

# Variable-Angle Rod-Climbing Robot

Aowu Wu

Oakland University, Michigan, United States

**Abstract:** This paper designs a set of rod-climbing robot which can flexibly change the angle of crawling through multiple rotation actions, in order to meet the rapid development of power transmission, urban lighting, communication engineering and other industries, reduce the labor intensity of high-altitude operation, and improve the safety of work.

**Keywords:** Ascending; Descending and clamping; Variable angle; Manipulator; CAD 2D design; Solid works 3D design

**Publication date:** January, 2020

**Publication online:** 31 January, 2020

**\*Corresponding author:** Aowu Wu, daimulin@xyzrgroup.com

## 1 Research background and significance

With the rapid development of China's economy, the workload of the construction and maintenance of power transmission, urban lighting, communication engineering and other aspects is increasing. Also, there are different environments, more mountains, many

rivers and unbalanced transportation development in China. With the development of economy, the cost of manpower is gradually higher. In equipment maintenance and installation, more and more automatic equipment which can be used easily and flexibly is needed to replace manual work, reducing labor intensity and improving work safety. These automatic devices are required to be simple in transportation, on-site installation and use. Further, their functions can meet various environmental changes like deicing robot, rod-climbing robot, etc. The existing rod-climbing robot has some problems, such as inconvenient installation, and obstacles can't be avoided in the process of climbing. Therefore, this design has carried on the improvement aiming at the design based on these questions<sup>[1]</sup>.

## 2 Overall design

This rod-climbing robot is composed of the following parts: climbing fixed mechanical gripper, rod-rotating mechanical gripper, anti-rotating and anti-falling fixed mechanical gripper, climbing lifting and withdrawing mechanism. The general drawing of the mechanism is as follows (Figure 1).

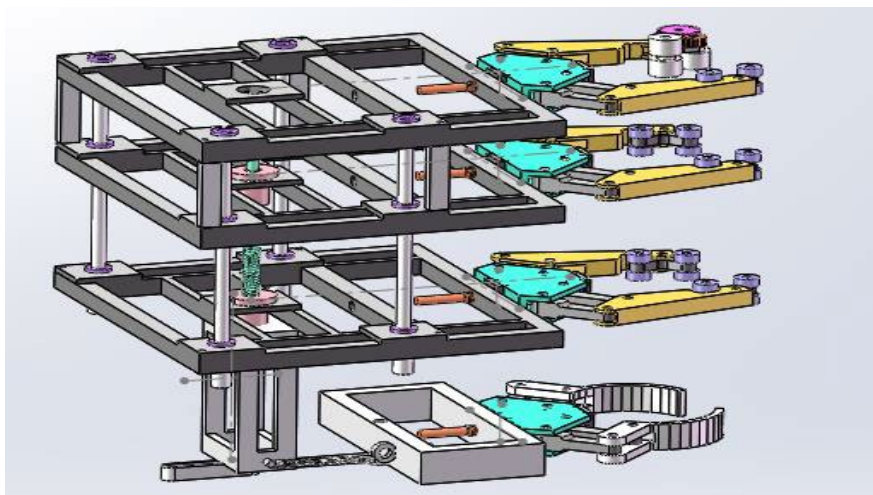


Figure 1. Institutions chart

### 3 Component structure

Climbing fixed mechanical gripper: the motor drives the screw rod to rotate, the screw rod drives the gear, and then it drives the lever structure to open and close. Each lever arm of the lever structure is equipped with a set of

clamping mechanism which can rotate at a small angle and is composed of four wheels with rubber rings<sup>[2]</sup>. Its main purpose is to adapt to the change of clamping angle when the rod surface is irregular or the diameter changes, as shown in Figure 2.

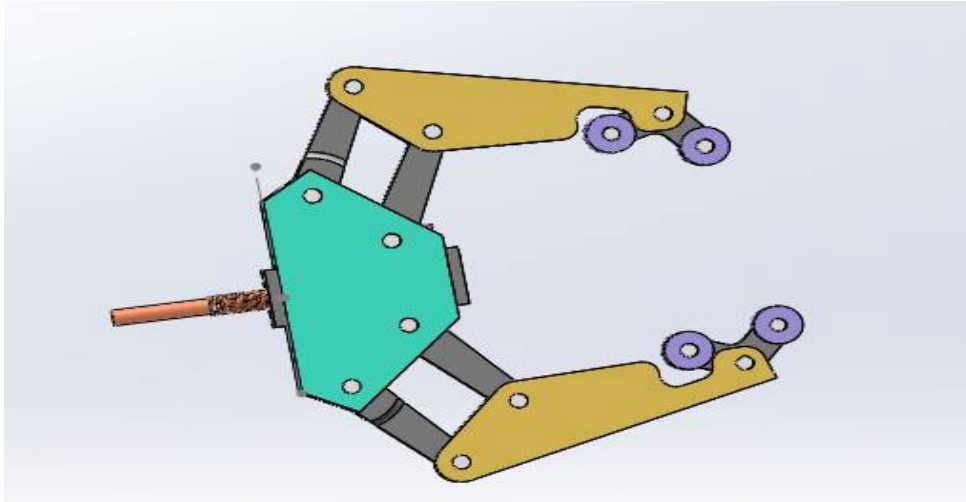


Figure 2. The mechanical paw

Rod-rotating mechanical gripper: the motor drives the screw rod to rotate, the screw rod drives the gear, and then it drives the lever structure to open and close. One arm of the lever structure is equipped with a set of clamping mechanism which can rotate at a small angle and is composed of four wheels with rubber rings.

Another lever arm of the lever structure is equipped with a set of clamping mechanism which can rotate at a small angle, which is also composed of three large wheels with installed rubber rings and a structure with installed gear transmission<sup>[3]</sup>. Its main purpose is to rotate around the rod when clamping the rod, as shown in Figure 3.

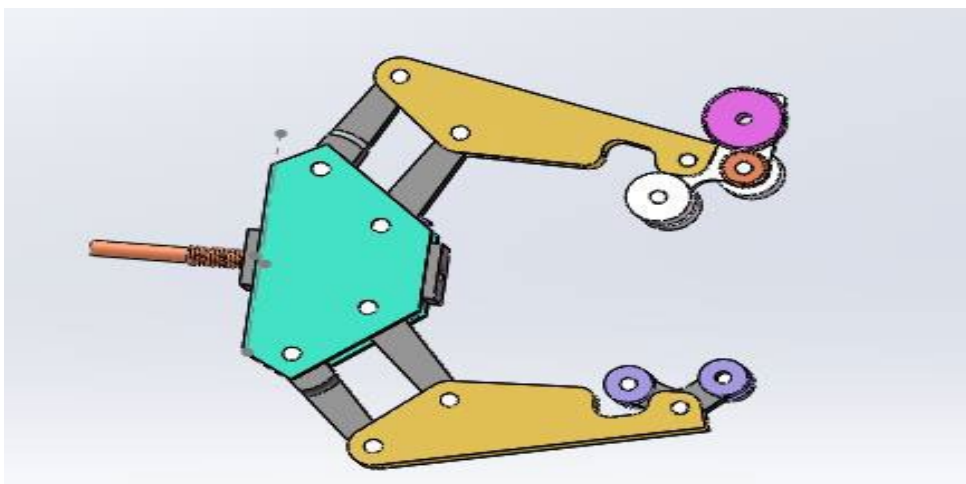
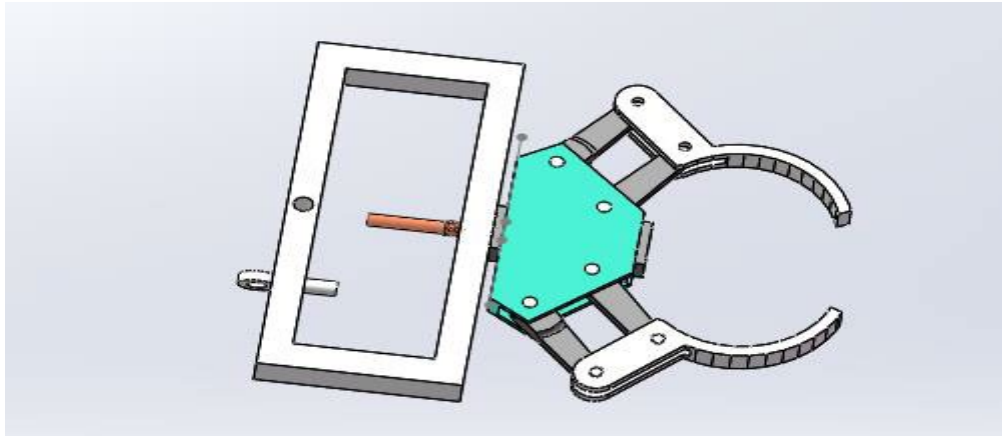


Figure 3. Rotary drive jaw

Fixed mechanical gripper against rotation and falling: the motor drives the screw rod to rotate, the screw rod drives the gear, and then it drives the lever structure to open and close. Each lever arm of the lever structure is

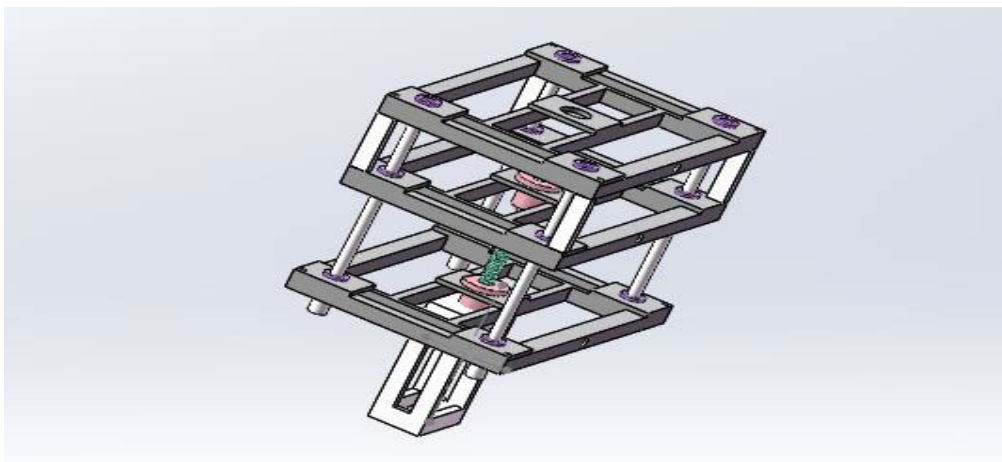
equipped with a mechanical clamping gripper. There are two functions of the mechanical gripper: the climbing process plays a fixed role, and the rotation process plays a role in preventing falling and sliding, as shown in Figure 4.



**Figure 4.** The mechanism holds the mechanical claw in place

Climbing and shrinking mechanism: the structure is composed of two parts, the upper mechanism is a fixed frame, the climbing fixed claw is installed, and the rod-winding rotating claw is installed. The substructure consists of two parts: a frame for mounting the climbing retaining claw, welded

together with a connecting rod with a swivel end and a sliding guide slot at the other end for mounting the anti-slide retaining claw<sup>[4]</sup>. The two parts are connected by a rotating screw and four guide rods, which are driven by a servo motor. As shown in Figure 5.



**Figure 5.** Lifting mechanism

#### 4 Movement process analysis:

Rising action: agencies lower fixed climbing machinery claw and the rotation fell fixed claw clamping pole, upper body mechanical paw to loosen, elevating screw rises in servo motor driven rotating the upper body, when screw rotation to stroke positioning largest position, the upper body of two groups of mechanical claw clamping bar, at the same time, the lower body mechanical paw to loosen, counter-rotating contraction lifting structure motor drive screw to screw stroke minimum location, drive the ascension of the lower body, reciprocating movement, the purpose of climbing.

Spins: when the robot encounter problems or need

to change the work point of view, on the lower part of the body anti slide fixed jaw clamping pole, while the other two fixed jaw clamping force change (smaller than climb clamping force), the upper body rotation claw clamping pole, servo motor drive mechanism the rod rotation (lower fixed jaw not rotating) is not greater than 90 degrees, when a rotation after the completion of the action, the above three mechanical claw increasing clamping force, slip below the fixed jaw loose, spring tensioning force on the fixed jaw, anti-skid claw position parallel to and the other claw, complete the entire rotation at a time. According to the robot around the rod Angle needs, can repeat the above action to achieve the purpose<sup>[5]</sup>.

## 5 Design parameters

Applicable pole diameter: 150 MM to 250 MM. The working table is 750\*600 MM, each climb height is 500 MM, each rotation Angle is not more than 90 degrees. Maximum working load: 70 kg, equipment weight: 50 kg. The diameter of the fixed claw clamping small wheel is 50MM, the rubber thickness of the wheel is 10MM, the total diameter is 70MM, the wheel thickness is 30MM, the diameter of the rotating claw rotating wheel is 65MM, the rubber thickness of the wheel is 10MM, the total diameter is 85MM, the wheel thickness is 30MM. Mechanical gripper screw tension servo motor: 0.75kw, rotary gripper rotating servo motor: 0.15kw; Slip - proof tension servo motor: 1.2kw, lift servo motor: 0.35kw.

## 6 Mechanical calculation:

### 6.1 Power calculation of mechanical claw (fixed claw, rotating claw) tensioning servo motor

Points on both sides of the equipment weight for:  $G_1$  and  $G_2$ , the maximum static friction nip respectively  $f_1$  and  $f_2$ , mechanical lever applied to wheel clamping force for  $f_1$  and  $f_2$ , in order to ensure the equipment is not sliding will guarantee the  $f_1 + f_2$  acuity  $G_1 + G_2$ , due to the clamping structure on both sides of the same, can when  $f_1$  and  $f_2$  are equal, equipment distribution on both sides of stem weight,  $G_1 = G_2$ , clamping wheel clamping force on both sides of the same, namely the  $f_1 = f_2$ . Clamping wheel and pole force diagram 6 is as follows.

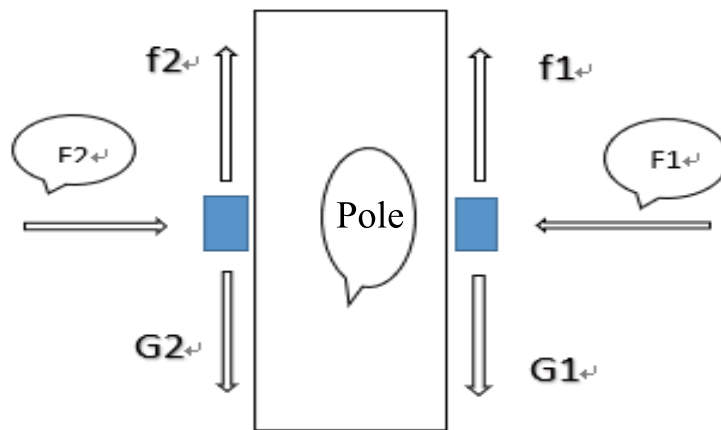
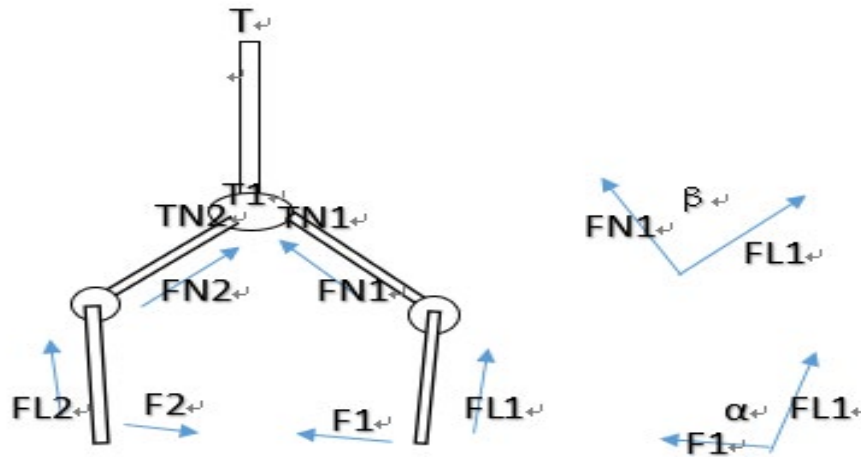


Figure 6. Clamping wheel and pole force diagram

The maximum static friction between the wheel and the rod can be obtained by calculating the dynamic friction between the two:  $f_1 = \mu \cdot N$ , and the friction coefficient between rubber and cement surface is 0.25-0.4, taking the minimum value.  $F_1 = 0.25 \cdot f_1$ , so  $f_1 = F_1 / 0.25$ ,  $f_1 \geq G_1 / 0.25$ ;  $G_1$  is half of the total weight of the device and the load weight,  $G_1 = 1/2 \cdot (50 + 70) \cdot 10 = 600\text{N}$ , so  $F_1$  is 2400N.

The clamping tension  $F_1$  is provided by the  $FL_1$  reaction force driven by the gear torque of the gear arm that connects the lever of the clamping wheel,  $F_1 = FL_1 \cdot \cos(\alpha)$ ,  $FL_1 = F_1 / \cos(\alpha)$ , (more than  $90^\circ$  less than  $180^\circ$ ). The lever Angle

is controlled by the other passive arm on the lever, in the case of  $F_1$  fixation, the larger the torque, the smaller the force required), see Figure 7: Gear arm when clamping 250 mm diameter pole arm nip pressure and the Angle between the clamping arm pull  $\alpha$  is 135 degrees (lever force needed in the design of setting Angle),  $\alpha$  when clamping 150 mm diameter pole Angle is greater than 135 degrees, clamping mechanism of tension when calculated on a 250 mm diameter pole can also meet less than the diameter of the pole, namely  $FL_1$  minimum:  $FL_1 = F_1 / \cos(180 - 135) = 1.41 F_1 = 3384\text{ n}$ .



**Figure 7.** The lever Angle is controlled by the other passive arm on the lever, in the case of F1 fixation

The gear arm pull FN1 can be calculated by lever arm pull FL1. When clamping the 250MM diameter pole (when the machine claw is designed, the Angle between the gear arm and lever arm is 135 degrees, so the Angle between the two forces is  $180-135=45$  degrees):  $FN1=FL1/\cos60=1.41FL1=4772N$ .

T1 screw output torque can be calculated through the gear arm torque TN1 + TN2:  $TN1 = FN1 * LN1$  ( $LN1 = 0.12 M$ , in the design of the gear arm length),  $TN1 = 4772 * 0.12 = 572.5 N.M$ , the total torque for screw T1 is: 1145 n. M, motor power calculation:  $P = 9550 * T1$  present input motor revolutions present ratio present use coefficient (turn this design USES the motor rated number is: 1000 RPM, speed ratio is 100, use coefficient according to the (1) motor power is about: 1.2 KW. In this design, the climbing mechanism has two sets of mechanical fixed claws grasping rods at the same time, so the servo motor motor power: 0.75 kw.

### 6.2 Power calculation of rotating servo motor with rotating claw

The whole mechanical arm robot by rotating claws on the motor output torque, the main gear (45) as follows: the number of turns the passive clamping arm (15) as follows: the number of turning, drives the wheels on the arm and clamping of the driving wheel around the pole pole surface movement, need in rotating traction is greater than the whole equipment of rolling friction couple can rotate.

Calculation of rolling friction couple between wheel and rod:  $f1(2)=f* f1$ , ( $f1$  is to ensure the clamping force of equipment fixed on the pole) rolling friction coefficient of rubber and cement surface is 0.015-0.02,

take  $0.02.F1 f1 = = 0.02 * 0.02 * 2400 = 48 n$ , in order to ensure the robot on the rod rotation, the rotating arm driving force than rotating wheel and the driven wheel rolling friction couple sum, namely  $F f1 + f2$ , or driving force F or 96 n, grip the wheel turning gear to drive torque:  $T = F * R = 96 * 0.0425 = 4.1 N.M$ , ( $R$  for clamping arm wheel drive wheel radius,  $R = 0.0425 M$ ), motor power calculation:  $P = 9550 * T$  present input motor revolutions present ratio present use coefficient (this design USES the motor rated revolution as follows:1000RPM, speed ratio 45/15=3) motor power: 0.15 kw.

### 6.3 Power calculation of anti-slide clamping jaw tension-closing servo motor:

According to the above calculation of mechanical jaw tension servo motor power, it can be concluded that the motor power is 1.2kw.

The lifting mechanism drive servo electric probability calculation: Robot upper body and load total weight: 100 kg, lifting mechanism servo motor needs to be greater than the load to guarantee agencies, the output torque is:  $100 * 10 * 0.020 = 20 n^{[6]}$ . M (lifting screw diameter of 40 mm), motor power calculation:  $P = 9550 * T$  present input motor revolutions present ratio present use coefficient (turn this design USES the motor rated number is: 3000 RPM, speed ratio of 20) motor for power: 0.35 kW.

## 7 Conclusion

Through the above analysis and calculation, we design a manned or load device of variable Angle can climbing robot, can satisfy the demands of different

diameter pole work, when faced with obstacles can't climb straight rod, can change the Angle directly avoid obstacles continue to climb, equipment is light, convenient installation, especially for an environment in which traffic is not convenient.

## References

- [1] Wang YX. Structural Innovation Design Methodology[M]. (First Edition), Tianjin University Press, 1996.
- [2] Sun H, Chen ZM. Principles of Machinery[M]. (Sixth Edition), Higher Education Press, Beijing, 2001.
- [3] Specification of Practical New-Type Patent (Patent No.: 200920039756.1), State Intellectual Property Office of the people's Republic of China.
- [4] Pan XS. Design of Manipulator Clamping Device Based on Series-Connection Force-Increasing Mechanism, Mechanical Engineering and Automation, 2013, 180 (5).
- [5] Dai FZ, Liu B, Yue YL. Robot Design and Production[M]. Chemical Industry Press, 2016.
- [6] Chen GD, Cao HQ, Yang HF, etc. Research Status and Prospect of Rod-Climbing Robot, Automation of Military Industry, March 201.