Design of Hexapod Walking Robot with Double Scara Legs

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ABSTRACT

Many walking prototypes have one or more degree of freedom leg mechanisms to obtain walking trajectory. Kinematic synthesis of one degree of freedom mechanisms is required to calculate correct links lengths according to desired trajectory. In this study, we designed, controlled, and tested a six-legged walking robot with double scara legs. Two actuators of double scara robot allows us to arrange any trajectory within workspace of our leg design. Three legs of them are working simultaneously to obtain smooth walking on terrain. Each servo motor attached to leg is working independently. Therefore, we can arrange several movements besides walking. Many parts of our walking robot which are necessary for assembly were designed in SolidWorks. These parts were printed by using a Ultimaker 3D printer with PLA material. Servo actuators of robot was controlled by using PWM pins of Arduino Mega microcontroller. We tested our robot using three different leg trajectories such as square, triangle and smooth trajectories. According to our test, we observed that smooth trajectory is the most energy efficient.

Keywords
multi-legged robot, walking robot, double scara, arduino, closed kinematic chain legs

1. INTRODUCTION

Walking machines and walking robots with legs are different. We can classify them with respect to actuation types and design of leg mechanisms. Walking machines have leg mechanism which are actuated by cranks or cams using single rotary motor whereas construction of walking robots include legs controlled by more than one actuator. Leg mechanism of walking mechanism is complex while leg control of walking robot is more sophisticated. Actuator of walking mechanism is generally a DC (Direct Current) motors with a speed controller driver circuit. However, walking robots have servo or BLDC (Brushless DC) with encoder actuators to control position of legs. Servo actuators have gear boxes to increase output torque. However, speed of actuators decreases according to transmission ratio.

The most popular leg mechanism is Jansen's linkage which is a planar leg mechanism designed by Theo Jansen. This mechanism has one DoF. Therefore, it can be controlled by single actuator. Kinematics and dynamics of Jansen leg mechanism is presented in [1].

Energy optimized leg trajectories of a multi-legged robot were studied by Roennau et. Al [2]. Adaptive Leg Trajectory model was proposed by using fifth order Bezier curves. Using new trajectories generated by their method, LAURON IV walking robot was tested for minimizing consumed energy.

New single DoF eight link leg mechanism of eight-legged walking machine was proposed by Shivamanappa et. al. [3]. Link lengths of mechanism was optimized by using genetic algorithm. Optimization results were used for a real prototype design of walking machine. Furthermore, they presented kinematic analysis of mechanism to plot position, velocity, and acceleration graphs.

Stanford Doggo which is a four-legged walking robot has eight BLDC (brushless dc motor) with a specific motor driver (Odrive) [4]. This walking robot has four double scara legs. Therefore, leg construction of this robot resembles our design except that we are using servo motors instead of BLDC motors. Vertical jumping is possible for Stanford Doggo due to actuator and driver technology. However, our walking robot which costs nearly 60 $ is much cheaper than Stanford Doggo (less than 3000 $).

Other recent walking and/or jumping robots are Miniatur [5], Salto1P [6], Jerboa [7], MIT Cheetah 2 [8], MIT Cheetah 3 [9], StarIETH [10], Anymal [10], and Little Dog [10]. 8 DoF quadruped Miniatur and 4 DoF Jerbao are direct drive robots. Direct drive robots have not a gear, belt, chain, or other reduction to increase torque. Salto 1P having only one leg is a jumping robot rather than walking.

A new design of hexapod walking robot is proposed in this paper. Introduction for walking machines and robots is completed in this section. In the second section, we present conceptual and mechanical design of our robot. Then, workspace and legs trajectories are introduced in the third section. Inverse kinematics of leg is presented in the fourth section. Finally, we present conclusion for current study.

2. CONCEPTUAL AND DETAIL DESIGN OF WALKING ROBOT

Our aim is to design a new walking robot with closed kinematic chain legs. We started design our robot with conceptual design of walking robot mechanism that is shown in Figure 1. We decided to use 6 legs for our robot design. Because we can increase walking stability, efficiency, and flexibility by using 6 leg instead of using 4 leg. Each leg of robot is a five-bar mechanism which can follow 2-D trajectory. At his stage of our design, link lengths are also determined as 45 mm and 60 mm for short and long links, respectively. These link lengths are required to analyze workspace of five-bar mechanism which presented in section 3 of this study. Chassis of robot, six legs of robot are shown in Figure 1. According to six leg, our robot can have 120 different walking combination. We selected one combination to test our walking robot.

$$N = (n - 1)!$$

$$N=5!=120$$

Each leg has two degrees of freedom closed chain, therefore our robot has totally twelve degrees of freedom.

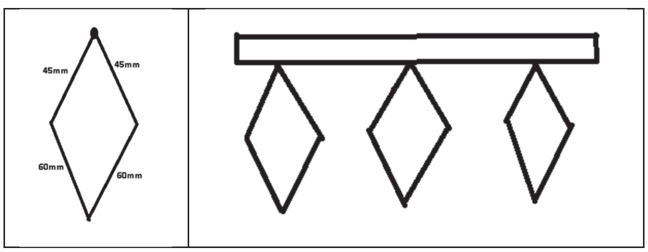

Figure 1. Conceptual Design of Walking Robot

All parts are designed in SolidWorks. After designing all parts with dimensions and shapes, leg assemblies which is shown in Figure 2 a) and (b) are constructed. After assembling six legs, all legs and electronic circuits are attached to base. Whole assembly of the robot can be seen in Figure2 (c).

All leg parts including short link, long link, second type of long link, and servo holder were manufactured by using 3-D printer with PLA material. Chassis was made by using plexiglass material. We drilled required holes on chassis. We assembled shaft to inner ring of ball bearing using standard tolerances. Electronic circuits were assembled on the chassis. Real assembly of walking robot is depicted in Figure 3 (a). A Cover with two parts shown in Figure 3 (b) was designed to hide and isolate electronic circuits.

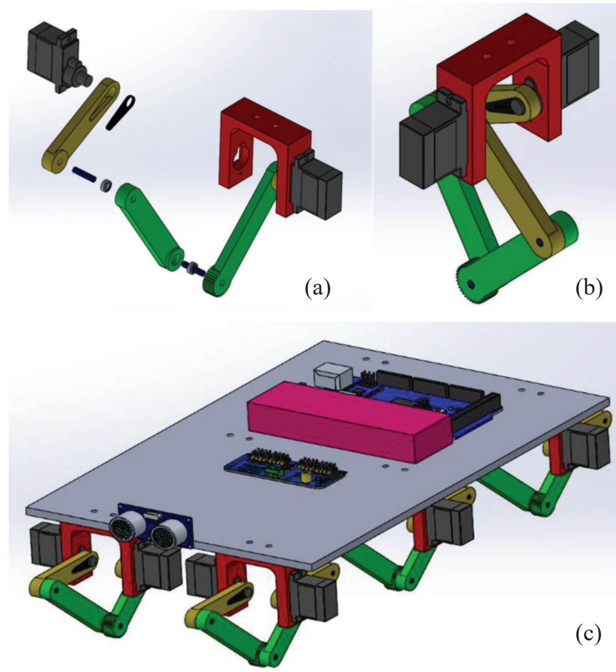

Figure 2. Assembly of one leg exploded (a), collapsed (b), and whole assembly of robot (c)

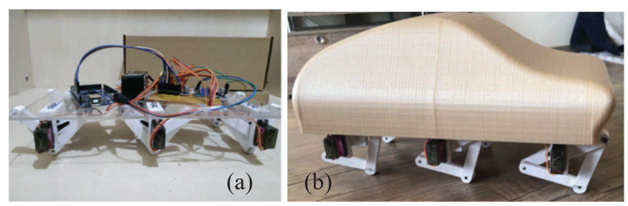

Figure 3. Final robot prototype (a) without cover (b) with cover

3. WORKSPACE AND LEG TRAJECTORIES

3.1 Workspace

We tested leg mechanism by taking limitations of rotational movement of servo motors into consideration. We reached fully extended and fully closed positions that is depicted in Fig.4. This limit is very important to determine workspace of legs. Because trajectory of end point of legs should be in reachable workspace. Workspace of legs was calculated according to this limitation. Trajectory workspace is illustrated in Fig.5.

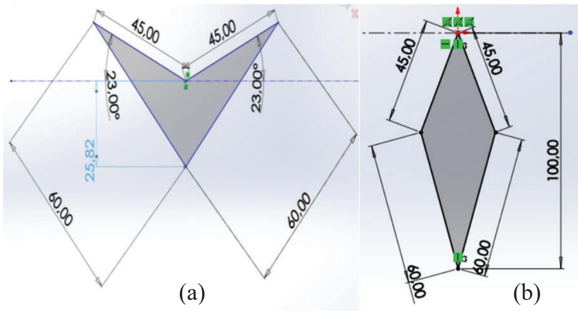

Figure 4 . Vertical reach limits (a) fully closed (b) fully extended

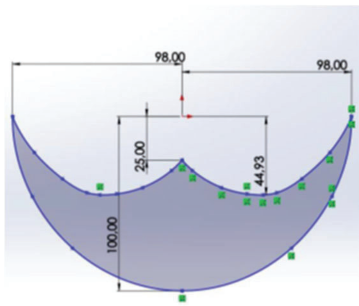

Figure 5. Trajectory Workspace

3.2 Three Trajectories

Walking motion can be obtained using trajectories of end point of five-bar mechanism. We defined three different trajectories in workspace of legs such as square, triangle, and smooth. The first trajectory is square trajectory shown in Figure 6. Solidworks was used to measure our trajectory positions 1, 2, 3, and 4 at the corners. We verified these measured points using our inverse kinematics approach. Initial position is indicated as 0.

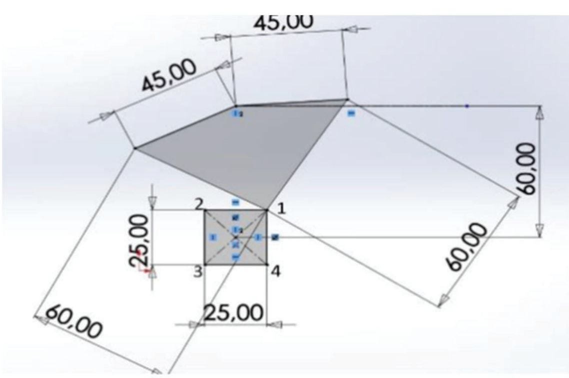

Figure 6. Square trajectory

Table 1. Square trajectory position

Position	θ1	θ2
0	0º	180º
1	3,67º	205,71º
2	334,34º	176,18º
3	314,8º	205,64º
4	334,6º	225,2º

The second trajectory is triangular trajectory depicted in Figure7. Three positions are listed in Table 2. Initial position is identified by using 0. This triangle is equilateral. Hence all lengths of triangle are equal. These points are also verified using inverse kinematics.

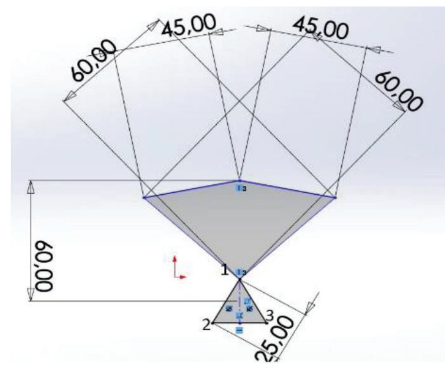

Figure 7. Triangular trajectory

Table 2. Triangular trajectory position

Position	θ1	θ2
0	0º	180º
1	7,02º	187,02º
2	319,22º	199,71º
3	340,29º	220,78º

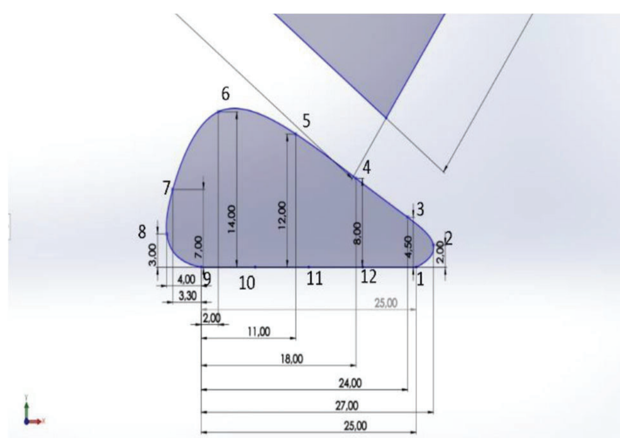

Figure 8. Smooth trajectory

Table 3. Smooth trajectory position

Position	θ1	θ2
0	0º	180º
1	337,17º	223,08º
2	340,65º	223,43º
3	341,55º	218,37º
4	340,84º	209,3º
5	338,46º	198,58º
6	330,36º	188,40º
7	319,03º	192,81º
8	315,30º	197,03º
9	316,92º	202,83º
10	322,23º	207,03º
11	328,14º	211,86º
12	332,97º	217,23º

The smooth trajectory shown in Figure 8 is the most complex trajectory. Twelve positions are used to describe this trajectory. In test phase of our robot, we used linear interpolation between defined points for all trajectories to follow trajectories correctly.

4. NOVEL INVERSE KINEMATICS APPROACH

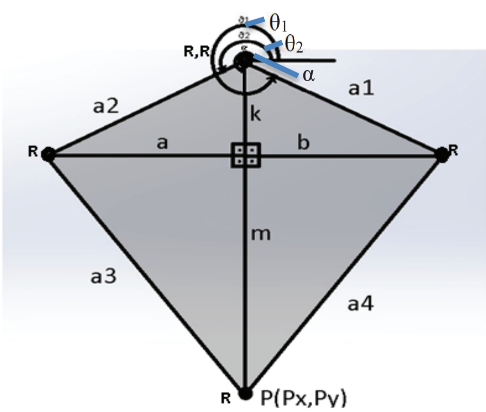

Figure 9. Kinematic diagram of double Scara

Geometry of leg resembles kite (see Figure 9), therefore link lengths a1=a2=45mm, a3=a4=60mm and a=b are determined. Using position of the end effector point and hypotenuse theorem, equations are written as follows,

$$s=k+m \quad (1)$$
$$s=\sqrt{Px^2+Py^2} \quad (2)$$
$$a^2+k^2=a_2^2 \quad (3)$$
$$k^2+b^2=a_1^2 \quad (4)$$
$$a^2+m^2=a_3^2 \quad (5)$$
$$m^2+b^2=a_4^2 \quad (6)$$

Subtracting from (4) and (5) each other, distances a, b are eliminated. Equation (7) can be expressed as,

$$k^2-m^2=a_1^2-a_3^2 \rightarrow (k-m)(k+m)=a_1^2-a_3^2 \quad (7)$$

If substituting term (k+m) in equation (7) into equation (1), one can find equation (8).

$$k-m=(a1^2-a3^2)/s \quad (8)$$

If equations (8) and (1) are solved simultaneously, distances k and m can be computed as given in equation (9)..

$$2k=(a1^2-a3^2+s^2)/s \quad (9)$$
$$k=(a1^2-a3^2+s^2)/2s$$
$$m=(s^2-a1^2+a3^2)/2s$$

We can compute distance a by substituting k into equation (3). (see equation 10)

$$a=\sqrt[2]{a_2^2-((a_1^2-a_3^2+s^2)/2s)}^2 \quad (10)$$

We can define distance b by substituting m into equation (6). (see equation (11)). Finally, actuator angles are defined in equation (12).

$$b=\sqrt[2]{a_4^2-((s^2-a_1^2-a_3^2)/2s)}^2 \quad (11)$$
$$\alpha=\arctan_2(Px,Py) \quad (12)$$
$$\theta_1=\alpha+\arcsin(b/a_1)$$
$$\theta_2=\alpha-\arcsin(a/a_2)$$

5. CONCLUSIONS

We proposed a hexapod walking robot design with double scara legs in this study. Mechanical elements and designed parts were assembled in Solidworks. We simulated our robot using motion study of Solidworks. Footstep planning was defined according to our simulations. When we tested our robot, we used three different trajectories. After 15 minutes walking test procedure, we found that smooth trajectory is more energy efficient. The cost of our robot is low compared to other walking robots.

Our robot can be improved by adding a single board computer and lidar to implement artificial intelligence packages, slam and navigation. For this purpose, ROS (Robot operating system) and available packages can be installed to a single board computer.

You can watch walking motion of our robot using link as follows, https://www.researchgate.net/publication/338630451_VID-20200116-WA0006mp4.

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