Analysis Rope Climbing Mechanism

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Abstract. A kinematic calculating and analyzing method for a robot moving on a horizontal bar using a four-bar mechanism is proposed. By using analytical methods, the kinematic model of the robot is included to examine parameters such as leg tilt, average moving velocity, position, and trajectory of the robot's legs. Using the inversion mechanism method, the basic calculation can determine the movement of the mechanism on the bar during the operation.

Keywords: Four-bar mechanism · Climbing robot · Kinetic analysis · Mechanism inversion

1 Introduction

The four-bar mechanism is one of the first mechanisms designed and analyzed in the history of mechanical engineering. Despite its simple structure, this mechanism is applied in many areas of social life, even in biology and constructing [1]. Variations of the mechanism have been studied and utilized as fundamental models for constructing machine parts (train wheel dampers, brakes, rock crushers, or even robotic arms [2]). From the movement of rods in the links, biomimetic linkages have been such as Jansen, Klann, Chebyshev, Ghassaei walking robots, etc. are developed [3–6] (c.f. Fig. 1).

The links mentioned are specifically employed to move robots in environments not suitable for the use of wheels. The similarity between these machines is the movement of output links corresponds to one rotation of the driver. With the given points acting as landing feet, some of the feet resting on the ground and bearing the weight of the whole machine (group A), some of them are moving forward (group B). For the remaining rotation of the driver, the feet in group A are moving while the weight transfer to group B (now are rested).

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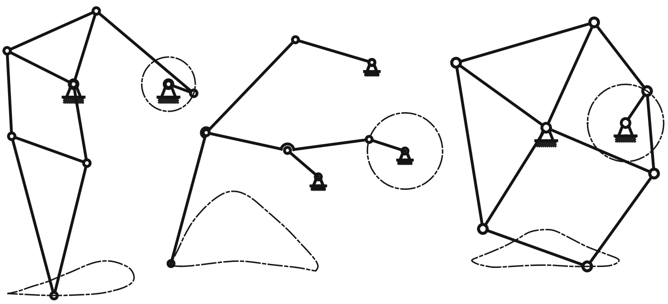

Fig. 1. Moving robot adapted from pin-joint mechanism: Jansen, Klann, Ghassaei linkages.

Designing movement methods for crawling robots is not a new study. There have been a number of studies using different approaches to construct and control the machines' movement [7–9]. Unlike walking robots whose feet set on the ground with the loading compressing the structure, a crawling robot leans its legs on a horizontal bar and tends to stretch the frames in the mechanism (c.f. Fig. 2).

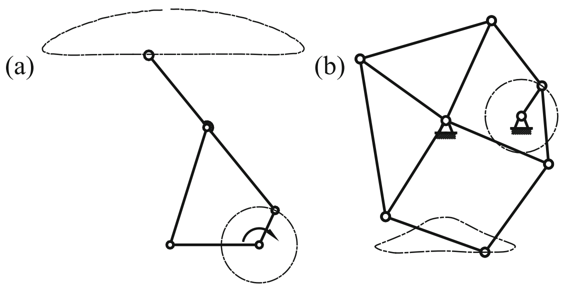

Fig. 2. Compare crawling type (a) and walking type (b) in robot'legs.

Clearly that even without wheels, using the structure from Fig. 2a to move the whole system along a hanging bar is still possible. However, it is not easy to analyze the movement and stability of the machine using movement linkages without simulation.

This study proposes an application of the inversion method in determining the movement of the mechanism. By employing analytical equations, the kinematic parameters of the robot are calculated, includes tilting, velocity, position, and even formation of the robotic legs. A 2D linkage was also constructed in the Working Model environment to verify the accuracy of the proposed model.

2 Kinetic and Dynamic Analysis

According to the locus of the leg from Fig. 2, its movement is separated into two phases: raising phase (a) moving leg from the bar and sliding phase (b) where this leg lean on the bar for the robot to crawl forward. The number of the leg also affects the stability of the mechanism. If the position of the feet is not symmetrical, the robot's center of gravity will be deflected, causing instability and oscillation during the movement.

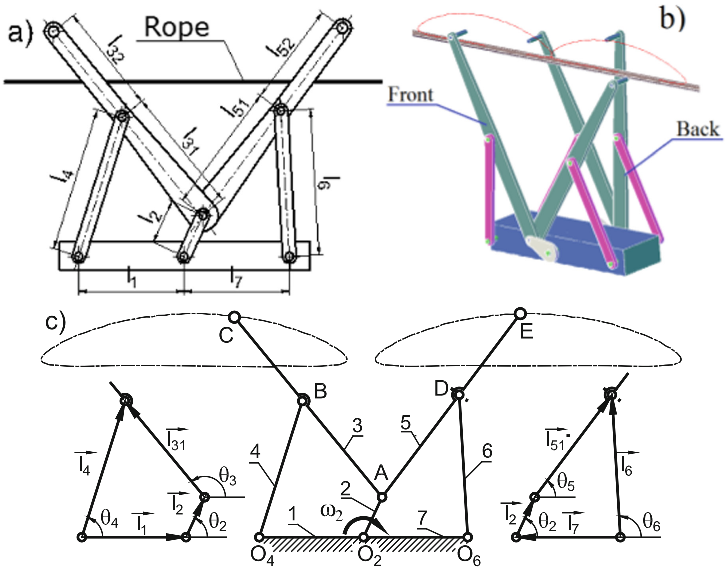

Fig. 3. Mechanism in 2D (a), 3D (b) and diagram of the front linkage (c).

To maintain the stability of the system, a 4-legs model, as shown in Fig. 3, is constructed. This model can ensure the balance of the platform while moving on a bar with the smallest tilting.

The kinetic analysis process will evaluate the position, velocity of joints, and links in the mechanism.

Using close loop equation for two side of legs as in Fig. 1 (with front side loop include links 1, 2, 3, 4 and back side loop are links 2, 5, 6, 7).

For front side loops:

$$\overrightarrow{l_1} + \overrightarrow{l_2} + \overrightarrow{l_{31}} = \overrightarrow{l_4} \tag{1}$$

$$l_1 e^{j\theta_1} + l_2 e^{j\theta_2} + l_{31} e^{j\theta_3} = l_4 e^{j\theta_4} \tag{2}$$

$$\begin{cases} l_4 \sin\theta_4 - l_{31} \sin\theta_3 = l_1 \sin\theta_1 + l_2 \sin\theta_2 \\ l_4 \cos\theta_4 - l_{31} \cos\theta_3 = l_1 \cos\theta_1 + l_2 \cos\theta_2 \end{cases} \quad (3)$$

For the back side loops:

$$\overrightarrow{l_7} + \overrightarrow{l_2} + \overrightarrow{l_{51}} = \overrightarrow{l_6} \quad (4)$$

$$l_7 e^{j\theta_7} + l_2 e^{j\theta_2} + l_{51} e^{j\theta_5} = l_6 e^{j\theta_6} \quad (5)$$

$$\begin{cases} l_6 \sin\theta_6 - l_{51} \sin\theta_5 = l_7 \sin\theta_7 + l_2 \sin\theta_2 \\ l_6 \cos\theta_6 - l_{51} \cos\theta_5 = l_7 \cos\theta_7 + l_2 \cos\theta_2 \end{cases} \quad (6)$$

With l_i is the vector of rigid link i in the close loop equations determined by angle θ_i and the given lengths $l_1 = l_7 = 30$; $l_2 = 10$; $l_{31} = l_{51} = l_{32} = l_{52} = l_4 = l_6 = 40$.

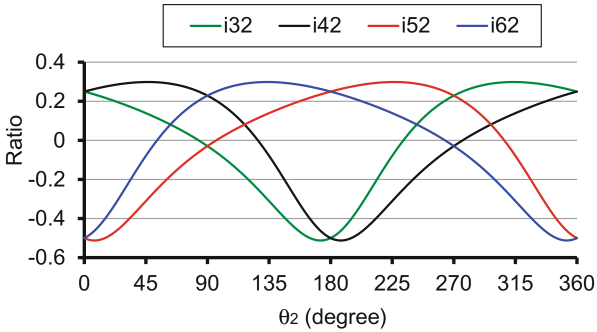

Fig. 4. Ratio of the rotation angle between of links k and link 2.

Solve (3) and (4) to get the corresponding angle θ_3, θ_4 and θ_5, θ_6 according to the movement of link 2 (θ_2). This calculation also can be used to determine the value of angular velocity ω_i in each link and constructing the graph of conversion ratio $i_{k2} = \omega_k/\omega_2$ in Fig. 4.

From the result, positions of point C and E defined by equations:

$$\overrightarrow{R_C} = \overrightarrow{l_2} + \overrightarrow{l_{31}} + \overrightarrow{l_{32}} \quad (7)$$

and

$$\overrightarrow{R_E} = \overrightarrow{l_2} + \overrightarrow{l_{51}} + \overrightarrow{l_{52}} \quad (8)$$

Solve the equations using the results from Fig. 5, the locus of points C and E are acquired:

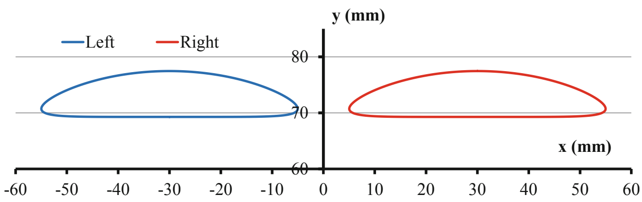

Fig. 5. Trajectories of points C and E.

We also can extract the position graphs of these points in y- direction for a cycle of motor (link 2) for the back side and front side, since the movements of these linkage are 180° difference (Fig. 6).

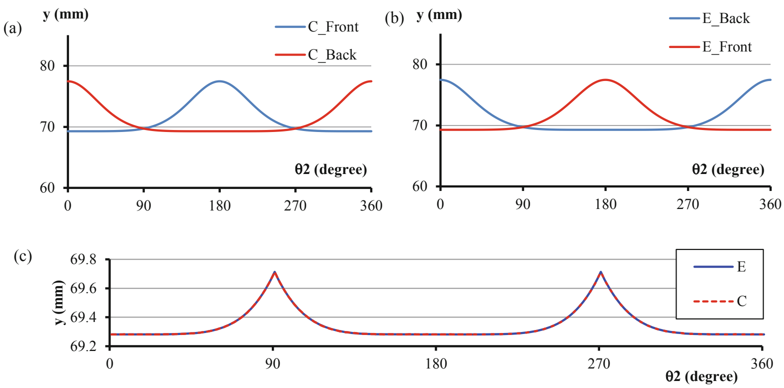

Fig. 6. Horizontal position of four legs (a, b), and the final movement of the structure (c)

It is noticed that during the movement of the mechanism, the period that feet C and E land on bar became fixed points. These point are determined by the y-coordinate of the leg in the back and front sides: $y_C = \min(y_{C\_Front}, y_{C\_Back})$ and $y_E = \min(y_{E\_Front}, y_{E\_Back})$. The result of the selection is the real movement of the legs and shown in Fig. 7.

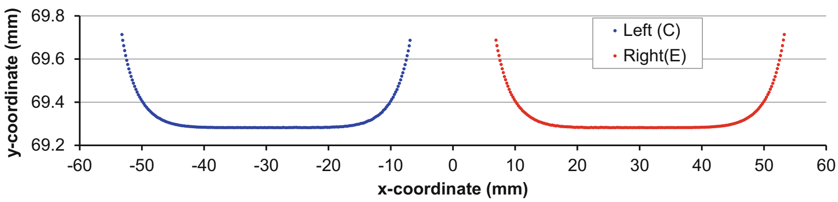

Fig. 7. Position of legs that lay on bar.

From the leg's movement, the inversion method is employed for determining the actual position of the mechanism on the bar. During the period of contact with the bar, the landing point are fixed on the bar while the other links change their positions. By

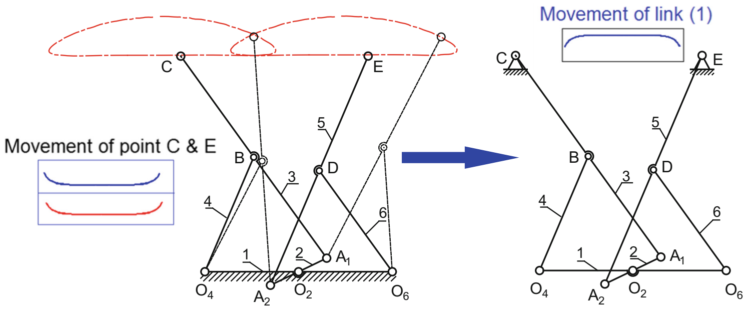

Fig. 8. Result of the mechanism inverse process.

taking the opposite value of the Y-coordinates of the legs in Fig. 7, the movement of the platform can be acquired, as shown in Fig. 8.

It is noticed that the coordinate of two points C and E are placed in the different loop of mechanism, these will exist a small error in their coordinate differences. This value will cause the pitch movement on link 1 and the tilting angle is determined by the equation:

$$\varphi_{tilted} = \arctan\left(\frac{\Delta y}{\Delta x}\right) = \arctan\left(\frac{y_C - y_E}{|x_C - x_E|}\right) \tag{9}$$

Result of the equation is illustrated in Fig. 9:

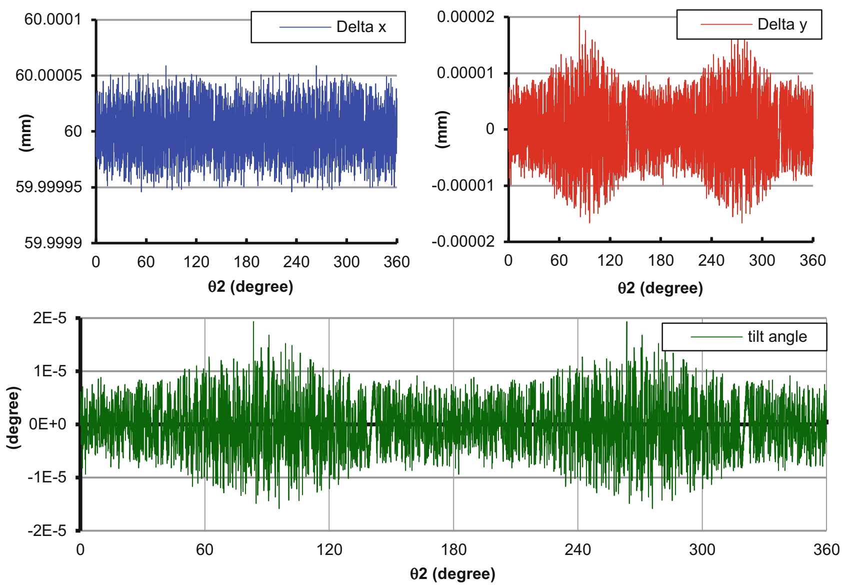

Fig. 9. Difference between position of legs C and E and the tilting angle of link 1.

The results of Fig. 9 show that there is a slight tilt during the movement of the platform (the angle varies from -2×10^{-5} to 2×10^{-5} degrees). These errors appear due to the in-sync of the feet on the left and right sides during their movement.

The mechanism is created in the Working Model environment to verify the accuracy of the calculation method. Figure 10 describe results of the simulation of the new design.

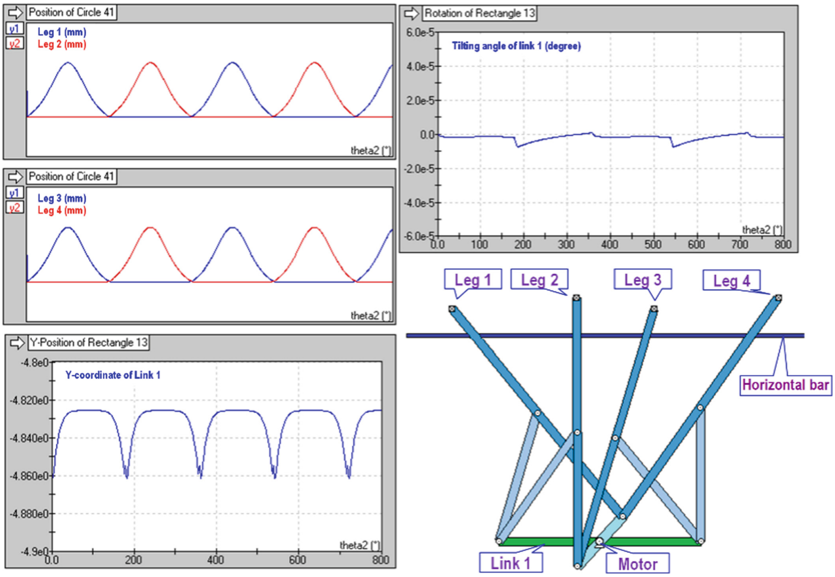

Fig. 10. Using Working Model to simulate the movement of the system.

The results from Fig. 10 show that the proposed method for determining the movement of link 1 is correct: A difference of 180° in the movement of the four legs produces a formation of the same range as the calculation for the platform (which is approximately 0.04 mm). Another notice from the graph in Fig. 10, there are small crooks in the Y-direction movement of link 1 (platform) every 180° rotation of the motor. These crooks can be explained that at these angle, the mechanism changes the landing legs on the b (from legs 1–3 to legs 2–4). Hence, the centroid of the robot changes the loading between the landing legs, causing tilting for the platform and affects the movement of the whole mechanism (Fig. 11).

The matches between results from the simulation model with those from the calculations prove the applicable of inversion method in kinetic analyzing for robotic mechanisms. This method can also be used to calculate the required power of the motor in cases platform is loaded and improve the efficiency of the mechanism in optimizing movement without simulation.

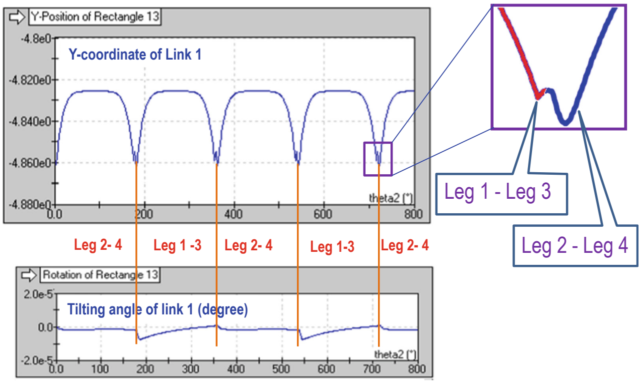

Fig. 11. Detailed explain for the crooked graph in the movement of link 1.

3 Conclusions

The paper proposes a method of calculating and analyzing robot structure formed of a four-bar mechanism. The structure is capable of moving on hanging bar with high stability. Different from solving by graphing method, the calculation using complex digital models helps the calculation process be done accurately and enabled to integrated with program software like Excel, Matlab to quickly give results. Based on the movement of the robot legs, the determination of working conditions (velocity ratio, tilted angled) is simplified and calculated. This method enables us to design for other models of robotic structures and to optimize dimensions of linkage to reduce engine power or raising stability of mechanism.

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