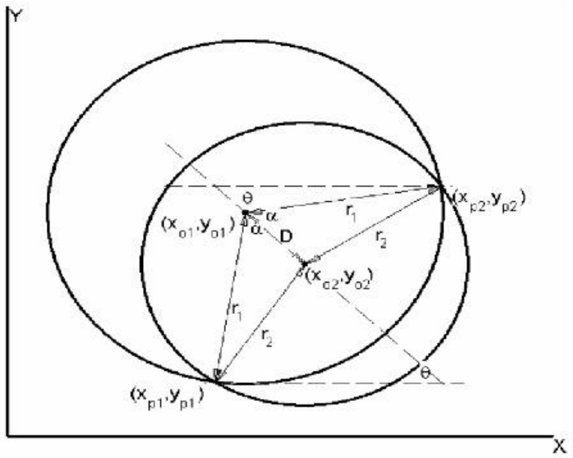
Equating equations 9 and equation 10

$$x_0 \pm \sqrt{\left(l_1\right)^2 - \left(y_1 - y_0\right)^2} = x_p \pm \sqrt{\left(l_9\right)^2 - \left(y_1 - y_p\right)^2}$$

….Eqn 11

Unfortunately equation 11 cannot be easily solved for y1, due to the presence of square root on both sides of the equation. There will always be terms in $\sqrt{\left(y_1 - y_{o,p}\right)^2}$ which cannot be eliminated, making an algebraic solution difficult.

The actual method of solution derives from the co-ordinate geometry, specifically the intersection points is as shown in the figure below.



The following Equations for intersection points $\left(x_{p1}, y_{p1}\right)$ and $\left(x_{p2}, y_{p2}\right)$ are standard in the fields of co-ordinate geometry

$$x_{p1} = x_{01} + r_1 \cos\left(\bar{\ } + \alpha\right)$$

…Eqn 12

$$y_{p1} = y_{01} + r_1 \sin\left(\bar{\ } + \alpha\right)$$

…Eqn 13

$$y_{p2} = y_{01} + r_1 \sin\left(\bar{\ } - \alpha\right)$$

…Eqn 14

$$x_{p2} = x_{01} + r_1 \cos\left(\bar{\ } - \alpha\right)$$

…Eqn 15

Where

$$\theta = \tan^{-1}\left(\frac{y_{02} - y_{01}}{x_{02} - x_{01}}\right)$$

…Eqn 16

$$\alpha = \cos^{-1}\left(\frac{\left(D^2 + r_1^2 - r_2^2\right)}{\left(2 \times D \times r_1\right)}\right)$$

…..Eqn 17

$$D = \sqrt{\left(x_{02} - x_{01}\right)^2 + \left(y_{02} - y_{01}\right)^2}$$

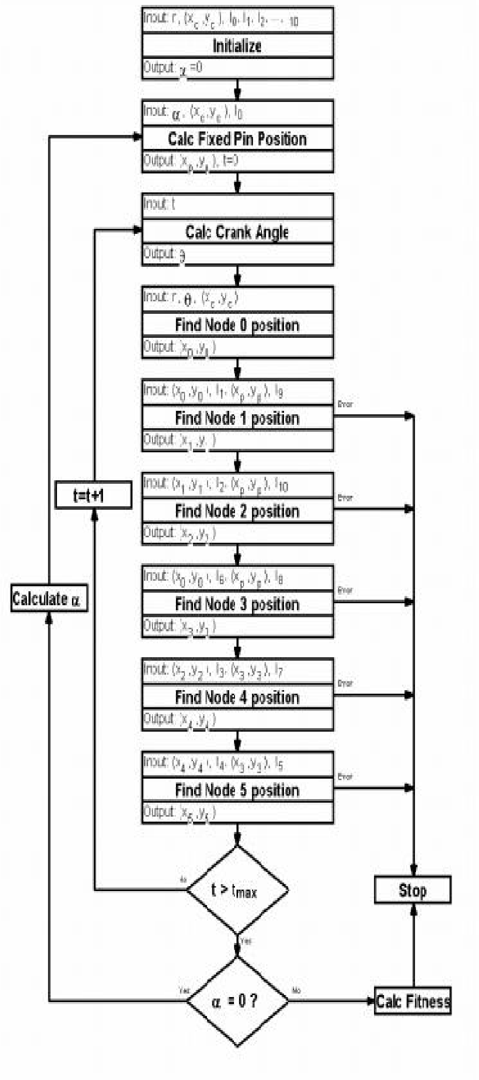
….Eqn 18

Although the equations 12 to 15 yield the positions of both the intersection points, only one point is relevant at each node. The software solution contains additional information to ensure that the correct intersection is possible; In addition the software checks the condition of correct intersection points, such as overlapping circles, etc

Computer model

The solution to solving this mechanism uses repeated application of the simple method outlined. Each node is considered as the intersection of two circular arcs, and by moving sequentially from node 0 to node 5, the positions of all nodes can be found. This method is shown graphically in the flow chart, below.

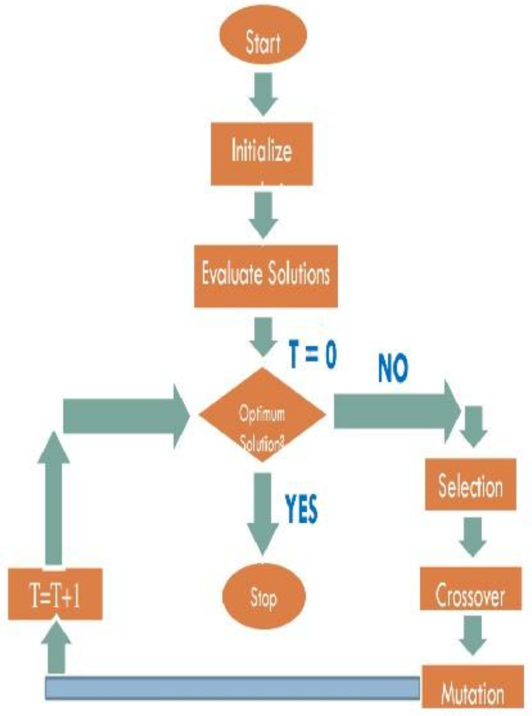
The inner loop of the algorithm detailed in Figure shows that a single revolution of the crank is broken up into a number of time slices, which are equivalent to angular positions, given that the drive shaft is assumed to be rotating at a constant angular velocity. In the software implementation, the maximum number of time slices permitted is 256, but there is no theoretical upper limit on how finely the time may be sliced. So t ranges from 0 to 255, although t_{max}= 239 is usually used, as this equates to 240 time slices with an angular position change between each of 1.5°.



V. GENETIC ALGORITHM

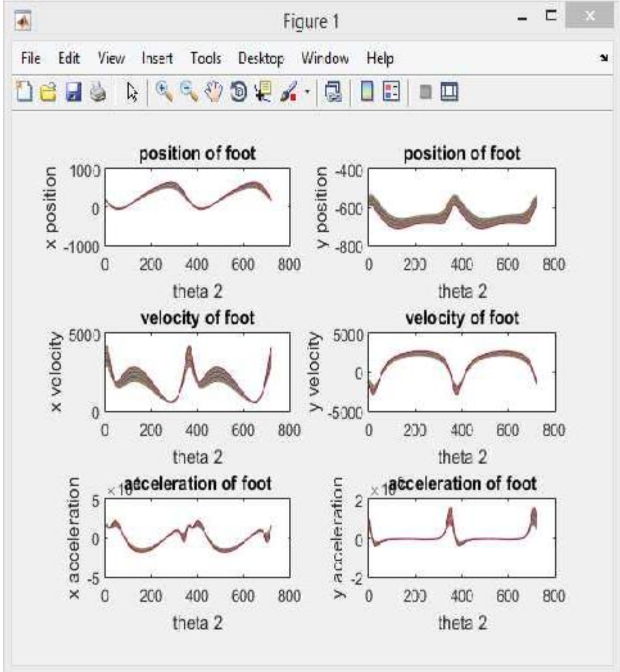
In nature, individual animals compete against other members of their species in a given environment. Those who are best able to make use of resources in their environment, said to be well adapted, will have sufficient means to give birth to and maintain offspring. These children will inherit properties and abilities from their parents, but will in general have a slightly different set of abilities than either parent. If the abilities of the children are still adapted enough to the environment, they in turn will bear children. If some offspring have variations that make them maladapted, then they will have fewer or no children. The result of this ongoing process is that new variations that are better adapted to an environment (or at least no worse adapted) and changes that match changes in the environment will come to predominate in a species of animal. All this presupposes some method of transmitting information about abilities from parents to children.

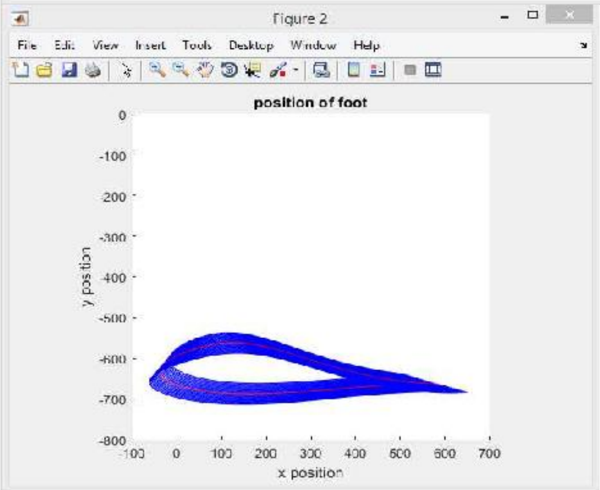
The simple genetic algorithm looks like as shown in the figure



Implementation of GA

The GA implemented attempts to solve the problem of the walking mechanism that will make a suitable leg for a walking machine. The type of solution required is a particular mechanism geometry that will give desired values for various properties, like the kinematics and kinetics of the leg which were solved. The other major parameter not known is r, the radius of the driving crank for the Jansen mechanism. Due to the scalability properties of the mechanism, the crank radius need not be considered as a variable property of each solution, if the search is for kinematically good legs. The problem can be simplified by eliminating this variable. The code for the walking machine was written in MATLAB with the earlier said criteria and the sample plots are obtained as shown in the figure





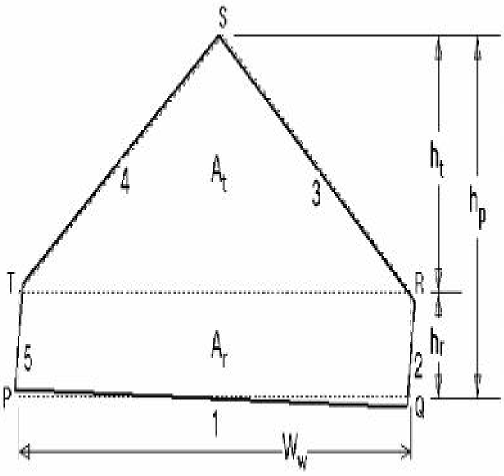
Fitness calculation

The “correct” shape of the foot trajectory was the main attribute needed in the leg mechanism. Different methods evolved as it became clearer how the GA responded to changes in the fitness calculation method and also to the types of trajectories being found by the GA. It became clear that the way the fitness function was defined mathematically would indeed apply significant selection pressure, and the mechanisms found would definitely provide foot trajectories that resembled the curve defined by the fitness scoring method. Defining the curve required was the fundamental problem.

Triangular trajectory

From experience with the straight line fitness factor, it became clear that a more complete definition of the shape of the entire foot trajectory curve would be required, to create selection pressure for a practical curve. To this end, the fitness calculation function was extended to consider the trajectory as triangular. The base of the triangle would be the walking portion of the trajectory, comprising 50% of the trajectory points. The other two legs of the triangle would be the upward, right-most part of the path and the left-most downward part. This new actual fitness score was defined as a sum of factors. The first factor was the flatness, as calculated previously. The second factor was the equality of the lengths of the two upper arms of the triangle, equal lengths being preferred. Finally, a factor proportional to the area of the triangle was added to the sum. This fitness calculation method was more successful in finding mechanism that gave practical foot trajectories.

The fitness calculation mechanism which was obtained in the straight line portion was a sort of irregular pentagon. a triangle at the top and a half triangle at the bottom which can be simplified as a rectangle for better accuracy



The foot trajectory is represented by the pentagon shown in solid lines. Line 1 (PQ) is the walking portion of the trajectory, line 2 (QR) is where the foot is lifted, returning along lines 3 (RS), 4 (ST) and ending at line 5 (TP), where the foot is returning to the ground. By regularising the pentagon, as shown by the dotted lines, it is simple to calculate the pentagon’s area, as the sum of A_r, the area of the lower rectangle and A_t, the area of the upper triangle.

Fitting a pentagon to the data point array provided by the mechanism solver was achieved in a step-wise fashion. First the walking portion of the cycle (PQ - line 1) was found, using the method used to compute the mechanism orientation angle The index of the highest point in the trajectory, point S, had been recorded when the data array was generated. To locate point T, the data was scanned from point S, until a point was found with the same horizontal coordinate or further to the left of point P, and this point taken as T. Similarly, point R is found by scanning backwards from point S, until a point directly above or to the right of Q is found. The ability to find a useable pentagon in the data points was a significant selection pressure. The fitness score could be calculated as a weighted average in a similar fashion to the method used earlier.

$$F=10+(W_f\times F_f)+(W_t\times F_t)+(W_b\times F_b)+(W_r\times F_r)+(W_a\times F_a)+(W_s\times F_s)$$

where

F = Fitness

10 = the 10 point bonus for fitting an assessment pentagon

Wf, Wt, Wb, Wr, Wa, Ws = weighting factors

Ff = flatness factor

Ft = triangle side length factor

Fb = bottom rectangle height factor

Fr = aspect ratio factor

Fa = area factor

Fs = mechanism size factor

To evaluate what maximum value of each factor could be. It will also be useful to know outcome what a "good' value would be. The final actual numerical value of the fitness score will depend on the values of the weighting factors used.

Fitness Results

The GA was run many times with various parameters, both to assess performance of the GA and to get a feel for the impact of the various parameters on the process. Although a series of formal experiments could have been run, to record performance and variations in it, this was not done. The primary objective of this thesis is to design walking machines, not to discuss genetic algorithms in detail. Although there is perhaps scope for further work in this direction, this has been deferred, in the interests of pursuing walking.

The conclusion of all runs of the GA and exhaustive searches has been the accumulation of records of some 1 million, all of which can be assembled and solved for a full crank rotation. With a probable success rate of 1%, this means at least 3.6 million configurations have been tested. The distinctness of these solutions has been checked.

This collected data has been accumulated for three main reasons. Firstly, it serves as feedstock for the current and future GA software, particularly when creating initial populations. Secondly, this catalogue of existing known working linkages can be initially assessed if new selection criteria are created. Lastly, the catalogue of linkages may be of some use to other designers who may wish to find linkages in this class, with other properties.

Of these 3.6 million linkages, only seven are currently considered practical for use in walking machines. There is however a list of approximately 200 configurations that have been considered manually and retained separately. Given the 10^{33} options, this seems slim pickings indeed! There is a definite conviction that the ultimate leg configuration exists in the space, but will forever remain elusive.

The problem with the optimization techniques applied in this thesis, and with all other methods, is that it is extremely difficult to encapsulate all knowledge, wisdom and their corresponding factors into quality solutions to problems may be impossible to define, but instantly recognized when encountered.

The usefulness of this GA in MatLab software has been in creating and presenting a wide range of new mechanisms that may be considered. With respect to finding solutions with high fitness scores, it is worth reconsidering the above set of equations, substituting the maximum values permissible for the various fitness factors, to obtain the maximum possible fitness score. This score depends on the weighting factors used, so these have been taken from the software settings and are also shown in the table. The table also lists "good" values for all factors, and a weighted "good" score is calculated.

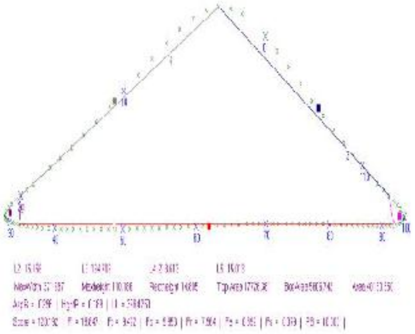
Description	Weight Factor	Max. Value	Max. Weighted	"Good" Value	"Good" Weighted
Bonus For Pentagon Fit	1	10	10	10	10
Flatness Factor	4	20	80	19.5	78
Triangle Side length Factor	1	10	10	9	9

Bottom rectangle height Factor	1	10	10	9	9
Aspect Ratio Factor	1	10	10	8	8
Area Factor	3	1	3	0.667	2
Mechanism Size Factor	1	1	1	0.1	0.1
Maximum			124		116.1

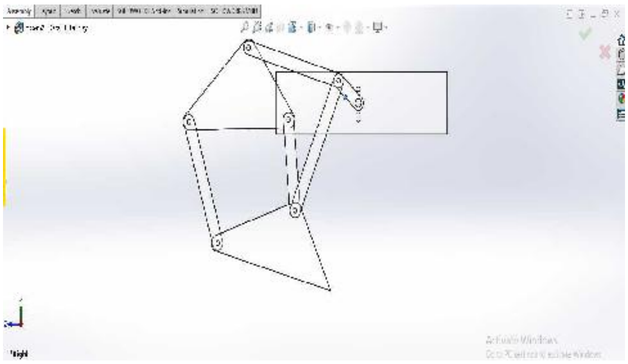
The highest scoring solution found by this GA implementation achieved a score of 120.19, the second best got 118.74 and the consolidated results of the various searches includes seven solutions with scores over 116. By comparison, the previous best walker leg mechanism used, the Jansen mechanism, scored 108.8 in the extensive research. If this value is taken for the value for a good walker, then the GA found 24 mechanisms with scores higher than this.

In this light the GA software implemented here can be considered a success ,in that it created a range of potential solutions that are better than the best solution previously available this assessment is done in the context of the evaluation criteria set by this model Jansen almost certainly had different criteria in his model which led him to choose his leg mechanism proportions for his 'strand beast' it would be interesting to know how well the best legs found with this GA would rate when rated with Jansen's fitness determination algorithm.

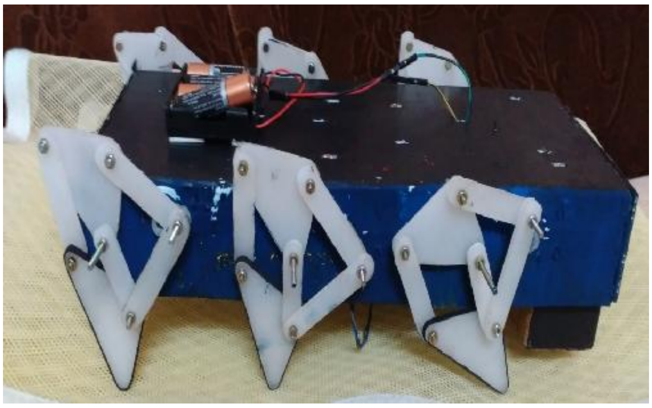
The best foot trajectory found by this with a fitness score of is shown in the figure as with other legs that have identified as usable by previous searches this leg design was used as the basis for a new walking machine prototype.



VI DESIGN OF MODEL LEG USING SOLID WORKS



PROTOTYPE



CONSTRUCTION DETAILS

The model shown in this project was planned according a cad prototype discussed in the previous Chapters. The Whole Model was considered after many hits and trails, to make it work Six Geared Motors were used to operate the Six legged Robot. The Following Dimensions were considered for the prototype. as shown in the figure

The Following Materials Were used For Different parts of the Model are mention as below

Component	Material
Body or Chassis	Coagulate Plastic Sheet
Axial(For Each leg)	SS(M3 Bolts)
Legs(links)	Poly propylene(pp)
Driver	75 rpm (nylon gear motors)
Power Source	AA Size Batteries
Connections	Copper jumper wires

VII. CONCLUSION

The core idea of this project has succeeded in its goal of providing a theoretical framework to facilitate the design of a walking machine. It describes in broad terms the existing devices and outlines the limitations of current attempts to walk using a machine. Simplifications of existing machines are required and the research work demonstrates how the Jansen mechanism meets the simplifying criteria better than any other mechanism considered here.

The details of the mechanism are exposed and the previously developed method is reintroduced, along with extensions to allow it to search for good designs. Requirements that a good design should fulfill are given and the use of the model to pursue an exhaustive search is described. The ineffectiveness of this means of searching is discussed.

The thesis then introduces optimization theories and assesses possible methods that could be used to find solutions. The method selected, optimization by genetic algorithm, is discussed. The details of the particular implementation used are given. The results of the search for good legs are discussed and a catalogue of mechanisms so far discovered in the class is presented. The best suited mechanism found in the search is described.

As this research has encompassed practical construction of prototype machine, the drawbacks in the implementation of the designed prototype, the details of the various the lessons learnt from each attempt are enumerated. The research has been successful in advancing knowledge on the subject of walking with Jansen linkages for legs. The initial hope that the mechanism could be used for locomotion has been justified by the construction of working prototype that perform as designed..

The work described here should be considered a preliminary step in the envisaged design and development of a practical transport walking machine. A very significant aspect of the performance of any useable machine, namely maneuverability and amphibious abilities, has only been touched on in this work. Clearly this problem requires a solution before any practical machine can be considered. Until this problem is solved, the Jansen legged walker will remain a curiosity.

An aspect that requires additional work is the detail design of large scale machines that can successfully carry significant cargo. The ability to safely carry passengers is also a necessity as a ride in a machine of this type will be an important aid in convincing the general public that walking machines may be a viable transport option.

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