Design and Analysis of Automatic Pruning Machine Electrical Control System for Hedgerows on Highway

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Abstract. It is difficult for workers to achieve the pruning effect when pruning the fence with hedgerow on the highway, which is heavy in workload and high in costs. Meanwhile, workers are not safe when working on a high-speed road. To solve these problems, a full-automatic pruning machine and its control system are designed. The machine kinematics and work processes are analysed. Then the control system is designed and the actual work is simulated under the monitoring environment for system debugging. Results show that the machine is universal and multifunctional. The equipment has a high degree of automation and low work intensity. The machine does not require workers to have the high operating skills, and has low normative requirement for the planting method. The adaptability is strong, which means that the equipment could cut not only the plan but also the entire geometrical shape, and it can be used normally in the complicated environment. The machine is especially suitable to prune hedgerows on a highway with good safety performance.

Keywords: Pruning machine, automation, control system, hedgerows, highway.

1. Introduction
The Ministry of Transport said that by the end of 2020, the total mileage of China’s highways is 5,198,100 kilometers, and the mileage of expressways is 161,000 kilometers. In order to accommodate the noise, relieve the visual fatigue of the driver and block the light of the opposition vehicle, the middle isolation belt of the expressway must be planted with green trees. The highway isolation belt needs to maintain a uniform shape, and the greening trees must be pruned regularly to avoid the fast-growing irregular branches from obstructing the driver’s sight. Existing pruning tools cannot be efficiently and reliably trim, nor can they flexibly adjust the height and trim automatically [1]. When the model is trimmed manually, only intuitive and general operational tools are used, and reference objects are lacking. On one hand, the pruning effect is not achieved, the neatness is not standardized, and it is easy to cause tree damage. On the other hand, the work intensity is brought up and the cost is high. In particular, workers have hidden safety hazards on highways, and the results are not satisfactory.

Existing pruning machines include manual operation, electric knapsack, and large-scale airborne pruning machines. Although these machines have automatic working functions to a certain extent, they still require manual intervention, and the pruning effect cannot reach the desired effect. The rapid development of robots has led to the development of unique robots. There is a huge gap between the
performance, quality and automation level of Chinese landscaping machinery and developed countries. It is still in a preliminary stage of research. Some university research institutes and related companies are developing [2]. The related development has also made some breakthroughs, but the application on the highway still needs to further improve its reliability. Therefore, it is necessary to design an automatic pruning machine.

2. Design and analysis of pruning machine

2.1. Structural design of pruner
The pruner structure is composed of a series of links connected by joints. The manipulator is an open loop spatial link structure. Through the relative changes, speed changes, and acceleration changes of each link, the end effector can reach the desired spatial position. Attitude, get different speed and acceleration, and complete the work requirements [3, 4]. According to the requirements of the pruning object, a pruning machine that can meet the needs of the highway is designed. The mechanical structure is shown in Fig. 1.

![Figure 1. Mechanical composed structural block diagram of pruning machine.](image)

The mechanical structure of the manipulator includes: Cartesian coordinate the manipulator, cylindrical coordinate the manipulator, spherical coordinate the manipulator, multi-joint coordinate manipulator, and compound coordinate manipulator. Each type of manipulator has high work efficiency in a specific working environment, but also has relatively shortcomings. Comprehensive analysis of the advantages and disadvantages of the above-mentioned various structures, the structure of the automatic pruner is established as an improved planar composite mechanical structure, as showed in Fig. 2.

![Figure 2. Diagram of pruning machine.](image)
The turntable f can rotate the robot as a whole, the main arm is divided into a lifting arm a and a telescopic arm b, and the slave arm is divided into a lifting arm d and a telescopic arm c [5]. The sub arm telescopic arm of the pruner robot has a self-adjusting length function, and there is an ultrasonic sensor at the end. After detecting the distance between the cutter and the pruning surface and comparing it with the set distance, the sub-arm will automatically adjust the length. The main arm and the slave arm are connected by a rotating joint e, the end has three degrees of freedom, the angle of the cutter can be adjusted when the shape is trimmed, and the end is equipped with a replaceable cutter. The pruner can be used to clean up river channels, wash tunnels, and clean road signs by replacing the end effector.

2.2. Kinematics analyses of pruner

The pruner is mainly composed of a master arm and a slave arm. The movement of the master arm is mainly used for large-range adjustment, and the movement of the slave arm is completely relied on when performing plane pruning or modelling pruning [6]. Therefore, when constructing the coordinate system showed in Fig. 3, you can choose the rotation axis $x oy z$ as the reference coordinate system. The end of the trimmer is represented by $x_1 o_1 y_1 z_1$. The coordinate transformation of the manipulator can be regarded as from $(x, y, z)$ to $(x_1, y_1, z_1)$, the relationship between the two is as formula (1).

$$\begin{align*}
x_1 &= x + l_1 \\
y_1 &= y + l_2 \\
z_1 &= z + l_3
\end{align*}$$

$l_1, l_2, l_3$ represents the relative position constant between the two coordinate axes.

Figure 3. Coordinate system diagram of pruning machine.

$\alpha$ represents the angle between the trimming tool and the lifting shaft of the slave arm, $\beta$ represents the angle between the trimming tool and the $y_1$ axis, the position and posture of the trimming tool can be described by $(x_1, y_1, z_1), (\alpha, \beta)$. $\alpha$ and $\beta$ can be solved by formula (2).

$$\begin{align*}
\alpha &= \arctan\left(\frac{\sqrt{x_1^2 + y_1^2}}{z_1}\right) \\
\beta &= \arctan\left(\frac{\sqrt{x_1^2 + z_1^2}}{y_1}\right)
\end{align*}$$
The motion trajectory of the pruning machine should be planned and the interpolation algorithm should be used to complete the task of the target curve. Use point-by-point comparison and interpolation algorithm to generate a series of coordinate values between the limited coordinate points, complete the data densification, and then allocate pulses to each coordinate axis to realize the trajectory planning of the entire curve, that is, determine the action of each axis in the linked motion sequence, displacement, direction and speed.

2.3. Analysis of working process of pruning machine

The working process of the fully automatic pruner includes two parts: automatic and manual. If the actual environment is complicated and obstacles restrict the continuous operation of the equipment, manual operation is adopted, and the single-step manual operation of the actuator is adopted. If the actual environment permits, automatic operation is adopted. According to characteristics of the pruning object, the corresponding control mode is selected. The block diagram of working process of the automatic pruning machine is shown in Fig. 4.

![Figure 4. Block diagram of full-automatic pruning machine working process.](image)

Pruning machine control system software is designed with PLC programming and monitors design. The PLC program is carried out in the Botu Tia-v14 environment, including the control of the hydraulic system, the control of the rotary joint, the control of the end joint, and the control of the tool start and stop. The monitor interface can complete the functions of pruner parameter setting, dynamic monitoring and remote operation. In order to meet the pruning requirements in different environments, the system should have several types of working methods. Under normal circumstances, it must have automatic control methods and manual control methods. The automatic method automatically completes tasks, and the manual method is used for equipment debugging and special environmental pruning. Among them, the automatic mode includes three modes of returning to the origin, single cycle and continuous operation. The main program flow chart is shown in Fig. 5.
Each function completed by the fully automatic pruner is supported by the corresponding closed loop subsystem. Controllers, sensors, and actuators constitute various subsystems, and the control program of each function runs in the controller PLC. SCARA mechanical structure equipped with this control system can complete the set tasks and make the pruning work develop in a more intelligent direction. The block diagram of control system of the automatic pruning machine is shown in Fig. 6.

**Figure 5.** Flow diagram of main program.

**Figure 6.** Structure block diagram of control system of automatic pruning machine.
3. Monitor and debugging

Using MCGS monitor software to complete the design of the system monitor screen on the touch screen, the functions of each working mode of the pruner can be simulated and debugged in the operating environment. The continuous automatic interface debugging is shown in Fig. 7(a), and the manual debugging interface is shown in Fig. 7(b).

![Continuous full-automatic debugging](image)

**Figure 7.** (a) (b) Main interface diagram of monitor debugging.
Through configuration simulation debugging, setting the parameters and work flow in the corresponding operation mode, simulating the working conditions of the pruning machine in different working modes, optimizing the system performance, and meeting the pruning requirements as a whole. The degree of automation is high, forming a closed-loop system that the upper computer monitors and issues instructions, and the lower computer executes and can feedback. The cutter can automatically adjust the inclination angle. It can be used for pruning of plants and sides, as well as pruning of symmetrical hedges such as spheres, cones, columns, and tables.

4. Conclusions
In this paper, automatic pruning machine is designed for pruning the hedgerow separation belt on the highway. It has the following advantages.
(1) The pruning machine can prune the shape automatically. The cutter can automatically adjust the inclination angle for geometric pruning. This function not only improves the work efficiency, but also makes the pruning effect more ideal, and the manual operation time is greatly reduced.
(2) Simulate actual working conditions for system debugging in the monitor environment, discover and solve existing problems. The pruning machine has high safety, strong operability and good reliability, and lays a test foundation for the subsequent prototype manufacturing.
(3) Strong adaptability, multi-purpose in one machine. The pruning machine can be used for both plane pruning and geometric pruning of the whole plant. At the same time, by replacing the end effector, it can be used to clean rivers, wash tunnels, and clean road signs, realizing a multi-purpose machine.

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