# Design And Synthesis Of Six Legged Walking Robot Using Single Degree Of Freedom Linkage

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*Abstract : In this project a six legged walking robot inspired by human locomotion is discussed. To implement the walking pattern of humans a four bar linkage based coupler curve is generated for the structure and its performance is analysed. Two servo motors are used for each leg of the robot the for turning and the other motor for achieving like human walking pattern. Stability (static) of the robot is maintained by using proper gait. In this project six legged walking robot has been design and synthesis has been discussed.*

## 1. Introduction

Locomotion in robots is commonly achieved using wheels. However, wheeled robots have deficiencies moving in complex terrain. Legged robots have discrete contacts with the ground that are good for walking over obstacles and navigating complex terrain. Legged robots can be protected from failure due to mechanical redundancy of legs.The main advantage of wheel locomotion is the ease with which it can be maneuvered. It is highly energy efficient and can reach high speeds can with the help of wheels. But it has disadvantages, one being that it demands cluttered terrain, which means that more than 50% of earth's terrain is inaccessible to wheeled robots also it can't be able to move on a large vertical step. It can be rectified by increasing the diameter of the wheel, but this may not be possible every time as there can be factors limiting wheel size. In an extreme case the wheel may just dig itself deeper until the vehicle stops permanently. Result in wastage of power. Legged locomotion on the other hand does not demand any special terrain.

It also causes less damage to natural terrain as it leaves behind footprints of discrete steps. There are many advantages of legged locomotion over wheeled one: One can step over obstacles can go up and down stairs. Legged locomotion can even carry a vehicle over wide chasms or extremely broken ground. One can achieve a smooth ride on rough ground by varying the effective length of its legs to match the undulations of the ground. It can work efficiently on soft grounds, where wheeled machines fail.

A multi-legged robot possesses tremendous potential for manoeuvrability over rough terrain, particularly in Comparison to conventional wheeled or tracked mobile robot. 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 behaviour of the complex multi-legged robotic mechanism.

Different types of walking robots are used such as 1.Two-legged Walker, 2.Four-legged Walker, and 3.Six-legged Walker

### Two-legged Walker

A two-legged walker/biped is, by far, the hardest to create. Since at the point of stride only one foot will be in contact with the ground and the centre of gravity must dynamically shift in order to keep the robot from falling over. Whilst neither as efficient nor as simple as the wheeled or a tracked vehicle, the potential for crossing more difficult terrain is paramount. An obstruction can merely be stepped over, pass between the legs. However, there is no redundancy in the legs. If one leg fails, the robot cannot walk at all.

### Four-legged Walker

A four-legged walker/quadruped is fairly common. An example of a commercially available quadruped is the Sony Ambo. A quadruped is simpler to control then a bipedal robot and so long as only one leg is ever off the ground no sophisticated balance is required. However, a 4 legged robot does not offer any redundancy in the

legs. If a leg fails the robot loses the ability to walk.

**Six-legged Walker**

The six-legged walker/hexapod is very stable. A designer can design a gait that can take three legs off the floor at any one time leaving a stable tripod. A hexapod is very good for complex terrain, and along with quadrupeds, it is the most common legged form robot. This form of robot offers excellent stability and redundancy in the mechanisms. The main problem with this robot is the extra cost incurred from implementing the additional legs.

## 2. Literature Review

**Gilles Ritter** et al., [1] describes the implementation of Disciples Simplex, an autonomous evolvable system that controls the walking of our six-legged robot Leonardo. Disciples Simplex is based on GAs and logic system reconfiguration, and is implemented into a single FPGA. As a result, a fully autonomous robot which is able to learn to walk with the aid of on-line evolvable hardware without any processors or off line computation.

**John D** et al., [2] described a coordinates of the coupler attachment points in two different coordinate frames, thereby reducing the number of independent variables defining a suitable dyad for the desired rigid-body motion from five to two. After applying these geometric constraints, numerical methods are used to size link lengths, locate joint axes, and decide between RR, PR, RP and PP dyads that, when combined, guide a rigid body through the best approximation, in a least-squares sense, of n specified positions and orientations, where n>5. No initial guesses of type or dimension are required. An example is presented illustrating the effectiveness and robustness of this approach.

**P.A. Simionescu *, D. Beale,** [3] analysed the problem of optimum synthesis of the planar four-bar function generator a practical case of the Ackermann steering linkage is considered. The reduced number of design parameters of this symmetric four-bar linkage allowed inspecting the design space of various types of objective functions through 3D representations, and their properties suggestively highlighted..

**Rafael Aviles**et al., [4] presented an improved approach to the optimum dimensional synthesis of planar linkages based on an elastic strain–energy error function, This method is suitable for any kind of kinematic synthesis for any planar linkage.

**Josep M. Porta** et al.,[5]Legged robots are well suited to walk on difficult terrains at the expense of requiring complex control systems to walk even on

at surfaces. It should be assumed that walking on abrupt terrain is the typical situation for a legged robot.

**Mustafa SuphiErden, kamalleblebicioglu,**[6] presented the problem of free gait generation and adaptability with reinforcement learning for a six-legged robot. Continuous walking pattern with a larger average stability margin. While walking in normal conditions with no external effects causing instability, the robot is guaranteed to have stable walk, and the reinforcement learning only improves the stability.

**Yu. F. Golubev and E. E. Selenskii,** [7] investigated the dynamics of the locomotion of a six-legged walking robot in horizontal cylindrical pipes. The results of the numerical mathematical modelling of a statically stable locomotion of the robot are presented for its motion on the bottom semi-cylinder with viscous friction when this motion is arranged by alternating the supporting triangles.

**Alberto Aguado Behar,** [8] discussed the design of a neuro PD control with gravity compensation for the generation of leg trajectories of a six-legged robot. The paper consists three parts parameters, finally in the third part also discussed the experimental results obtained by computer simulation.

**Ajay Kumar Singh** et al., [9] presented kinematic and dynamic analysis of a six-legged robot. A three-revolute (3R) kinematic chain has been chosen for each leg mechanism in order to mimic the leg structure of an insect. Denavit–Hartenberg (D-H) conventions are used to perform kinematic analysis of the six-legged robot.

## 3. Conceptual Design

The first phase of the design was selection of design requirements. Some of the key Objectives of the design were:

- less weight
- Simplicity
- Less no of actuators.

The following sections explain the design decisions made regarding the legged walking robot.

**The Design Process**

The process of designing mechanisms, basically can be divided into two distinct Phases, namely

1. Synthesis
2. Analysis

After a proper specification of objective, the first step in the design cycle consists of the synthesis phase, in which the designer attempts to find the type of mechanism and its dimensions, such that the requirements are met (as good as possible). Experience, from the, previous designs, mechanism handbooks and simulation software can guide this creative process.

## Synthesis

It is the very fundamental of design, for it represents the creation of new hardware to meet particular needs in motion, displacement, velocity, or acceleration-singly or in combination.

### Selection of no of legs

We looked into a four-legged design. Although, it is lower in cost than the eight-legged robot and it required fewer controls and actuators, it also increased the design complexity and decreased stability. A two legged walker is even more complex and unstable than a four legged walker. A six legged/ hexapod design was chosen as it is more stable and was easier to implement than a two-legged walker.

### Selection of Degrees of Freedom

The number of joints in a robot roughly translates to the degrees of freedom. In the design process three different possibilities were considered. A leg with one degrees of freedom using indirectly driven joints in a shoulder and elbow configuration yields motion at the tip of the leg. The foot of the leg is constrained to a spherical surface. However the up-down and forward-back motion is approximately linear and provides a method to propel forward or backward while adjusting to some uneven terrain. A two degree of freedom leg offers very limited capabilities and produces legs which act similar to uneven wheels.

Legs with two degree of freedom also prevent the robot from adjusting its step sizes to compensate for the environment rendering one degree of freedom inadequate. A three degree of freedom design offers superb manoeuvrability allowing the robot to adjust too many situations. However, the three degree of freedom design significantly increases the cost of the robot. A one degree of freedom leg was chosen since two degree of freedom does not offer the required capabilities and three degrees of freedom is costly.

### Types of Actuators

Actuators in robots are like muscles in the human body. Without the actuators, the limbs of the robot cannot move. There are many types of actuators available but only certain types suit the needs of the project. Below is a comparison of some common actuators. Following the comparison a decision was made on the method of actuation for the robot legs.

- Pneumatics and Hydraulics
- DC motors
- Stepper motors

### Pneumatics and Hydraulics

Pneumatics and hydraulics run on the basis of a pressurized fluid driving a piston or motor mechanism. The system requires a pump or compressor to provide the necessary pressure to drive the piston or motor. This setup is large, noisy, and expensive.

### DC motors

DC motors are commonly found in wheeled robots. DC motors rotate as long as power is applied and stops when power is removed. A continuous rotation at a constant speed can be achieved by applying a constant voltage. However, extra support circuitry including a sensor for feedback is needed for position control.

### Stepper motors

A stepper motor is a very simple DC motor. Because it has no brushes or contacts, it operates by having its magnetic field electronically switched to rotate the armature magnet. This setup allows the motor to rotate and halt at specific angles. There are two types of stepper motors bipolar and unipolar. The bipolar stepper motor consists of two coils. The current direction is reversed in each coil to achieve four separate positions.

The unipolar stepper motor consists of four coils. When each coil is energized individually and working in proper sequence, the motor shaft turns the inherent number of degrees per step. Regardless of the type of stepper motor used there is no closed loop feedback unless an external position sensor is used.

### RC Servo Motors

An RC servo motor is a DC motor combined with position sensing parts. RC servo motors have 3 wires running out from the motor. Two lines are for power and the third line is for the control input. A pulse width signal applied to the

input indicates to the motor the desired position. The exact relation of pulse width to output shaft location varies by motor model; but as a standard all RC servos moves to the centre position with a 1.5 Ms input pulse. Inside the RC servo motor, the components consist of a DC motor, a gear train, limits stops, a potentiometer for position feedback and some control circuitry.

RC servo motors serve as an easy to implement open loop control system for robots. They remove complexity from the control system hardware and software and also reduce the total part cost and design time. The diagram shown in Figure 1 serves as reference to the control of an RC servo:

## Actuator Used in Project

Pneumatics and hydraulics increase the cost and weight of the robot without offering any functional benefits. To reduce weight the pump or compressor can be taken off the robot and a tether can be extended to the robot to provide the pressurized fluid. Unfortunately this means the robot would have a tether and a limited walking range. Although DC motors are inexpensive they lack position control and are not directly suitable for this robotic application. Stepper motors have an open loop position control and can easily skip steps resulting in poor correlation between expected and actual position. RC servos were chosen because of their relatively low cost and their ease of control. The main drawback of an RC servo was the loss of feedback position control to the external device providing the control pulse.



Figure9: Motor labelling and six legged
## 4. Design of Four-Bar Linkage Based Leg

### Design of leg

The first stage of leg design is the design of a four-bar linkage as shown in figure 10.In support phase, the four-bar linkage $O_A O_B$ AB is driven by the main actuator $O_A$ H only. The foot path should be an approximation of a horizontal straight line. At the end of the stroke, the foot is lifting actuator $O_B$B and moved back to the front by the main actuator with the help of gravity.

The foot of the leg was considered to be a rigid body attached to the shank at this stage. The foot profile is circular and the foot reference point is at the center of the circle. The foot is to roll on the ground during walking. The radius of the foot circle depended on the soil conditions and is to be selected to provide proper contact pressure. The radius of 10mm is selected for a bare foot. Different shoes could be put on when the robot is operating in different soil conditions.

The leg of a walking machine serves to provide a desired working volume, which is the three-dimensional reachable work space of the foot reference point. The second is to carry the weight of the vehicle. Also, interference between links and among legs should be avoided. Considering these three aspects, the design specification of the four-bar leg is determined.
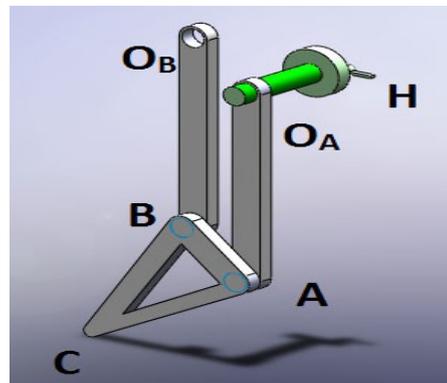


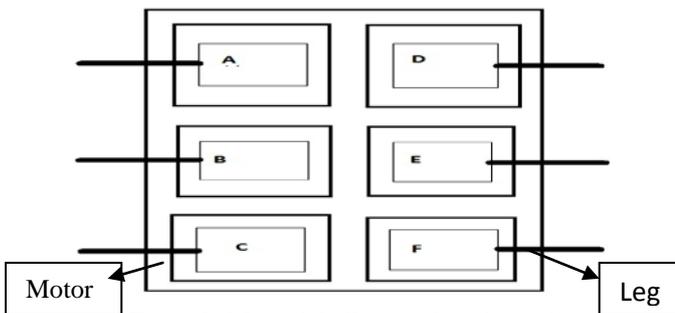Figure 10: Model of Legged Robot

### Leg strokes

The stroke pitch was selected to be 120mm since the predetermined maximum length of the vehicle was 300mm. Hence, the leg stroke was selected to be 80mm in ordered to avoid any interference between the feet. The vertical stroke is originally used to lift the foot in transfer phase only. Hence, a small amount of vertical stroke, such as 14mm, was sufficient. This was suitable for walking on smooth terrain only. Later, the vertical stroke was increased to 40mm in ordered to be able to walk in rough terrain.

After the mobility requirement was finally determined, the vertical stroke was increased to 80mm to satisfy the requirement of vertical step crossing ability. While the vehicle is walking in a tripod wave gait, a four foot stroke results in less than one Hertz cycling frequency at cruise speed, which is 170mm/seconds. If the feet contact the ground at different times, the height of each supporting leg will be different due to this vertical variation. This different leg height will contribute

to undesired pitching and rolling of the vehicle and will result in energy losses. Therefore the vertical variation should be as small as possible.

**Loads**

When the center of gravity is kept in the center line of the support pattern, the supporting legs on each side bear half the vehicle weight. In an alternating tripod gait at any time, one side of the robot is supported by only one leg. In this case, the maximum vertical load on that leg is half the vehicle weight. Hence, the leg has to be able to take a vertical load of 1/3 in its working volume. The maximum horizontal load was taken to be the longitudinal components of half the weight when the vehicle is walking on a 5% slope. The leg bears lateral load when it is abducted or adducted.

**Leg size**

 The dimension of the leg was determined according to stroke pitch; the maximum width in the longitudinal direction for one leg to move between its two extreme positions is about 99mm in order to avoid interference between legs. The maximal leg height is determined to be 168mm. Since the foot radius is about 10mm, a leg height of 155mm is used for the linkage synthesis. The leg thickness should be as small as possible and the maximum thickness is temporarily determined to be 20mm.
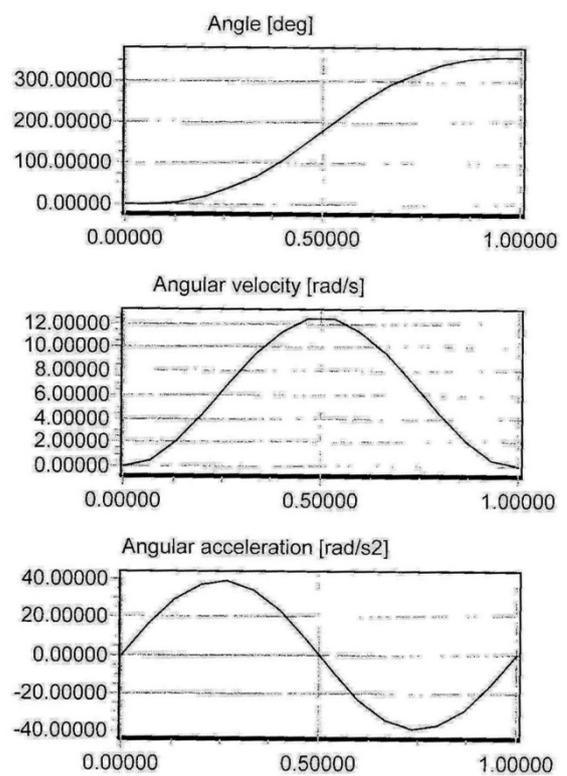


Figure 11: Linear Motion

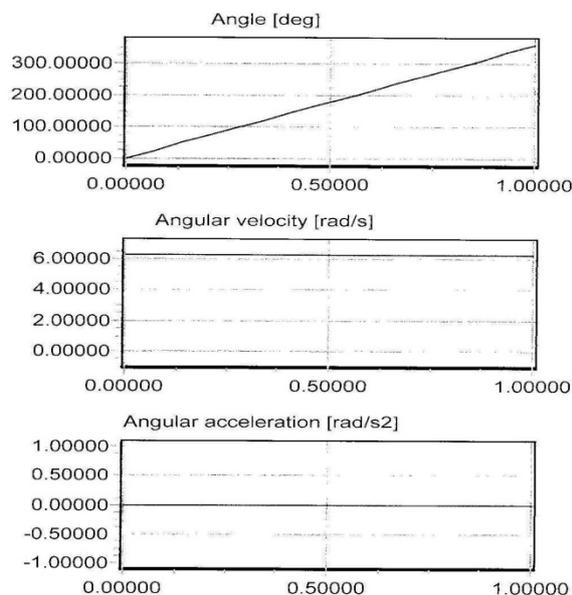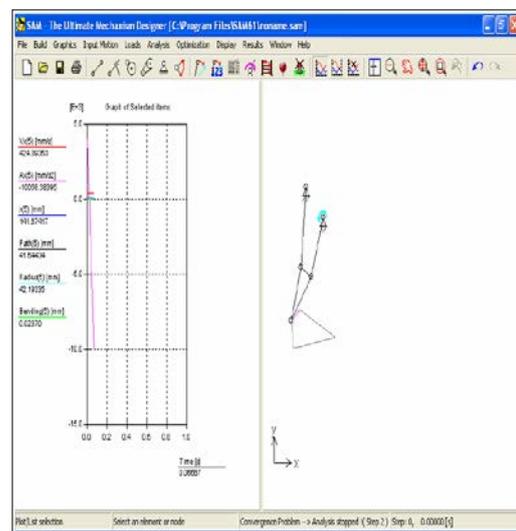

Figure 12: Sinusoidal Motion



Figure 13: Linear motion for a four bar leg
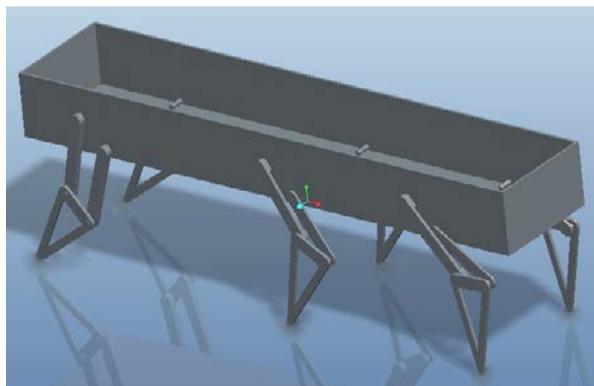
Figure 14: Modeling of six legged walking robot
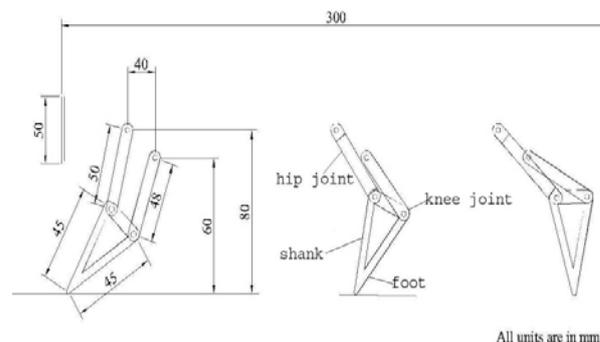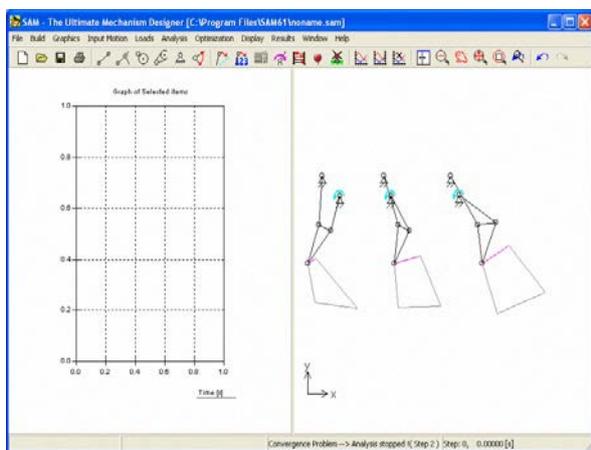


Figure 15: Three leg coupler curves generate and synthesis

**Geometric Design**

A general construction of a walking machine with four bar legs figure 10 is shown. The entire leg below the hip joint is composed of a four-bar linkage. The thigh is the two cranks and the shank is the coupler. The primary objective was to design a four-bar linkage with a foot point (a point in the coupler) moving along a good approximation to a level straight line relative to the body SAM.

Since close approximation of a straight line is required, a large number of design positions should be used. Five position synthesis does not allow the designer to optimizer the solution linkage. Hence, a four position synthesis is proper for this design. Another reason for using four position synthesis is that it results in a relatively symmetric trajectory of the foot point, while a three position specification usually results in an asymmetric foot trajectory.



Figure16: Structure of walking robot leg

**Calculation of Design Positions**

The four design positions are calculated as follows: Let the reference frame be attached to the machine body as shown in figure 6.10. Link OQ is a driven-crank with length b is a part of the coupler. Points O, Q and P are the driven-crank center-point, the driven-crank circle-point and the foot point, respectively. If the foot point p moves on a horizontal straight line relative to the body, the hip joint O will also move on a straight line if P is fixed on the ground. From Figure 6.10, the position of point P can be defined according to

The reference frame as

$$h = a. Sin$$

(1)

$$X = a .Cos$$

(2)

These equations can be combined to eliminate    as follows:

$$(h — a. Sin Ø)^2 + (X — a .Cos Ø)^2 = b^2$$

(3)

This can be expanded and reduced to the following form:

$$A - Cos Ø + B. Sin    + C = 0$$

(4)

Where

$$A = —2a.X$$

$$B = —2a. h$$

$$C = a^2 + h^2 — b^2 + X^2$$

If  U = tan (  /2), Equation (4) can be rewritten as

$$A (1 - U^2) + 2B.U + C (1 + U^2) = 0$$
(5)

Or

$$(C-A)U^2 + 2B.U + C + A = 0$$
(6)

The solution to this quadratic equation is

$$U = -B + (A^2 + B^2 - C^2)^{1/2} / C - A$$
(7)

Where $=\pm 1$. For the leg design, $b < h$ and length a is positive. This means

$$-B = 2a. h > 0$$

And

$$C - A = a^2 + h^2 - b^2 + X^2 - 2a. X$$

$$= (a - X)^2 + h^2 - b^2 > 0$$

Since the smaller value of

$-$ is obtained from

$$\tan \emptyset/2 = \underline{B + (A^2 + B^2 - C^2)^{1/2}}$$
(8)
$$A - C$$

Elimination of from Equations (1) and (2) yields

$$(h - b. \sin \quad - \quad )^2 = a^2$$
(9)

Which can be expanded and reduced to the form

$$A'. \cos \quad + C1 = 0$$
(10)

Where

$$A' = -2b .X$$

$$B' = -2b. h$$

$$C' = b^2 + h^2 - a^2 + X^2$$

After a similar process to that used for $\tan ($ /2) is given by

$$\tan \quad /2 = \underline{B' + (A'^2 + B'^2 - C'^2)^{1/2}}$$
(11)
$$A' - C'$$

The full foot step length is shown in Figure 14. The minimum and maximum coupler-point displacements in the X direction are

$$X_{max} = -[a^2 - (h-b)^2]^{1/2}$$
(12)

and

$$X_{min} = [(a+b)^2 - h^2]^{1/2}$$
(13)

For a good estimate of optimum design point spacing, four positions Chebychev spacing can be specified as follows:

$$X_1 = X_a - X_r .\cos (22.5°)$$

$$X_2 = X_a - X_r. \cos (67.5°)$$
(14)

$$X_3 = X_a + X_r. \cos (67.5°)$$

$$X_4 = X_a + X_r. \cos (22.5°)$$

where

$$X a = (X max + X min)/ 2$$

$$Xr = (X max - X min)/ 2$$

Since X1, X2, X 3 and X4 are the four positions of point P, Equations (8) and (11) can be used to compute the values of at these four position.
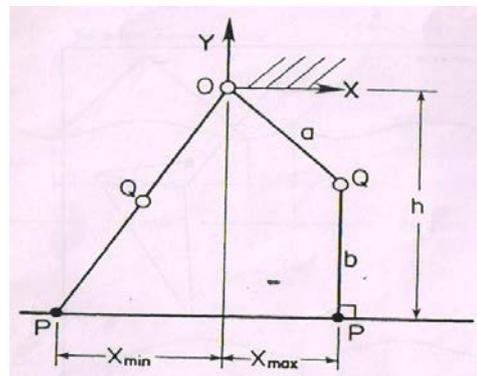


Figure 18: A full step used for the calculation of design position

The coordinates of point Q at the four positions can then be computed using elementary. The locations of Q and values of O, which are in terms of a, b and h, provide the design positions for the four positions synthesis problem. These sets of design positions are called the Knee design positions because point Q is one of Knee joints.

A problem was written to calculate the desired positions. Table: 1 is an example of Knee design positions with a=1, b=1, and h=1...This set of Knee design positions is also used in the example of

linkage synthesis in the next section. Another alternative is to use the foot positions with corresponding shank angles as the four desired positions.

| Position | X | Y | 0 |
|---|---|---|---|
| 1 | 2.160 | -2.894 | -93.099 |
| 2 | 1.810 | -3.125 | -110.824 |
| 3 | 0.592 | -3.562 | -125.557 |
| 4 | -0.967 | -3.479 | -123.223 |

Table 1: Foot Design position with a=1,b=1 and h=1.8, the leg height is 6.5 feet.
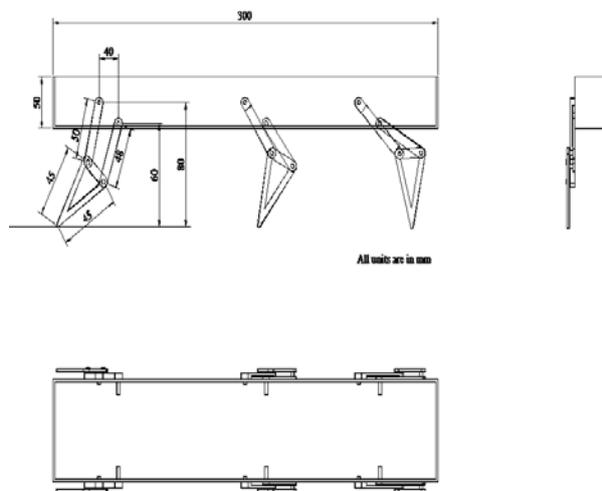


## 5. CONCLUSIONS

The goal of this project is to design synthesis and analysis of a six legged walking robot without the aid of a premade kit. The scope of the project involved the conceptual design of the robot, linkage synthesis, and couple curve generation and motor selection. The able to move along and cross irregular terrains and narrow passages, actively adapting its long body to the terrain profile.

Present high reliability and easy maintenance due to their redundant unified structure. The malfunction segment can be easily disconnected and separately repaired. It can be easily transported, dividing the robot in its elementary segments.
A Simplicity and Low weight
 Thus the six legged robot is able to walk by itself in a straight line from starting point to the destination.

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