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A novel grafting machine for Solanaceae based on big data and deep learning technologies

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Abstract: *This paper addresses the issue of low manual grafting efficiency in solanaceous crops and the high training and operational costs associated with current expensive grafting equipment. Traditional grafting methods mainly rely on manual operations, which are inefficient and require high technical skills from workers. To improve grafting efficiency and reduce labor intensity, there is an urgent need to develop automated or semi-automated grafting machinery. This type of equipment can not only reduce the use of pesticides and pesticide residues but also significantly increase economic benefits, with potential yields of 7-10 tons per acre, which is 2-3 times higher than the benefits of non-grafted planting[2]. In response to these backgrounds and needs, this project has designed a new type of Solanaceae grafting machine based on big data and deep learning, accelerating the process of smart agriculture and comprehensive mechanization in agriculture, bringing new hope for the development of the Solanaceae crop industry.*

Keywords: *solanaceous crops, grafting efficiency, expert system, mechanical structures, deep learning*

1. Introduction

The project team has designed a new grafting device that integrates seedling insertion, grafting, and cultivation tasks. Additionally, the system uses Baidu’ s intelligent cloud big data model for cloud-based expert system management. The device employs mechanical structures such as four-bar linkages, chucks, crank-slides, and incomplete gears to perform feeding and replanting functions. It also utilizes a negative pressure environment for the grafting process. Furthermore, the system incorporates a Raspberry Pi, robotic arms, and deep learning models to implement expert system functionality. This overall design optimizes the workflow, resulting in a compact, lightweight, and intelligent machine.

2. Properties

The project integrates the processes of seedling planting, grafting, and replanting, adopting a semi-automated working mode. The seedling planting module handles the rootstock and scion using a four-bar small mechanical structure, negative pressure port, horizontal push rod, and cutting knife. First, the rootstock seedling is clamped at the end of the cylinder push rod, and the rod is moved by inflating. The cutting tool performs both horizontal and vertical cuts to create an insertion point. The scion is drawn into the grafting tube by the four-bar mechanism. The grafting module uses a negative pressure system to insert the scion into the incision, with a duckbill-shaped guide plate limiting its position. An automatic grafting film bundler completes the binding, and the grafted seedlings are transported to the planting holes by a conveyor belt. The replanting module includes an upper and lower picking device, a rotary cutting soil digger, and a Ferris wheel-style mechanical claw. It automatically digs soil and places the grafted seedlings into the soil, and finally, the bottom plate compresses the soil to complete the replanting process.

2.1 Adhesive flexible gripper

After the workers place the scion seedlings into the notch, the chain in the notch performs a rotational movement, transporting the scions one by one to the picking device. The rotation frequency matches that of the picking device, enabling continuous operation. The picking structure consists of four linkages (Rod 1, Rod 2, Rod 3, and Rod 4) connected by two shafts, forming a closed structure. The system operates by utilizing the movement of the linkages, with Rods 1 and 4 transmitting the driving force, while Rods 2 and 3 are passive, coupling to achieve the required motion. The mechanism achieves combined linear and rotational periodic motion to pick and place the scion seedlings.

The original mechanical grasping is replaced with flexible adhesion. The airflow from the vacuum generator adjusts the amount and degree of liquid adsorption. Whenever the surface liquid level drops to a certain extent, negative pressure continues to supply liquid to ensure adequate adhesion fluid, as shown in Figure 1.

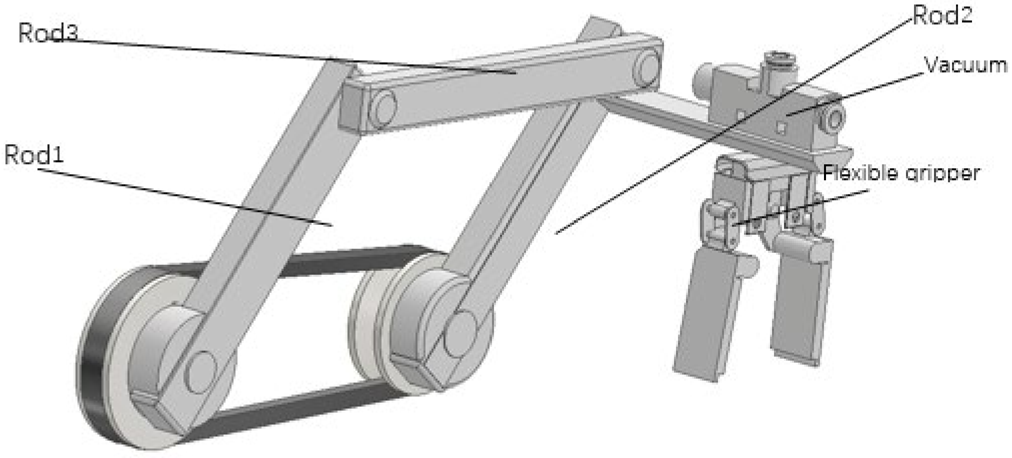

Fig. 1 Adhesive flexible gripper

2.2 Automatic cutting tool

The cylinder rod has a circular and groove-shaped baffle. The circular baffle secures the bottom of the seedling, while the groove baffle fixes the stem in horizontal motion. When the cylinder inflates, it drives the pushrod. An infrared sensor triggers the motor, activating the chuck structure. Cutting tools perform vertical and horizontal cuts. Six blunt conical knives fix the rootstock, and sharp conical knives make precise cuts. The process ensures automated, accurate cutting, with rootstock length maintained at 7-8 cm and slit width at 1-1.5 cm[1-3], offering better precision and speed than manual methods, as shown in Figure 2.

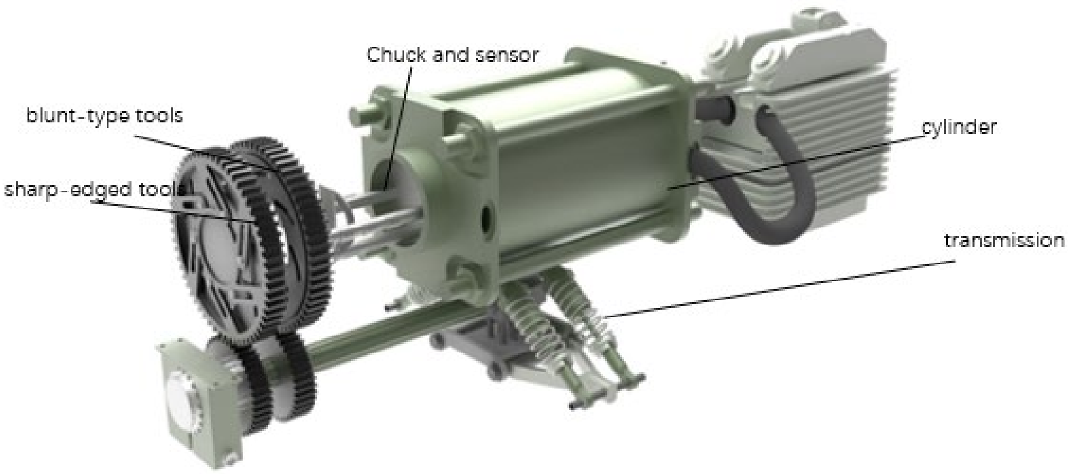

Fig. 2 Automatic cutting tool

2.3 Negative pressure grafting module

The electric suction system works through a collaboration of an electric fan, pipes, filtration devices, and a control system to create a negative pressure environment. The fan is responsible for drawing in air, reducing the internal air pressure, while the filter ensures clean air to prevent impurities from entering. The pipe system directs air from the fan to the suction inlet, and the control system adjusts the fan speed and negative pressure value through electronic modules to maintain stable suction. The system design also includes precise alignment of the suction inlet to ensure effective suction of objects or gases. It is widely used in automation, handling, and processing fields. The generated suction force evenly acts on the seedlings, allowing for effective grafting of rootstocks and scions, with a duck-bill-shaped baffle in the middle to guide and facilitate accurate grafting[4].

2.4 Adjustable Binding Machine

Through the four-bar feeding mechanism, negative pressure suction, and mechanical push rod action, the rootstock and scion are grafted together. Then, the binding rope is used to secure them, ensuring the scion's survival as the cells heal and fuse into a whole. The system utilizes the engagement of incomplete gears and complementary gears to achieve automatic wrapping. The spring pawl pushes the complementary peg up, opening the tape claw. After engagement, the claw closes and grabs the tape. The microcontroller controls the cylinder to prevent accidental opening. Counting and sensors ensure the tape is wrapped to the preset number of turns, ensuring wrapping precision and automation, as shown in Figure 3.

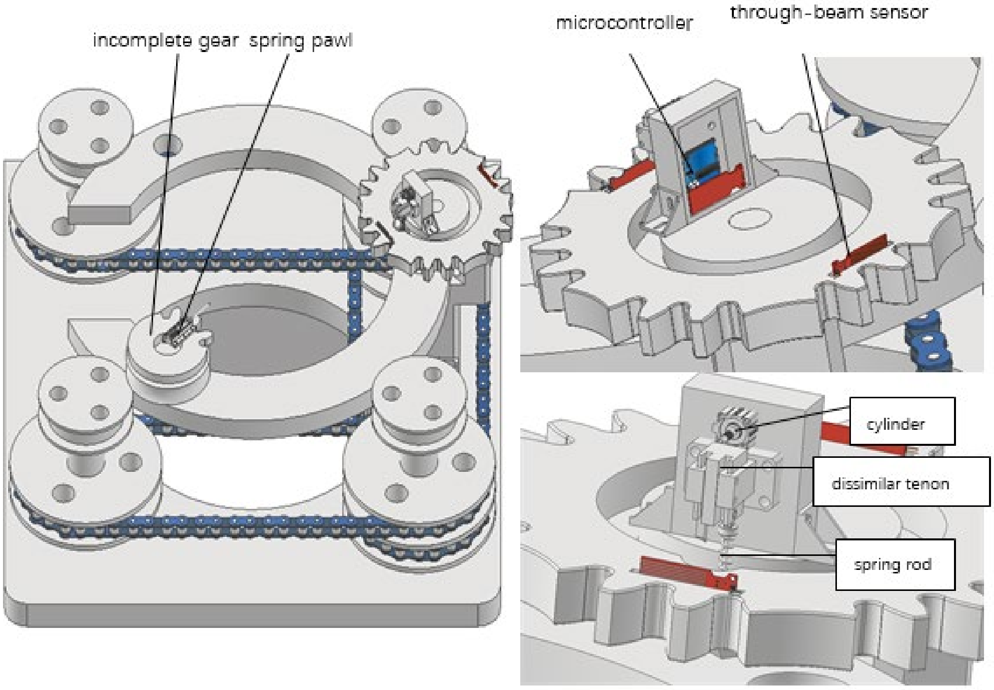

Fig. 3 Adjustable Binding Machine

2.5 Expert System

To address the labor shortage in real-time field management, this project designed a video transmission system based on UDP network communication, laying the foundation for a future expert system. The system displays real-time video streams and GPS positioning information of smart agricultural machinery on the host computer interface. Using UDP communication and a 5G server, it ensures low-latency, long-distance video transmission. The system also integrates a large database of pepper images, both healthy and diseased, and uses YOLOv5 for model training to detect diseased peppers. By analyzing these images and visualizing the data, farmers can quickly identify and treat plant diseases. Disease detection results are stored in a CSV file for real-time monitoring and management of crop conditions, as shown in Figure 4 and Figure 5.

Fig. 4 Training Results

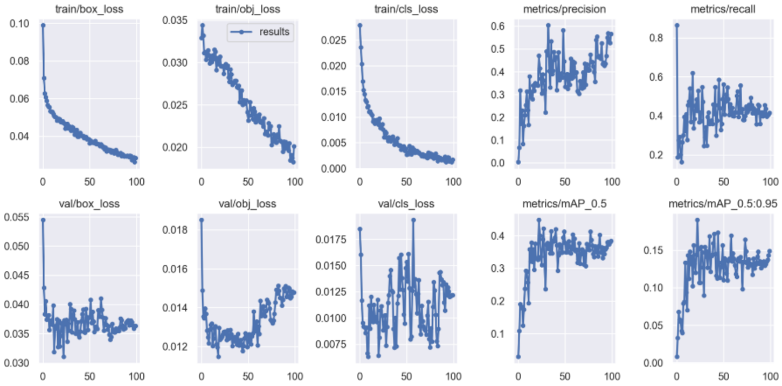

Fig. 5 Training Data

3. Feasibility Analysis

3.1 Mechanical analysis of cutting device

For the scion handling device, most of the existing methods for processing the rootstock are manual. The length of the rootstock after cutting and the depth of the grafting slot have strict requirements, that is, the grafting depth should be between 1.5cm and 2cm, and the remaining length should be between 5cm and 7cm. Manual methods are difficult to achieve precise cutting. To address these issues, an intelligent cutting device can achieve accurate results. The relevant data are as follows.

The calculation for the cutting force of the tool is as follows[5]:

$$F_1 = K_c \times A_e \times V_c \times t \times A_P \times c \tag{1}$$

In the formula:

- **F** is the cutting force, in N;
- **Kc** is the cutting force coefficient;
- **A_e** is the effective cutting edge length, in meters;
- **A_P** is the cutting area, in cm²;
- **V_c** is the cutting speed, in m/s;
- **t** is the cutting force coupling coefficient;
- **c** is the number of effective cutting edges.

From the data, the cutting force coefficient is 1.2, the effective cutting edge length is 5.6 cm, the cutting area is 5.2 cm², the cutting speed is 15 m/s, the cutting force coupling coefficient is 2.3, and the number of effective cutting blades is 6.

By calculation, the cutting force is approximately 72 N. Based on experimental data, the force required to cut rootstock seedlings with a diameter of 1 cm is between 50 N and 60 N, which adequately meets the required cutting force.

3.2 Negative pressure analysis

The analysis of negative pressure is as follows:

$$P = P_1 - P_2 \tag{2}$$

$$F' = S \times P \times f_1 \times \theta \tag{3}$$

In the formula:

- **P** represents the pressure difference created by the negative pressure environment, in pascals (Pa);
- $\mathbf{P_1}$ is the working environment pressure, in pascals (Pa);
- $\mathbf{P_2}$ is the negative pressure, in pascals (Pa);
- **F'** is the adsorption force provided by the negative pressure environment, in newtons (N);
- **S** is the pore size, in square meters (m²);
- $\mathbf{f_1}$ is the resistance coefficient;
- **θ** is the air flow system coefficient.

Based on the data, the pressure difference created in the negative pressure environment is 50,000 Pa, the pore size is 0.0025 m², the resistance coefficient is 0.48, and the flow system coefficient is 0.76. The attraction force of 30 N is sufficient to attract the scion seedlings.

Calculations show that the attraction force provided by the negative pressure environment is 45.6 N, which is sufficient for the attraction operation.

The efficiency of this device is 380 plants/hour, while the manual grafting efficiency is 100 plants/hour. Additionally, the grafting film applied mechanically is more uniform than manual grafting, resulting in a breakage rate of 3.6% for mechanical grafting, compared to 10.9% for manual grafting. Compared to manual grafting, the mechanical grafting improves both efficiency and the protection rate of the grafted plants.

4. Conclusion

This device has broad application prospects. In Solanaceae crops, grafting is often required to prevent pests and diseases, making this project highly versatile. By adjusting the relevant parameters of the device according to different planting conditions, it can meet the needs of various planting scenarios.

The new grafting machine can greatly improve the efficiency and quality of plant propagation. In the propagation process of fruit trees, vegetables, flowers, and other crops, the automatic grafting machine can replace manual grafting, thereby improving production efficiency. Moreover, the automatic grafting machine ensures the accuracy and success rate of grafting, ensuring that every step of the process is correctly executed. This is highly beneficial for large-scale agricultural and horticultural production, as it not only saves labor resources but also improves crop yield and quality, bringing better economic benefits to agricultural production.

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