Analysis and Research on Tree-climbing and Pruning Robots

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Abstract. Tree climbing and pruning robot mainly achieve climbing and pruning two movements to help people from the dangerous high environment. This paper analyzed the research and application status of tree climbing and pruning robot at home and abroad. Finally, the development trend of tree climbing and pruning robot is discussed.

1. Introduction

Tree pruning is a very important work in forestry production, which plays an important role in the growth and lumber of trees. In today's general environment of mechanical automation production, the market needs a robot that can achieve pruning work. The robot can replace a large number of artificial, improve forest economic benefits. At present, tree-climbing and pruning robots are mainly concentrated in Germany, Japan, China and Europe, with some research achievements in other regions. Generally speaking, the research on tree climbing and pruning robot technology is still in its initial stage, so it is necessary to summarize the research status.

2. Research on tree climbing and pruning robot abroad

The research on tree pruning machinery started earlier in foreign countries, mainly in the economically developed Countries such as Europe, America, Japan and so on. In the early 20th century, Western countries had already used machines for heavy tree trimming. Due to the rapid development of the world's overall economy, pruning machinery began to develop rapidly in the 1980s in order to meet the needs of its development. Specialized tree climbing and pruning machinery appeared in various fields, and various types of models were gradually improved. In foreign countries, the research on tree climbing robots is relatively abundant, and the research is more mature in European countries with a high degree of industrial automation.

2.1 In Germany

The Advaligno PATAS was developed by the Jordan family company in Germany. It was named after the fastest monkey climbing. As shown in Figure 1, the whole system consists of two modules: a drive unit for connecting the standardized small tractor, and a cutting unit, which then works on the tree. At work, the required speed was achieved through a hydraulically driven rubber belt. It ensured minimal bark pressure and maximum grip. The blade on the cutting head separated all branches from the tree cleanly and safely. Advaligno PATAS [1-2] had a very high work efficiency. It could repair 40 trees per hour. Simple operations could be performed within a range of 12 to 15 meters. But its mass was larger, cutting head part alone was 50 kg.
2.2 In Japan
Gifu University in Japan had developed a pruning robot with an energy-saving chainsaw drive for more than 10 years [3-8], as shown in Figure 2. The whole robot was a ring structure. It was driven by the servo motor turbine reduction mechanism, with two climbing functions: linear climbing and spiral climbing. At the same time, the machine could realize self-locking fastening and prevent biting with the branches during the working process. The pruning chainsaw had the function of adjustment, and the position control of the chainsaw can be realized according to the actual working condition through the principle of fuzzy control.

The climbing device consists of four driving wheel mechanisms with steering devices and a 2-DOF attitude adjustment mechanism, so that the robot could always maintain a horizontal posture during tree climbing. At the same time, the robot could achieve self-locking only by gravity.

2.3 In India
In 2016, Akshay Prasad Dubey of India designed a coconut tree climbing harvesting robot [9]. It could take the place of human pickers to climb up to ten meters high coconut trees to pick coconuts. The robot was composed of two ring structures. As shown in Figure 3, the robot climbed up and down by holding the tree alternately. Its frame was made of aluminium. The robot had six motors, which drive the worm gear to climb up and down and harvest coconuts. The Robotic Harvester was a robotic arm with four degrees of freedom, and was also equipped with a rotary cutter as an end effector, as shown in Figure 4. Including the electric cutting machine, the Robotic Harvester had a total weight of about 7 kg and a total length of 1 meter. In a field test conducted on a coconut farm, the robot successfully climbed a tree as high as 15.2 m with a trunk incline of up to 30 degrees. Also, while the human coconut harvester worked faster, the Amaran could work longer.
3. Research of tree-climbing and pruning robot in China

At present, there are generally three pruning methods. The first is manual pruning. People used special scissors, hand saws for work. For high branches, people used ladder sawing or cutting or sawing with high branches. This way of working had a lot of labor intensity, and there was a certain danger when working under the tree. The second is pruned by manual mechanical equipment. It mainly used power saws and shears. This kind of operation still had to work under the tree, also had certain danger. The third is the use of large special mechanical equipment for pruning operations. This kind of equipment could only be used in better conditions of parks and road operations, but it was seldom used in mountainous areas. With the development of science and technology, a new mechanized pruning method had gradually appeared in China. But there is not yet a robot on the market that can automate pruning. Most of the automated tree climbing and pruning machines are still under development in the laboratory.

In 2007, Beijing Forestry University studied a kind of spiral lift tree pruning machine [10-12], as shown in Figure 5. The power source of the robot was a small gasoline engine, using a wheel drive structure. The driving wheels were arranged at an Angle to the tree trunk and used the friction of the tires to drive the pruner up and down in a spiral. The robot had a simple structure and continuous work. Its rise and cutting action at the same time, the work efficiency was relatively high. The cutting mechanism adopted chainsaw type. It had an induction device at the top, when the lower end of the branch approaches the upper end of the cutting mechanism, the whole cutting mechanism produced a downward evasive action. The branch was sawed in the next work cycle.

In the field of tree-climbing and pruning robot, Shandong Agricultural University had also done a lot of research. Professor Yuan J and his team developed a tree-climbing and pruning robot for fast-growing forests [13-15]. As shown in Figure 6, the climbing mechanism used eight inflatable rubber tires as climbing wheels. Four of them were driving wheels and four were clamping wheels. They were positioned on either side of the trunk at a 77.5 degree Angle to the trunk, creating a 12.5 degree climb Angle. The working position of the climbing wheel was adjusted by swinging the beam, so as to ensure the climbing efficiency of the machine, the ability to climb obstacles and the adaptability to different trees. In order to make the robot had a certain damping buffering ability when encountering obstacles, the robot provided clamping force through the electric push rod, and adopted the clamping mechanism of guide rod sleeve and spring. The cutter was used as cutting tool for pruning mechanism. The tool was always kept at a distance from the trunk by a spring slider mechanism. This mechanism not only ensured that the height of the left pile of the cut branches was consistent, but also protected the bark of the trunk from damage.

Several groups of data were obtained through the test, and several data points were selected to obtain the speed test data table [13], as shown in Table 1. Under the influence of the length of push rod and throttle percentage, there was a peak value of no-load speed and loading speed respectively. The peak no-load speed was about 6.78cm/s, and the loading speed was about 5.64cm/s. When the speed reached the peak, the length of the push rod was in the range of 2.24-2.49cm, and the throttle percentage was in the range of 37.5%-52.5%.
Table 1. Speed Test Data Sheet

| The Length of the Push Rod(cm) | 0.46 | 0.88 | 1.26 | 1.56 | 1.92 | 2.09 | 2.24 | 2.49 | 2.68 |
|-------------------------------|------|------|------|------|------|------|------|------|------|
| Throttle Percentage (%)       | 0    | 7.5  | 15   | 22.5 | 30   | 37.5 | 45   | 52.5 | 60   |
| No-Load Speed(cm/s)           | 0    | 0.14 | 1.63 | 2.19 | 4.41 | 5.89 | 6.78 | 6.56 | 6.08 |
| Loading Speed(cm/s)           | 0    | 0    | 1.59 | 2.24 | 3.73 | 4.86 | 5.86 | 5.64 | 5.06 |

Zheng Xian and others from the School of Mechanical Engineering of Guangxi University developed a eucalyptus tree climbing and pruning machine [16-17]. As shown in Figure 7, the climbing device adopted two opposite distributed driving wheels as the climbing driving mechanism, so that the pruner could climb directly along the trunk. Climbing device was mainly composed of left drive wheel, left wheel frame, left connecting rod, left reducer, left brushless motor, right drive wheel, right wheel frame, right reducer lever, right brushless motor, right connecting rod, push and pull rod, electric push rod, upper driven wheel, lower driven wheel.

The pruning device mainly includes a fixed blade, a left moving blade and its mounting seat, a right moving blade and its mounting seat, an electric push rod and an opening and closing driving mechanism composed of a left connecting rod, a right connecting rod and a push-pull rod, as shown in Figure 8. Among them, the fixed blade was fixed on the frame. The left acting blade and the right blade are two symmetrical blades. When installing, the left and right blades were staggered at a certain distance in the vertical direction, so that the blades were fully wrapped around the trunk to avoid the omission of branches. When the pruning device was working, the electric push rod retracted to make the left and right moving blades embrace the trunk. As the robot climbs up the trunk, the blade used the robot's kinetic energy to cut the branches off.

4. Development trend of tree-climbing and pruning robot

At present, the domestic tree climbing and pruning robot is still in the research and development stage, there are still many problems.

(1) At present, tree-climbing and pruning robot mainly realizes pruning side branches. In the process of climbing to achieve the pruning of the side branches, generally can be pruned the side branches are relatively thin. If the diameter of the side branch is more than 5mm, the effect is poor. However, less research has been done on lateral branches that are pruned far from the trunk.

(2) In the process of pruning, the climbing height of the tree climbing and pruning robot can reach about 10 meters. At this time, the ground operator cannot clearly observe the working condition of the tree climbing and pruning robot. It is necessary to use more intelligent image processing technology and a variety of sensors to work together. In this way, the ability of autonomous navigation, obstacle avoidance and object recognition can be improved, and the work efficiency can be improved.

(3) At present, the tire is used as the wheel of the climbing mechanism of the domestic tree climbing and pruning robot. Tires are in direct contact with trees, and wear is more serious in the working process. It is also easy to slip longitudinally. So it is necessary to study a new material to reduce the wear and slip, and further improve the climbing efficiency.
5. Conclusion
In a word, the current domestic research on tree-climbing and pruning robots has made some breakthrough achievements, but there is still a lot of room for development. Due to the complexity of the working environment, the research and development of tree-climbing and pruning robots has brought a lot of difficulties. It is necessary for relevant researchers to carry out further exploration and research on tree-climbing robot based on the current main problems.

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