Optimizing Mechanism for a Polymorphic Tracked Robot

Jia Xu, Qingsheng Luo, Ningjun Fan, and Jiwei Yang

School of Aerospace Science and Engineering,
Beijing Institute of Technology, Beijing, China
mailxujia@gmail.com

Abstract. A new type shape-shifting mechanism of the polymorphic tracked robot has been designed and optimized. A virtual prototype has been established under Adams. We analyzed the sensitivity of design parameters and optimized the design variables using the Design Evaluation Tools of Adams. In order to find the optimized result, sequential quadratic programming has been selected to running the iterative simulation. The optimized mechanism can control the track configuration neither too loose nor too tight, which achieved the tension requirement of the crawling mechanism. The driving mode of the shape-shifting mechanism has also been optimized to improve transforming process of the track configuration.

Keywords: polymorphic tracked robot, shape-shifting mechanism, design variable, changing rate of the track perimeter.

1 Introduction

With its excellent climbing obstacle capability, tracked robot counts for crucial role among the ground mobile robots. By combining variable poses and changing the approach angle of multiple tracks (Fig.1 shows an example), the polymorphic tracked robot further enhances the adaptability to terrain [1].

Since the position of its front idler is changeable in vertical direction, polymorphic tracked robot mentioned in this paper shares both the abilities of passing through the low gaps and stepping across the high obstacles [2]. The key point in its mechanical design, among this kind of robots, lies in the method how to keep the tracks moderate tense as its configuration is changing and thus protecting the tracks from loose or fracture. Usually, there are mainly two methods adopted in design: 1) by using the special elastic tension devices 2) keeping the perimeter of a polygon constituted by bracing gear trains constant or oscillatory within a small area.

Reference [3] designed a variable configuration tracked robot. It keep the tracks real-time tense as its configuration is changing by applying a theorem that the perimeter of a triangle which originated from an arbitrary point and two focus points of the same elliptic is const and a series of transmission mechanisms. However, this kind of robots is usually complex and huge (Fig.2 shows an example), and hard to miniaturize. Therefore it’s necessary for us to further develop a new shape-shifting mechanism, which could satisfy the practical needs for the miniaturization of robots.

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Fig. 1. Polymorphic tracked robot in its down position (left), partly raised position (right)

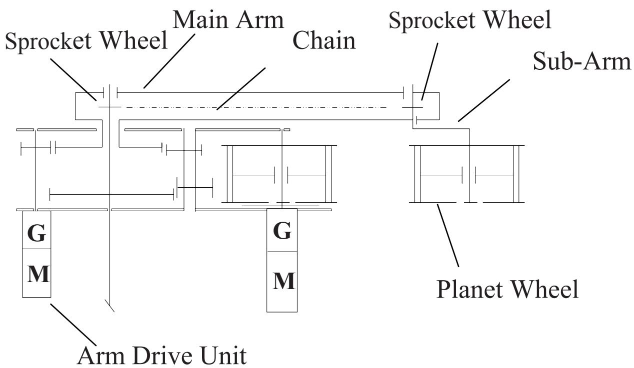

Fig. 2. Arm transmission mechanisms of the robot in reference [3], the mechanism is so complex that is difficult to miniaturize

2 Analyze on Characteristics of the Shape-Shifting Mechanism

First of all we make analyze on the shape-shifting mechanism which is without tension device. As Fig. 3 shows, the radius of road wheels and front idler are both R; the length of the main arm is A; the distance between the road wheels is L and the angle of main arm is α. The shaft of the main arm locates on the connect centre between the two road wheels.

When $0° \le \alpha \le 90°$

The perimeter C can be shown as follows:

$$C = L + 2\pi R + \sqrt{A^2 + (L/2)^2 - 2AL\cos(\alpha)} + \sqrt{A^2 + (L/2)^2 + 2AL\cos(\alpha)} \tag{1}$$

In order to facilitate the analyze toward C, and simultaneously make sure that polymorphic tracked robot has rational mechanism, we presume that: A=（160, 180, 200, 220, 240）; L=200; R=20.

As figure 4 shows, C is varying with α and monotone increasing; when A varies from 150 to 240, the difference between the maximum and minimum is monotone decreasing:

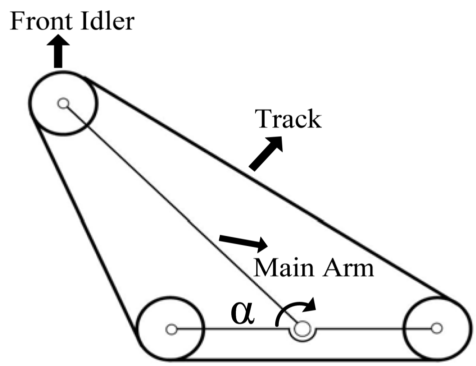

Fig. 3. Sketch map of shape-shifting mechanism without tension device

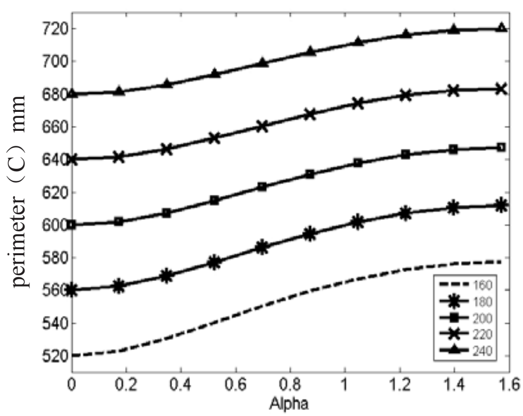

Fig. 4. Variety of the tracks perimeter as the length of main arm is changing

$$\Delta C = C_{max} - C_{min} \tag{2}$$

$$\eta = \Delta C / C \tag{3}$$

However, its rate of change remains above 5%. When the main arm is raised up, the tense tracks begin to fall off. When the main arm is brought down, the tense tracks will fracture, which is unacceptable for the tracked vehicle.

Aiming at these problems, we adopt the diamond pantograph mechanism [4] (see figure 5) instead of rigid linkage between the road wheels, and connect the revolute joint M on main arm and on pantograph mechanism with linkage. When the main arm is raised up around the revolute joint O, the diamond pantograph mechanism is accordingly shortened, which means decreasing L, thus minishing the change range of perimeter C as much as possible.

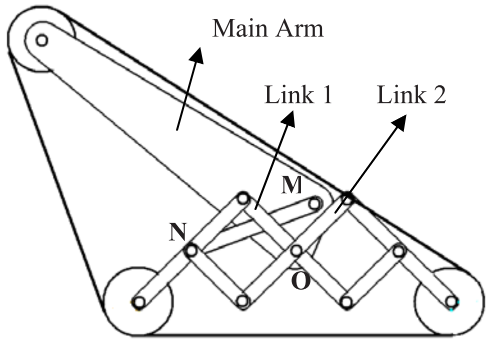

Fig. 5. Diamond pantograph mechanism for shape shifting

3 The Establishment of Optimal Design Model

Aiming at the shape-shifting mechanism as figure 5 shows, we establish parametric model in Adams to study its characteristics both in dynamics and kinematics. Since the main focus in optimal design is to control the variety extent of perimeter C, we set the minimum of η

The mechanical design parameters in this model are mainly including: $X = [x_1, x_2, x_3, x_4]^T$, where x_1 denotes the distance between the shaft of main arm and front guide wheel axle; x_2 denotes the length of links in diamond pantograph mechanism; x_3 denotes the horizontal coordinate of revolute joint M in main arm coordinate system, while x_4 denotes its vertical coordinate(see Fig. 6).

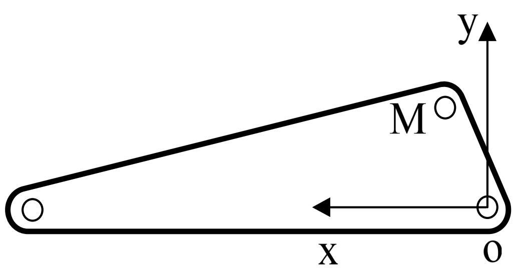

Fig. 6. Coordinate system of main arm

4 Optimal Design for Shape- Shifting Mechanism

4.1 Sensitivity Analyze on Design Parameter

Before optimization, we are obliged to discuss the sensitivity of the four parameter mentioned above, and then pick up the greater one to optimize, thus enhancing the efficiency [5].

We can have an intuitive analyze on the sensitivity of mechanism parameter by freely use of ‘Design Evaluation tool in Adams simulation environment. We first define all the parameters as variables, and give their value range and initiate value. Then we define a new ‘design study’, where we select the design variables we need. Subsequently Adams will work out the kinematics simulation of model automatically, and draw up variation curves of track perimeter according to different value of design parameters.

Fig. 7 shows the different cases for the track perimeter when these parameters change. It is obviously seen that the rate of change η is more sensitive to x_3 and x_4 , which clearly indicates that the position of revolute joint M on the main arm is one of the main influential factors for the change of the track perimeter.

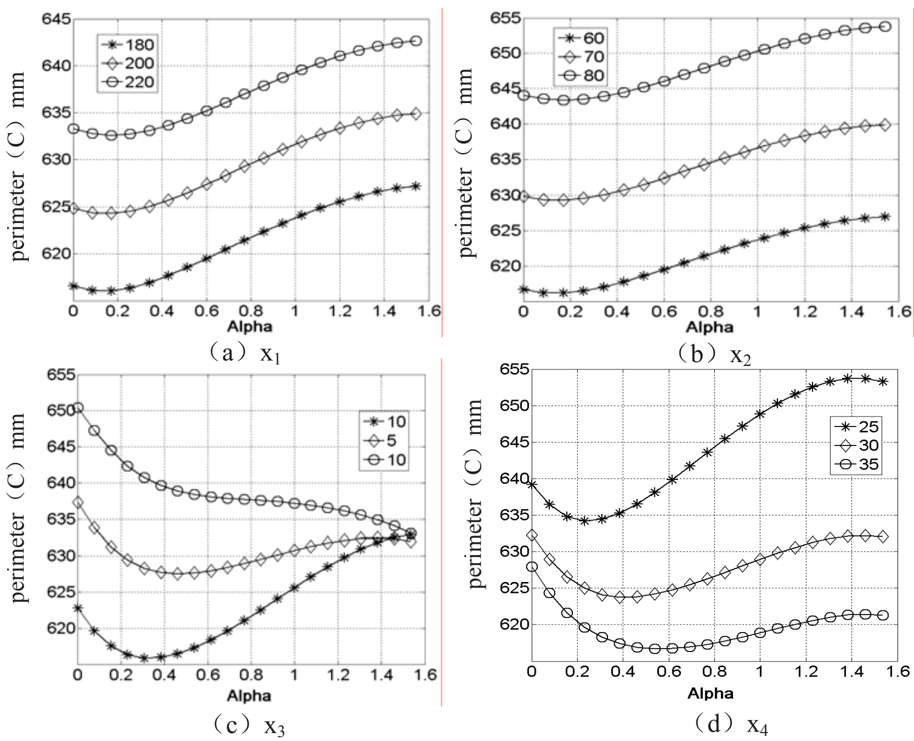

Fig. 7. Sensitivity analyze on design parameter

Up to this point, the mechanism optimal model of polymorphic tracked robot can be described as follows [6]:

Get a value of $X = [x_3, x_4]^T$, then let:

$$\eta(x) \rightarrow \min \quad (4)$$

Such that:

$$x_{\min} \le x_i \le x_{\max} \qquad i = 3,4 \tag{5}$$

$$0^\circ \le \alpha \le 90^\circ \tag{6}$$

$$\overline{MN} \le x_2 \tag{7}$$

Where $x_{\max}, x_{\min}$ is the upper and lower limit of design parameter; α is the angle of main arm; $\overline{MN} \le x_2$ is the length of link MN

4.2 The Optimal Design Result of Shape-Shifting Mechanism

According to the optimal model established in 4.1, we adopt sequential quadratic programming [7] to optimize the two parameters x_3 and x_4. Fig. 8 shows the iterative process, and Fig. 9 shows the final result. When x_3 equals to 43.83 and x_4 equals to

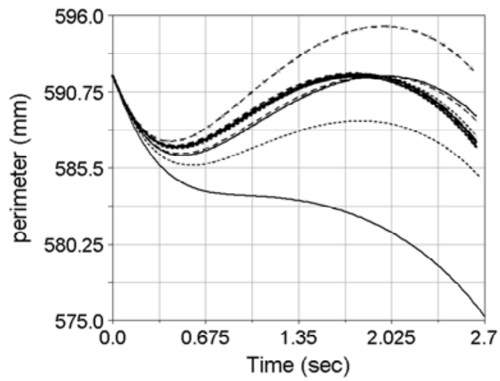

Fig. 8. Iterative process of the optimization

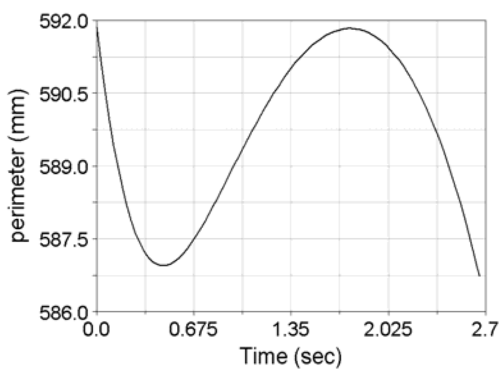

Fig. 9. Final result of the optimized track perimeter

86.15, the change of the length of track in the shape shifting process ΔC is 4.91, which means η is 0.67%. As for the tracked vehicle, the tracks are moderate tense when the change of perimeter is restrained by suspension and support devices within 1%, and the tracked vehicle can run normally , without falling off or fracture.

5 Optimal Driving Mode for Shape-Shifting Mechanism

With the size optimization above, we achieve the optimal mechanism size for polymorphic tracked robot. Based on this, we are necessary to discuss the driving mode of shape-shifting mechanism from the point view of power, then select a driving mode with low energy consumption.

As Figure 5 shows, when the main arm is rotating, the two links between the main arm and diamond pantograph mechanism rotates around revolute joint M. Here, we call link 1 to the link whose rotating direction is the same to the main arm's and link 2 to the link rotating in the opposite direction. The shape-shifting mechanism driving mode can be summarized as the following three:

Scheme 1: direct drive main arm, the rotation directly works on the main arm, with the driving main arm rotating around revolute joint O;

Scheme 2: direct drive link 1, the rotation directly works on the drive link 1, with its driving device rotating around revolute joint O. The rotation of link 1 is passed to main arm, through diamond pantograph mechanism and link MN, and then drive the main arm in the same direction;

Scheme 3: direct drive link 2, the rotation directly works on the drive link 2, with its driving device rotating around revolute joint O. The rotation of link 2 is passed to main arm, through diamond pantograph mechanism and link MN, and then drive the main arm in the opposite direction.

Aiming at the three driving mode above, we run dynamic simulation on Adams virtual prototype respectively. The curve of driving moment varied with the angle of main arm is achieved as figure 10 shows. In scheme 1, the driving moment gradually decrease as the main arm is raised, ultimately approaching to 0; in scheme 2 and 3, the driving moment keeps staying above 200mmN, and suddenly increasing when the

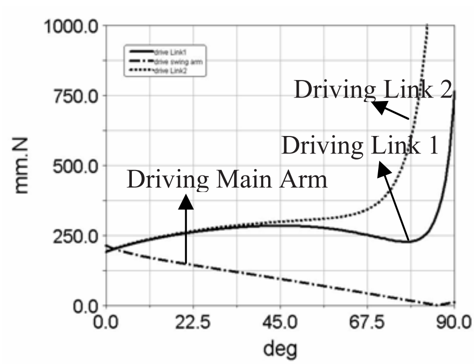

Fig. 10. The curve of driving moment varied with the angle of main arm

angle of main arm is approaching to 90° due to self-locking of mechanism when link MN and O-M are overlapped. Above all, scheme 1 requires little about the output of driving device, which can be selected as the best scheme for the shape-shifting mechanism.

6 Conclusions

This paper introduces a kind of shape-shifting mechanism for micro polymorphic tracked robot, and build parametric virtual prototype in the Adams simulation environment. After accomplishing the optimal design of shape-shifting mechanism and optimal the driving mode, we achieve these following conclusions:

1) Adams can be freely used to make sensitivity analyze on each design parameter. The result intuitively reflects the influence of design parameter to optimal target, which simplifies the variable and enhances the design efficiency.
2) The final result is achieved through the optimization towards design variables by using Design Evaluation tool and iterative simulation towards variables by applying sequential quadratic programming algorithm. In this method, the optimal result is quickly achieved and intuitively reflected on virtual prototype without encountering great work of modeling the complex mechanism.
3) The final result guarantees that the change rate of tracks perimeter is no higher than 1% during the shape shifting process, which meets design requirement that the tracked vehicle should be always tension.
4) Comparing three schemes for the driving mode of shape-shifting mechanism, we conclude that the direct drive main arm scheme requires low about the output of driving device, and is considered as first choice for the shape-shifting mechanism.

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