https://doi.org/10.31256/Su2Rz3Z

Robotic Climbing of Ladder Civil Infrastructure

Shijia Wu
University of Leeds
Leeds, UK
ml18s35w@leeds.ac.uk

Robert Richardson
University of Leeds
Leeds, UK
R.C.Richardson@leeds.ac.uk

Bilal Kaddouh
University of Leeds
Leeds, UK
b.kaddouh@leeds.ac.uk

***Abstract*— This research explores the mechanism feasibility of the ladder climbing process with one motor driving, and redundant mechanism coordination in ladder-climbing will be researched, which will benefit the research in transmission tower inspection and maintenance methods. Hoeken Straight mechanism is selected as the current adhesion mechanism due to its structure and trajectory characteristics. Since each independent module of this robot is driven by a single motor, the structure will be much simpler than the previous climbing robot. With the help of redundant adhesion mechanisms, the robot will have a high degree of fault tolerance, increasing climbing efficiency and reducing the possibility of falling. The result will benefit the climbing robot development, which will provide a theoretical basis for the robot to replace ladder or lattice inspection and maintenance by the workforce in the future.**

***Keywords*—one motor driving, Hoeken Straight mechanism, climbing robot**

I. Introduction

With the development of society, the use of power transmission towers is becoming more and more widespread. However, people need to check and repair the tower regularly [1]. Due to the danger of working at height, people have developed some robots to assist the tasks. At present, many robots have been designed for ladder and lattice transmission tower inspection [2][3], and inchworm locomotion is widely used in these robots. Although the designed robots can complete the climbing tasks, their complex structure and low locomotion efficiency limit the applications. For example, grippers are selected as the adhesion mechanism in most designs [1]. However, the gripper's frequent grabbing and releasing actions affect the climbing speed, and slipping accidents may also happen due to the changing bracing dimension [1]. Therefore, most of the work is still done by people.

II. Hardware Overview

A. Originality

In this study, as figure 1 shows, the Hoeken-type mechanism was used for the first time to perform grab-climbing. Unlike previous studies and applications on plane climbing [4], the Hoeken trajectory will be vertical to the climbing plane, and the mechanism will use the characteristics of the trajectory to grab and release the rungs. Compared with the other climbing robot, which moves step-by-step, this research will use continuous climbing with Hoeken's rotation, which will improve efficiency.

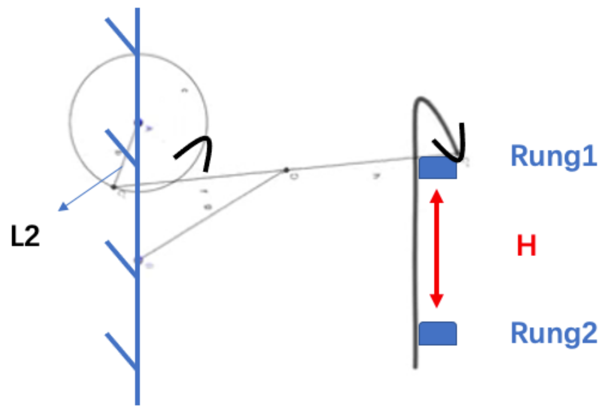

Figure 1: The two rungs' cross section are contained by the trajectory which is left by the Hoeken mechanism. H is the distance between the two rungs.

According to the coordinate of the motion trajectory [4], Figure 1 shows the motion trajectory of the endpoint. When l_2 rotates counterclockwise, the endpoint moves downward, which will push the robot upward. The climbing process is reversible, which means the robot performs well during both ascent and descent. When the two rungs are contained in the trajectory domain, the gap between the rungs is each step's distance. The coordinate of the motion trajectory is described as:

$$\begin{cases} x_B = l_2 + l_2 \frac{\sqrt{5-sin\theta}cos\theta}{\sqrt{5+4sin\theta}} - \frac{1}{2} l_2 sin\theta \\ y_B = l_2 + l_2 \frac{\sqrt{5-sin\theta}(2+sin\theta)}{\sqrt{5+4sin\theta}} + \frac{1}{2} l_2 cos\theta \end{cases} \quad (1)$$

Where, l_2 is the input linkage, θ is the rotation angle.

The Hoeken mechanism's movement and the velocity of P5 (the end point) are shown in Figure2 and Figure3 respectively.

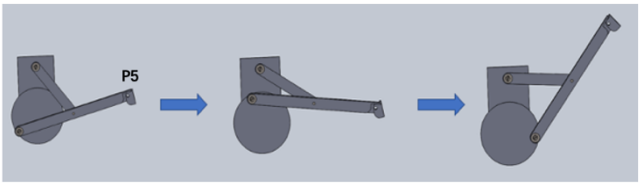

Figure 2: The Hoeken mechanism moves with the wheel part's rotation.

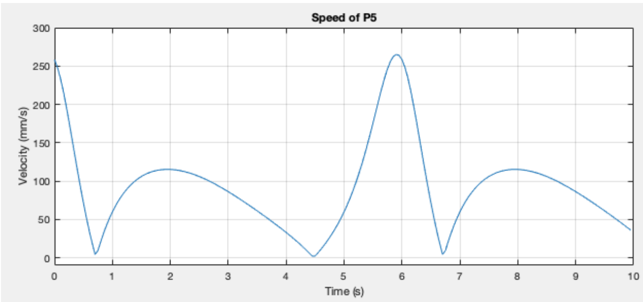

Figure3: The velocity of the P5 (the end point). The length of L2 is set as 50 mm.

B. Value

Benefit from the continuity of rotation of the Hoeken structure, the use of this mechanism has three advantages over previous climbing robots. Firstly, the motor's continuous rotation brings the robot higher efficiency comparing with the current inchworm locomotion. Secondly, the robot does not need additional grippers to grab and release objectives step by step, which further improves the climbing efficiency. Thirdly, due to the locomotion optimization, the new mechanism does not need multiply servos' control, which makes a single motor possible to drive all the adhesion mechanisms through mechanical transmission, which will reduce the robot's weight and cost.

III. Simulation

The MATLAB trajectory simulation in figure 4 shows the feasibility of the locomotion method. In figure 4A, the top linkage holds the rung and going to leave, and the bottom linkage is going to hold the rung. When the condition changes from A to B, the bottom linkage holds the rung and going to leave, and the middle linkage is going to hold the rung. The coordinate of three pairs of adhesion mechanisms keep the robot moving during climbing, and the movement will show better adaptability to the environment with the help of redundant adhesion mechanisms.

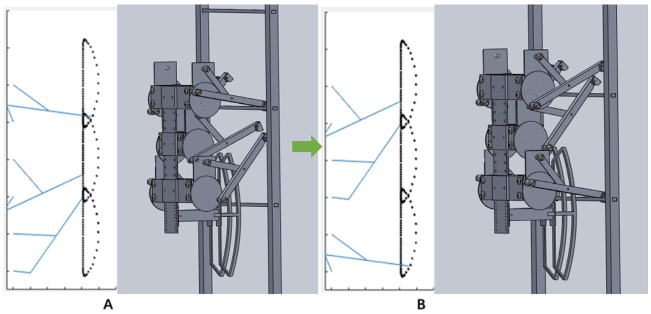

Figure4: When the mechanisms rotate clockwise, the robot moves from moment A to B.

IV. Conclusion

The Hoeken mechanism shows potential in ladder climbing. Due to the motor's continuous rotation, the mechanism has higher efficiency and a simpler structure than inchworm climbing robot. However, the bracings easily interfere with the mechanism during the movement, and sometimes the output torque is not strong enough to make the robot move. Therefore, the performance of the Hoeken mechanism in grasping needs to be further studied. A more adaptable structure will be researched later to optimize the trajectory and transmission ratio, and accommodate the lattice climbing.

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