Design and Research on End Effector of a Pruning Robot

Biao Huang [1, *] , Ming Shao [1] and Wenjun Chen [2]

1 *School of Mechanical and Automotive Engineering*, South China University of Technology, Guangzhou 510640, Guangdong, China
2 *Department of Electronic and Automatic Engineering*, Guangzhou Huali Science and Technology Vocational College, Guangzhou 510640, Guangdong, China
* Corresponding author E-mail: hbiao2002@163.com

Abstract **- Due to the complicated working environment in the field, the problem of automatic pruning of fruit trees and the utilization of tree debris have not been well addressed. Therefore, this paper analyzes the agronomic characteristics, working environment, transportation, treatment of residual branches and weight of the end effector of the pruner to design a multi-functional end effector with the function of pruning and smashing. This end effector cuts and grinds tree branches through six steps, namely: preparation, entering, cutting, transportation and smashing. During the working process, the end effector is powered by four low-power motors to cut with its blade saw. Experiment shows that this end effector can perform the task of cutting and smashing branches within 1 cm.**

Keywords - pruning robot, end effector, robot

I. INTRODUCTION

Pruning is a cultivation technology that has great influence on the size, flowering and production of fruit trees [1-3]. With the development of fruit industry and the improvement of labor cost, the traditional pruning method has failed to satisfy the need of production and development. It is urgent to develop automatic pruning equipment for the fruit industry. As the key equipment to cut branches, the end actuator of the pruner will directly influence the result of tree pruning, which is a core technology in the intellectualization of pruning.

At present, the development of the end actuator of pruner is still in the beginning stages and is mainly focused on the automatic pruning of woods branches [5-14]. This type of end actuator is usually composed of electric saw and driving motor. The actuator moves with the robot along the trunk, scrambling, to prune the branches around it [9, 10, 15]. It is simple in structure, fast in responding, reliable and easy to control [16]. No report on the related research about the automatic pruning of fruit trees has yet been seen. Because of the difference in the pruning of fruit trees and common woods, it focuses on the pruning of specific branches and the process usually involves recognition, analysis, identifying, positioning and cutting. So, in accordance with the characteristics of the pruning process, a pruning robot is developed, which is easy to carry, efficient and capable of cutting branches.

II. REQUIREMENT FOR THE DESIGN OF THE END EFFECTOR OF A PRUNER

A. Agricultural Requirement for Pruning Fruit Trees

Smoothness of the edge is the most important agricultural requirement in pruning fruit trees. If the edge is not smooth, it will not only affect the healing of the cut, but will also cause dry rot. Therefore, it has to be made sure that the edge is smooth and there is no split.

B. Special Requirement in Pruning Fruit Trees

The main purpose of pruning fruit trees is to avoid over density of branches and improve illumination. The branches that need cutting are usually crowded with each other. To enable the end effector of the pruner to get to the precise location, the size of the end effector needs to be controlled.

C. Requirement in Disposing Debris

Fruit trees are often planted on mountain slopes with a large coverage, which makes it hard to timely dispose of and utilize the debris, an important biomass energy. Therefore, in the designing process of the end effector, the disposition and utilization of the debris should be taken into consideration as one of the requirements.

D. The Bearing Capacity of The Mechanical Arm

The end actuator of the pruner is located at the end of the mechanical arm to cut branches. The heavier it is, the stronger the bearing capacity of the mechanical arm needs to be, the higher the cost. To reduce the production cost, in the designing process of the end actuator, the weight of the actuator should be taken into consideration.

E. Other Requirements

In order to adapt to the requirements of the society for the robot pruning end effector, the pruning end effector should have the strong adaptability, simple operation, small volume, safe and reliable, low cost and other requirements.

III. STRUCTURAL DESIGN OF THE END EFFECTOR OF THE PRUNER

According to the design requirements, the body of the end effector of the pruner is close to a rectangle with a size of 100mm×170mm×300mm as shown in Fig. (1).The width and height allows the end effector of the pruner to perform tasks in a space of high branch density. The end effector is composed of a leading truck, a transporting unit and a smashing unit, weighing 3kg with a power of 300W. This design effectively lower the bearing capacity requirement and energy consumption, thus reducing the production cost.

The overall design of the end effector used for pruning the branches of fruit trees is shown in Fig.(2). The guide frame is used to guide the branches which are to be pruned to move into the end effector according to certain tracks. This frame is located at the forefront and mainly composed of a guide channel made of two curved branches and a channel valve. The gripping and delivery devices are employed to fix and deliver branches and mainly consisted of compression rollers, spindles, reels and two motors used for gripping and delivery respectively. The two sides of compression rollers are connected by a spring and the guide frame. At the same time the motors for gripping branches is connected by the connection rollers and the delivery rollers. The rollers for gripping branches are combined by wire rope and reels. The pruning and crushing parts are designed for pruning and crushing broken branches, which are partly consisted of motors characterized by moving saws, motors used for crushing, lead screw, limit switch, saws and rigid shafts. The motors characterized by moving saws are connected by lead screw and the motors for crushing are linked by flexible shaft and saws.

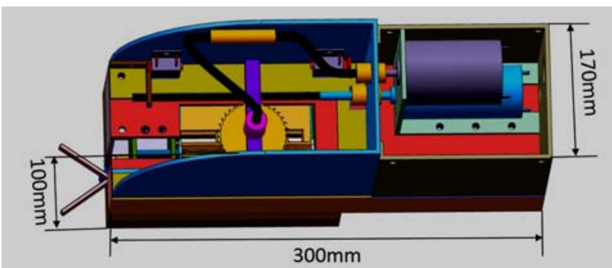
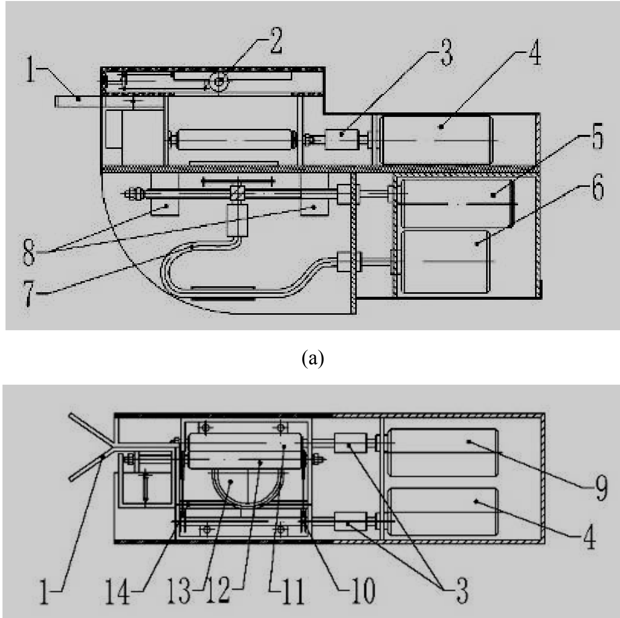


Fig. (1). Diagrammatic Sketch of the Pruning Robot's End Effector



(a)

(b)

Fig. (2). The CAD Chart Involving the End Effector from Robot Used for Pruning Branches of Fruit Trees. (a) The Front View (b) The Top View.

In Fig. (2), each symbol is expressed as: 1.guide frame, 2.gompression rollers, 3.connection reels, 4.motors for gripping branches, 5.motors characterized for moving saws, 6.motors for crushing, 7.rigid shafts, 8. limit switch, 9.motors for branches delivery, 10.reels, 11.rollers for branches delivery, 12.rollers for gripping branches, 13.saws, 14.lead screw.

IV. THE WORK PRINCIPLE OF THE END EFFECTOR INVOLVING PRUNİNG BRANCHES

The operations of the end effector involving pruning branches have six stages including preparation, entry, gripping, pruning, delivery and crushing.

A. Preparation

During the preparation process, the visual system of robot is used for collecting the image information. Apart from this, the branches to be pruned and their positions are determined by analyzing the control unit.

B. Entry

During the entrance process of branches, instructions are given by the control unit so as to drive the movement of each joint of the robot designed for pruning. So the end effector can move to the branches which are to be pruned according to certain tracks. After branches moving into the guide channel, branches are able to move along the guide channel into end effector with the assistance of the pressure from the guide frame. Meanwhile, the visual system can feed back the movement of the end effector to the control unit in time by real-time collecting the image information and the control unit regulates driving joints by the feedback information until the branches reach the predetermined positions.

C. Gripping

During the gripping stage, the motors for delivering branches is started to make the rollers to release wire rope and reels for gripping branches under the help of tension from the springs located in two sides so as to squeeze rollers used for delivering branches in order to realizing the gridding of branches.

D. Pruning

In the pruning process, the motors for crushing and the motors characterized by moving saws are started successively by the control unit. The motors for crushing make the saws rotate at high speed by using rigid rollers to drive saws. Lead screw spins along the axle under the drive of motors characterized moving saws so that the high-speed spinning saws begin the movement of translation by the beam and this process of movement can cut branches. When the saws move to the two sides of the end, limit sensor passes the information to the control unit which can help the control unit based on sensor signal realize the control for the motors.

E. Delivery

In the branches delivery phase, the control unit uses the information acquired by the limit sensor. After making sure that branches have been cut, the motors for gripping branches are run immediately which can allow the rollers designed for delivering branches to spin and branches can move to the end effector in the pruning direction. By these operations, the branches are delivered.

F. Crushing

During the crushing stage, the branches which have been cut are continuously cut into small pieces which can be regarded as the raw material of organic fertilizers to throw them into soil. This process is characterized by the continuous cycle of separating and delivering branches and this process will be stopped until the broken branches are all crushed into pieces.

V. EXPERIMENTS AND RESULTS

Through the above analysis of work principle, it is thought that the end effector has certain feasibility. So the mentioned end effector is made and used for experimental verification. The motors' parameters are indicated in Table 1.

TABLE 1. THE PARAMETERS OF MOTORS IN END EFFECTOR

Parameters	I	II	III	IV
Rated Voltage(V)	12	12	24	12
Unloaded Speed(r/min)	100	688	9000	54
No-load current (A)	1.6	1.6		1.6
Load Speed (r/min)	85	585	6480	46
Rated Moment (kg.cm)	40	9		45
Power Rating (W)	60	60	80	60
Load Current (A)	1.5	2.5	4.8	1.5
Stalling Torque(kg.cm)	150	55		180
Stalling current (A)	7	7		7
Motor Length (mm)	120	108		129
Weight of Motor (kg)	0.34	0.28	0.35	0.36

In Table 1, I stands for motors for branches delivery, II stands for motors characterized for moving saws, III stands for motors for crushing, IV stands for motors for gripping branches.

Loquat is one of most common fruit trees. This kind of tree has the similar characteristics involving the diameter of one-year-old branches and the degree of lignifications comparing with other branches of majority fruit trees. Considering these conditions, the branches of loquat are chosen as pruning materials in this experiment to make sure whether the end effector is the ideal experimental device. Several typical one-year-old branches of loquat are shown in Fig. (3).

(a)

Fig. (3). The Experiment of Pruning Branches by Using the End Effector (a) The pruning scene, continued on next page.

(b)

Fig. (3). The Experiment of Pruning Branches by Using the End Effector (a) The pruning scene, (b) The loquat branches of different varieties.

The designed end effector is applied to the pruning of branches from different varieties and various diameters. And the cut time for a single branch is recorded. It was found that varieties have less influence on the cut time of a single branch and this cut time mainly depends on the diameter of branches. The relationship between the diameter and the cut time of branches is depicted in Fig. (4).

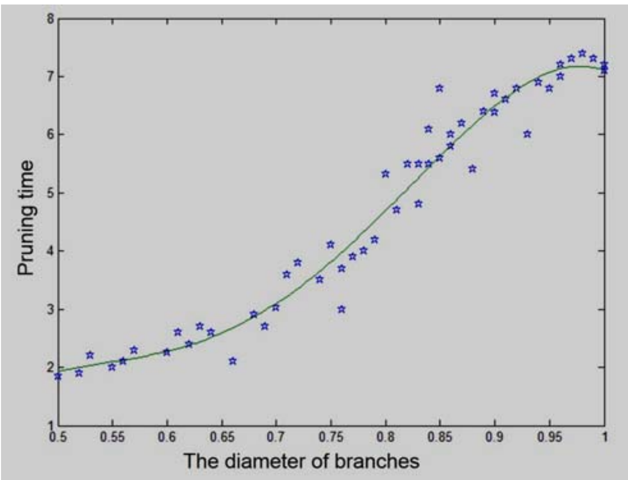


Fig. (4). The figure reflecting the changes between different diameters and different cut time of branches.

Due to differences in the degree of lignifications of branches having different diameters, the cut time gradually grows with the branches increasing from 0.5 cm to 1 cm. And the rate of increase begins to become smaller with the diameter of branches exceeding 0.9 cm because of the minor differences in the degree of lignifications. The pruned fruit trees are mainly one year and the diameters of these branches are generally less than 1 cm, so the range of diameter of this end effector meets the requirements about pruning fruit trees. After carefully observing the shear plane, it was shown that the shear surface is smooth, free from splitting and easy for healing notches. After pruning, the diameters and hardness of broken branches are smaller than these data acquired from the fracture sections, which is beneficial to the crushing operations at high speed. It could also be concluded that the end effector has perfect crushing performance. The debris crushed is shown in Fig. (5).

Fig. (5). The debris by crushed

Experiments show that the shear opening branches after pruning branches are smooth and easy to restore, and crushing branches meet energy requirements of recovery. Therefore, the end effector meets requirements of agricultural production.

VI. CONCLUSIONS

Because of the constraints from the complex field working conditions, automatic pruning fruits trees and making the most use of broken branches are technological difficulties which have not been better solved. An end effector equipment is designed which is based on the development of pruning robots. This kind of device has the following characteristics:

(1) It possesses the simple, compact and lightweight structural features. The shape of the designed end effector is the 10cm × 17cm × 30cm rectangular and the overall weight is about 3kg. This device includes the guide frame, the gripping, delivery and pruning parts which can independently complete the pruning and crushing operations in a relatively small space.

(2) It has the characteristic of low consumes energies. Since the branches is one year, the diameters is small and the degree of lignifications is low, this end effector only employed four low-power motors which the total power is 300 watts to supply electricity. This experimental method can save energy significantly.

(3) It combines the pruning and crushing processes so as to improve the efficiency of the use of broken branches. As most of the pruning broken branches are one year and have

low degree of lignifications which is easy to corrupt, the broken branches are cut into small pieces by using the pruning principle and then throw them into soil. These broken branches can be used again by fruit trees as organic fertilizers.

With the extensive research about the robot used for pruning branches of fruit trees, the invention of the end effector of pruning branches of fruit trees have laid a solid foundation for the automatic pruning branches which promotes the research of this kind of research and contributes to the development of automatic equipment in this research field.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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