Structure Design of Surrounding Tree-climbing and Pruning Robot

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Abstract. Tree pruning is a very important work in forestry production, which plays an important role in the growth and lumber of trees. In the general environment of automatic production of machinery, the market urgently needs a robot that can realize pruning work to replace a large amount of manual labor and increase the economic benefits of forests. In this paper, a tree-climbing and pruning robot with simple operation and automatic climbing function suitable for trimming a variety of trees is designed. The climbing mechanism of the robot adopts an enveloping wheel climbing structure, and the wheels are installed obliquely to achieve spiral ascent. The pruning mechanism adopts a combination of a mechanical arm and a saw blade, which can change the pruning method according to actual work requirements.

1. Introduction

Tree pruning is a very important task in forestry production. It plays an important role in the growth and production of trees, and the improvement of straightness, roundness, toughness and bending strength of trees. At present, my country has planted a large number of fast-growing trees in order to quickly restore the green ecological environment of the forest. Due to the backwardness of forest trimming technology, the fast-growing forests are often not managed in time, and a large number of dense branches, stuck-necked branches, competitive branches, etc. are not easy to manage. [1] The phenomenon of forest growth greatly affects the quality of wood and reduces forestry revenue.

In today's general environment of mechanical automation production and rapid development of the country, the market urgently needs a robot that can realize pruning work to reduce a lot of manual labor and increase the economic benefits of forests. Therefore, the study of a pruning robot with automatic climbing function, simple operation, and suitable for trimming a variety of trees has great market prospects and social significance. [2]

2. Work requirements

The objects are mainly tall and fast-growing perennial trees, as shown in Figure 1, which are characterized by high planting density, remote planting location, rugged roads, fast growth, and generally straight trunks. For example, eucalyptus has a height of 20-30 meters, even up to 100 meters, a trunk diameter of 10-30 cm, and many weeping branches. Ordinary manual pruning is time-consuming, labor-intensive, and low-efficiency. Working at heights on tall trees is also dangerous. Therefore, in order to improve the efficiency of pruning and reduce the risk of work, the tree-climbing and pruning robot needs to be simple to operate, have a certain degree of automation, and can automatically climb
to a certain height to perform pruning operations on branches. At the same time, considering the changes in the load-bearing capacity of tree trunks of different heights, the overall weight of the machine should not be too large, and the climbing mechanism of the machine can be adjusted accordingly with the diameter of the trunk to ensure that the tree climbing and pruning robot can always hold the trunk firmly and work steadily. The tree-climbing and pruning robot designed in this paper needs to trim the side branches of the trunk and cut off the top of the tree. The pruning height range is 20-30 meters, and the climbing speed is 1-2m/min.

Figure 1 Tall and fast-growing trees

3. Overall scheme design
In this paper, a semi-automatic tree climbing and pruning robot driven by a motor is designed using an embracing wheel type tree climbing mechanism, a combined electric saw and a mechanical arm pruning mechanism. The tree-climbing and pruning robot has two working states: side branch pruning and top pruning. According to actual work requirements, the mechanical arm can adjust the posture and drive the electric saw to complete the corresponding pruning work. The climbing method of the tree-climbing and pruning robot adopts a wheeled spiral ascent, and the tree-climbing mechanism is composed of driving wheels, driven wheels and fastening devices. [3-4] Both the driving wheel and the driven wheel are installed obliquely to ensure that they have the same helix angle. The driven wheel can swing to a certain extent, so that the wheels can roll close to the trunk under the trunks of different diameters. The fastening device consists of an active clamping device and a passive clamping device. The active clamping device works when the machine needs to be fixed on the tree trunk to complete the cutting tip, and the passive clamping device is in operation during the entire working state of the tree climbing and pruning robot.

The working process of the tree-climbing and pruning robot can be roughly divided into four stages: the preparation stage, the tree-climbing stage, the top-cutting stage, and the return stage. The four stages are carried out in sequence to complete a complete pruning work. According to actual work needs, you can skip the top-cutting stage and only trim the side branches of the trunk.
3

(1) Preparation stage: Put the frame on the bottom trunk, close the lock, and start the tree climbing and pruning robot. At this time, the electric push rod connected to the driven wheel starts to work, and the push rod returns from the maximum stroke state. The two driven wheels are respectively pulled by the push rod and start to close, and the wheels keep close to the tree trunk. When the pulling force of the push rod reaches a rated value, the force sensor installed on the push rod sends a feedback signal to the system, and the electric push rod stops moving. At this time, the tree-climbing and pruning robot is firmly fastened to the trunk.

(2) Tree-climbing stage: The tree-climbing and pruning robot is remotely controlled to ascend via Bluetooth. When the motor connected to the driving wheel works, the chainsaw blade starts to operate, the machine slowly spirals up around the tree, and the chainsaw completes the cutting of the side branches. During the ascent of the tree-climbing and pruning robot, as the diameter of the trunk changes, the force between the driven wheel and the trunk will change to a certain extent. The force sensor provides timely feedback to the system, and the electric push rod of the driven wheel operates to ensure that the wheel firmly hugs the tree trunk.

(3) Top-cutting stage: When the tree-climbing and pruning robot rises to the required height, the machine is remotely controlled via Bluetooth to stop the ascent and start the top-cutting program. Actively clamp the electric push rod to work, and the push rod drives the clamping device to clamp the tree trunk. Then, the pruning mechanism is adjusted to the top-cutting state. As the mechanical arm rises and the rotating pair rotates, the electric saw slowly cuts off the top of the tree.

(4) Return phase: When the machine completes the top-cutting work, the mechanical arm is converted to the initial state. The return stroke of the active clamping electric push rod is released, the driving wheel motor reverses, and the tree climbing and pruning robot descends slowly and spirally around the tree. When it reaches a lower height, the motor can be stopped via Bluetooth.

4. Structural design

4.1 Crawling mechanism design

The working part of this wheeled mechanism consists of a driving wheel and three driven wheels. The driving wheel is connected with the motor through the sprocket, chain, and gear. When the motor is working, it drives the driving wheel to rotate, and drives the machine to operate under the action of the friction between the driving wheel and the tree trunk. [5] The three driven wheels play an auxiliary supporting role to ensure that the driving wheels are close to the trunk and the machine as a whole work stably without shaking. The four wheels are arranged alternately in space, and each wheel forms a certain angle with the horizontal plane individually, so that each wheel can contact the tree trunk during the climbing process, and the whole spiral rises at a certain inclination angle, as shown in Figure 4. The tilt-wheel working mechanism has the characteristics: the friction between the tire and the trunk is used to push the machine up; the amount of friction is related to the pressure between the wheel and the trunk, the roughness of the wheel surface and the tilt angle of the wheel; the speed is related to the inclination of the wheels; the height that the machine rises after turning around a tree is related to the inclination of the wheels.

Figure 4 Tilt installation of wheels
4.2 Design of pruning mechanism
The manipulator needs to complete the posture adjustment of side branch pruning and top pruning. Before top trimming, the chainsaw needs to rise to a certain height to find a suitable trimming position. The electric saw cuts the top branch by rotating, and the cutting surface of the electric saw can leave a certain angle with the horizontal plane to avoid knife jamming. Therefore, the robotic arm must have a rising structure and two rotating structures.

![State 1 and State 2](image)

**Figure 5 Working status of pruning mechanism**

As shown in Figure 5, working state 1 is the state when the tree-climbing and pruning robot is ascending spirally. The chainsaw is placed vertically, consistent with the ascending direction of the tree-climbing robot. The front of the guide plate is opposite to the trunk. As the body rotates around the tree, the chainsaw continuously cuts the side branches. Working state 2 is the state when the tree climbing and pruning robot is pruning the top of the tree. The push rod pushes the guide rod to rise vertically, the guide rod drives the chainsaw to a certain height, and the steering gear drives the chainsaw to rotate around the rotating pair to cut off the top of the tree.

5. Simulation analysis

5.1 Stress analysis of driving wheel
The driving wheel is mainly subjected to four forces in the working process: gravity G, the friction force f between the trunk and the wheel, the driving force F received by the wheel and the thrust FN of the trunk against the wheel in the horizontal direction. The force of the driving wheel is similar to that of the driven wheel. The thrust of the trunk to the wheel is 2000N, and the weight of the whole machine is evenly distributed to the three wheels. The resultant force of the driving wheel by gravity and the friction between the trunk is:

\[ F_2 = F = 383 \text{N} \]  

(1)

The structural parameters of the driving wheel are:
- Driving wheel support length a=150mm
- The driving wheel diameter is D=2b=150mm

Then the maximum torque received by the support is:

\[ M_2 = F_2 l_2 = F_2 (a + b) = 383 \times (0.15 + 0.15 \div 2) = 86.2 \text{ N/m} \]  

(2)

At the same time, the driving wheel is also subjected to the torque transmitted by the sprocket. Since the rated output power of the selected driving wheel drive motor is \( P_e = 400 \text{ W} \) and the speed \( n_3 = 1800 \text{r/min} \), the total transmission efficiency transmitted is \( \eta = 0.65 \), then the output power of the wheel is:

\[ P_o = P_e \times \eta = 400 \times 0.65 = 260 \text{ W} \]  

(3)

The speed of the wheels is:
\[ n_1 = \frac{n_2}{i_{12}} = 1800 \div (2 \times 55) = 16.4 \text{ r/min} \] (4)

Then the output torque of the driving wheel is:
\[ M_o = \frac{30P_o}{\pi n_1} = 30 \times \frac{260}{3.14 \times 16.4} = 151.5 \text{ N} \cdot \text{m} \] (5)

Figure 6 Finite element analysis of driving wheel

From Figure 6, the maximum stress concentration of the driving wheel is at the connection between the bracket and the frame.

6. Conclusions
This paper presents a design of a tree-climbing and pruning robot. In the tree climbing process, the driving wheel and the driven wheel are assembled at a certain inclination angle, which can realize the spiral ascent of the tree-climbing and pruning robot as a whole. At the same time, the principle of partiality can be used to meet the requirements of trees of different diameters. The pruning mechanism adopts a structure that combines a mechanical arm and an electric saw. The mechanical arm can adjust the posture according to the work requirements, change the position of the electric saw, and realize the pruning of the side branches or the top of the tree. At the same time, a clamping mechanism is designed, including active clamping and passive clamping. The active clamping mechanism is separately equipped with two electric push rods to actively control and clamp the trunk when cutting the top, so as to ensure that the machine firmly grasps the trunk and the chainsaw operates smoothly. The passive clamping mechanism is equipped with an electric push rod for each driven wheel to control the swing of the driven wheel. During the swing of the driven wheel, the distance between the wheel and the axis of the tree trunk is changed. Under the feedback of the force sensor, the swing angle is adjusted in real time to ensure that the driven wheel is always clamped with the tree trunk.

The tree-climbing and pruning robot has a simple structure and flexible assembly. It can build side branches during tree-climbing and build top branches after climbing to a certain height to improve work efficiency. Finally, it is simulated to verify the reliability of the design.

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