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Development of automatic conveying system for vegetable seedlings

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Abstract

In order to improve the automation and reliability of the mechanized transplanting, a vegetable seedling automatic conveying system was designed. The functional execution component of the system consists of a tank-wheel storage seedling mechanism, a seedling tray conveyor, and a hanging cup circulating conveying mechanism. Combined with the communication technology between host computer and programmable logic controller (PLC), the user interface software of automatic conveying system for potted vegetable was developed by using Visual Studio to control and monitor the transmission progress. The PVDF pressure sensor was used to detect the pressure change of the seedling storage disk to obtain the information of the loading seedling tray. The limit switch and stroke switch were combined to obtain the information of the push rod and feed plate. The timing of each component is controlled by the PLC controller combined with the feedback information of each sensor. The test results show the effect of taking an individual seedling is excellent, the error rate of the pushing mechanism is about 2.08%, and the success rate was 97.91%.

Keywords: Vegetable seedling, Seedling conveying, PLC, Monitoring, Control, Design

1 Introduction

Vegetable bowl seedling automatic conveying is an important step in the realization of automatic vegetable transplanting technology [1, 2]; the key problem is how to convey seedlings orderly to planting institutions, including the exact supply of seedlings, seedling bowl individual removal, and orderly delivery and delivery operations [3–5]. All operations require a steady convergence of action and high efficiency, to ensure the delivery speed while avoiding the phenomenon of seedling saplings and leakage of seedlings to prevent subsequent planting operations, resulting in leakage planted and the survival rate decreased [6–8]. At present, the conveying process of most vegetable automatic transplanting machine seedlings rely on the mechanical structure of the transmission [9]. Meanwhile, they are in low degree of automation, reliability is not good, and the transmission process is prone to injury, leakage, and other problems.

In view of the problem of low automation and low reliability of vegetable seedlings in the process of vegetable transplanting machine operation, the related field personnel carried out research. Jin et al. designed a vegetable transplanting plug seedling automatic transmission device; the device reduced the transmission of vegetable seedling bowl failure rate and improved the delivery reliability [10]. Wang et al. designed a vegetable bowl seedling transplanter automatic potting and conveying device based on PLC, using of the top of the folder to take the seedling method to achieve the accurate launch and positioning of vegetable seedlings, effectively reducing the degree of loss of vegetable seedlings [11]. Yang et al. designed a seedling transplanter automatic transfer device based on the PLC vegetable and precise control of the motor speed to improve the accuracy of the vote during the delivery process [12]. Fan et al. designed a belt-type automatic seedling feeding mechanism with functions of detecting seedling row and transporting and feeding seedling, which reduced the seedling loss in the seedling feeding link [13]. In the existing researches, most researches are on the ways of taking seedling mechanisms. However, there have been few reports in the literature about the development of a fully automatic conveying

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and monitoring system for vegetable seedling conveying system.

In order to improve the operation quality of automatic transplanting machine and enhance the automation level and reliability for vegetable seedling delivery, a mechanical automatic transmission system of vegetable seedlings is designed in this paper. Mechanical transmission, sensor technology and PLC control technology, and the functions of monitoring and control technology were combined to develop a fully automated vegetable seedling conveying control software. The whole system can realize the exact supply of seedlings and individual seedling conveying function, which can provide technical support for the design of a fully automatic transplanter.

2 Methods/experimental

1. Based on sensors and PLC control technology, a vegetable seedling automatic conveying system was designed.
2. Based on the communication between the host computer and the PLC, integrated monitoring and control functions, using Visual Studio, developed a human-computer interaction software for the vegetable seedling automatic conveying system.
3. Monitor the transport status by CCD camera, through the PLC controller combined with the sensor feedback to control the various components of the implementation of timing.
4. The purpose of this experiment is to investigate the reliability of the feeding function of the automatic conveying system of vegetable seedling.

The remainder of this paper is organized as follows. Section 1 describes the overall design and system composition. Section 2 describes the functional design and implementation of the device. In Section 3, the experiment and analysis are introduced in detail and the experimental results are presented. Finally, Section 4 concludes the proposed work at the end of this paper.

3 Overall design and system composition

The vegetable seedling automatic conveying system consists of conveying mechanical structure part, automatic loading and unloading system, hanging cup-type cycle conveying system, and human-computer interaction control system.

3.1 Automatic conveying device design

As shown in Fig. 1, the automatic conveying device of potted vegetable seedling includes grooved wheeled seedling storage mechanism, push rod mechanism, limit sensor, missing tray detection sensor, seedling plate conveyor belt, seedling picking mechanism, potted seedling carrier, leak seedling detection sensor, and potted seedling delivery mechanism. The whole machine adopts a modular design. Aluminum profile is used to build the frame body, and the fastener is used to connect each module. The installation mode of each module is simple with compact layout, and the maintenance is convenient. The seedling storage module is designed with slot wheel type and has eight pairs of seedling storage plates. Each pair of seedling storage plate adopts the open-type design with the effective seedling storage quantity of three disks and is installed vertically in the front of the seedling tray conveyor belt. The potted vegetable seedling plate is pushed to the seedling tray conveyor belt through the push rod mechanism. The push rod mechanism adopts the ball screw slide block design, and the drive shaft of the lead screw is connected with the drive motor through the coupling. A finite position sensor is set up between the tray conveyor belt and the push rod mechanism to detect the movement of the

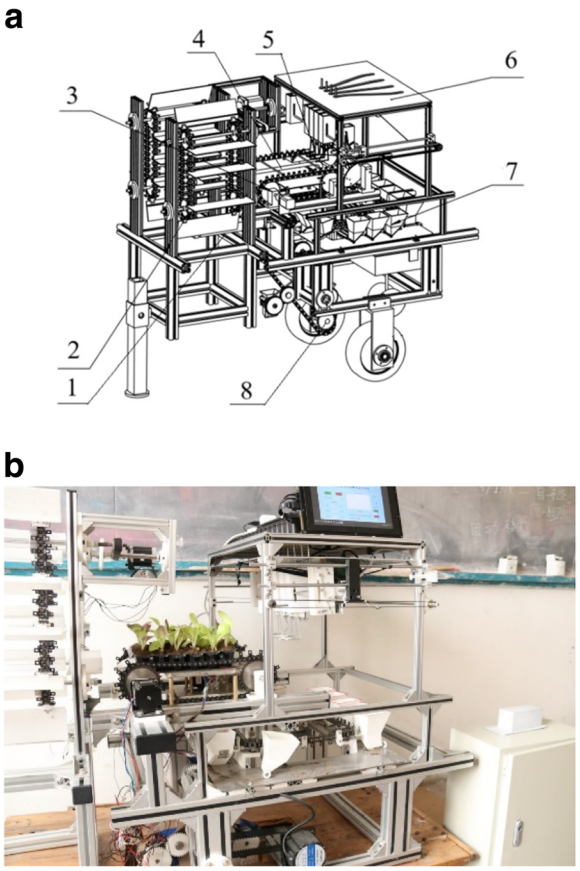

Fig. 1 Automatic conveying device for vegetable seedlings. **a** Structure diagram. 1 Pushing mechanism, 2 seedling storage plate, 3 seedling tray conveyor motor, 4 seedling tray conveyor belt, 5 bowl seedling ejection mechanism, 6 rowed clamp seedling-taking mechanism, 7 drive motor of cup conveying mechanism. **b** Diagram of device

push rod mechanism and to ensure the stability of the potted vegetable seedling tray from the seedling tray to the seedling plate conveyor belt. The conveyor belt of seedling tray adopts chain transmission, and a cylindrical steel column is arranged above the conveyor belt. The steel column is fastened on the chain by bolt nut, and the linkage is formed with the chain. The clearance of adjacent steel column is set to 8 cm (the gap can be adjusted). It is convenient to apply all kinds of seedling tray. When the device is working, the seedling tray was fixed with the conveyor with a steel column clip fit to the bottom clearance of the tray. The driving motor drives the sprocket to rotate, which drives the movement of the steel column and the seedling tray. A seedling-collecting mechanism is arranged up and down the seedling tray conveyor belt, and the potted seedling in the seedling tray is conveyed to the circulating conveying mechanism with hoisting cups by ejecting out and clamping the seedlings. The hanging cup-type circulating conveying mechanism is arranged at the tail end of the moving track of the seedling fetching claw, and the seedling picking claw finishes the delivery of the potted vegetable seedlings along the track movement. The cups in the conveying mechanism receive the potted vegetable seedlings and deliver the potted vegetable seedlings to the delivery mechanism along the preset track and complete the automatic extraction and transportation process of the potted vegetable seedlings from the seedling tray to the planting mechanism.

Key performance indicators of the automatic conveying system for potted vegetable seedlings are shown in Table 1.

3.2 System scheme and composition

The automatic conveying control system of vegetable bowl seedling consists of driving motor, sensor module, controller module, microcomputer, and system software (Fig. 2). The coprocessor and the main controller are used to complete the monitoring and control process of potted vegetable seedlings. The coprocessor converts the analog output signal of the sensor into the digital switch input to the main controller, which is convenient for the system to monitor the analog signal [14, 15]. The signal monitoring is stable and reliable, and the maintenance cost of the system is reduced. The main controller communicates with the microcomputer through the RS485 interface and displays the monitoring and control information in the interactive interface to realize the user interface. The system structure diagram is shown in Fig. 3.

Table 1 Key performance indicators of automatic conveying system for vegetable seedlings

Index	Value
Effective storage capacity of seedling tray	3
Number of potted seedlings for single ejection/number of seedlings taking	4
Adjustment range of needle opening and closing/mm	20–50
Speed seedling tray conveying (m min^{-1})	0.6–12
Capacity of conveying cup (strains/min)	30–120
Accuracy of positioning seedling tray/mm	±2
The number of conveying cup	16
Maximum volume of seedlings/cm^3	80

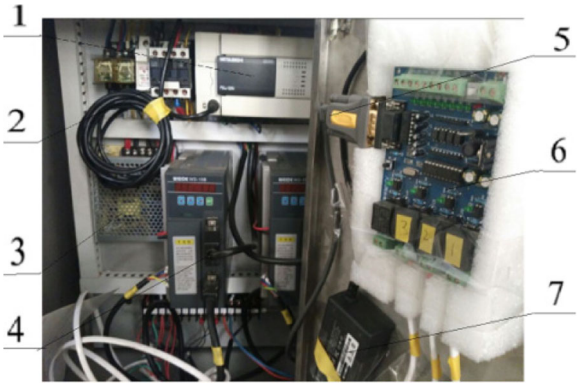

Fig. 2 System control cabinet. 1 PLC controller, 2 relay, 3 PLC power supply module, 4 Servo motor driver, 5 signal cable, 6 MCU, 7 MCU power supply

3.2.1 *Conveying control system*

The controller module is composed of coprocessor and main controller to monitor the analog signal and digital signal of the sensor and to control the operation of the motor. The coprocessor uses a series of Macro STC12C2052AD single-chip computers, including CPU SRAM and flash, 15 common I/O ports with 8-bit precision ADC. The speed of the ADC conversion is as high as 250 k/s. The controller module, as the primary processing module of the level signal, can send the processed level signal to the PLC master controller in the way of switch quantity. The main controller adopts the Japanese Mitsubishi PLC controller, FX3U-32M, 32 I/O input and output points; supports the RS485 interface; and meets the communication interface requirement of the whole system. The memory capacity of RAM is 64 kg/basic instruction and the processing speed is 0.065 μs. It supports the function of three-axis linkage positioning. The driving motor selected is Wade DS series servo motor. The specific model is 60ST-M00630, and the model of the servo driver is the Wade WD-15B020A driver. According to the working steps of the conveying system, the automatic conveying system of vegetable bowl and seedling needs to control the continuous coordination of three motors, and the controller can meet the control requirements. The monitoring data of all kinds of sensors are transmitted through I/O to

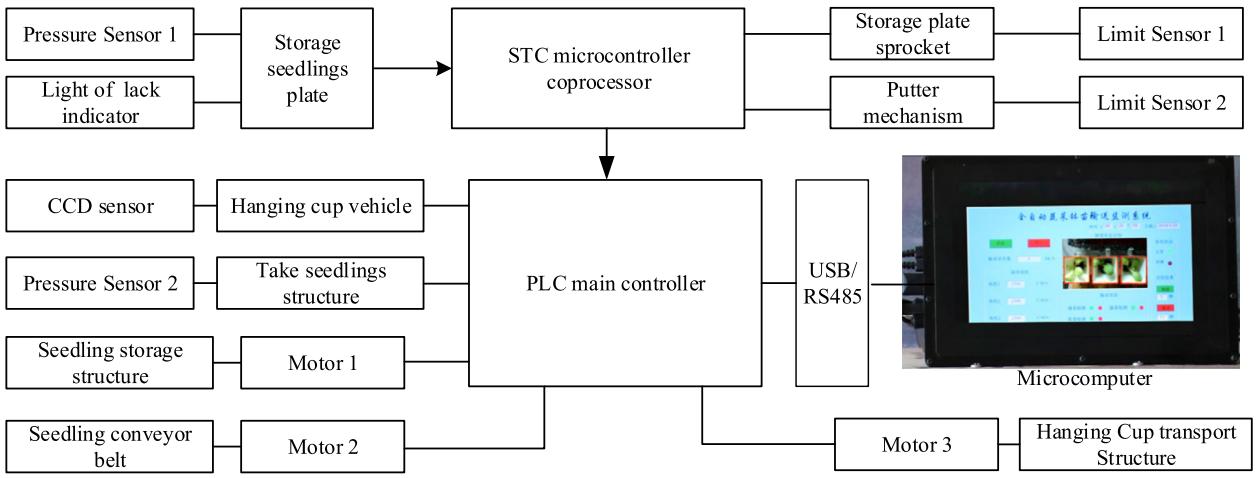

Fig. 3 Structure diagram of automatic conveying system for potted vegetable seedlings

the main controller of PLC, and the PLC controller communicates with the microcomputer through the RS485 interface to realize the function of system monitoring and man-machine interaction [16]. The control cabinet installation diagram is shown in Fig. 2.

3.2.2 Monitoring system of conveying

The conveying monitoring module comprises a seedling storage monitoring module, a seedling taking monitoring module, and a cup-type circulating conveying monitoring module. The monitoring module includes a pressure sensor and a lack of seedling indicator light. A PVDF pressure sensor (response time < 1 ms, response point < 200 g, range 0–50 kg) was arranged on the slot-wheeled seedling storage tray and used to detect whether there is a potted vegetable seedling tray waiting to be delivered. According to the change of the pressure signal, the controller directs the motor to drive the sprocket wheel of the storage plate and carries out the transfer of the seedling plate. By setting a stroke switch on the sprocket conveyor belt, the position of the seedling tray conveying is detected, and the push rod mechanism is triggered to perform the pushing action, and the seedling tray is moved from the seedling storage mechanism to the seedling tray conveyor belt. A finite position sensor is arranged at the junction between the conveyor belt of the seedling tray and the push rod mechanism. When it is detected that the seedling tray enters the conveyor belt from the storage mechanism, the signal is sent to the controller to stop the pushing action. The stability of the conveying action is ensured. The abnormal extraction of seedling was obtained by detecting the pressure change of the seedling pushing mechanism by pressure sensor. The potted vegetable seedling is taken out from the seedling tray and conveyed to the conveying mechanism. The CCD camera is arranged above the conveying track of the cup to monitor the leakage and load status of the potted vegetable seedling in the cups and to obtain the conveying information.

4 Functional design and implementation

4.1 Automatic loading and unloading functions

The automatic loading and unloading functions of the system mainly depend on the grooved wheeled seedling storage mechanism, the seedling tray conveyor belt, and the push rod mechanism to realize the process of conveying the vegetable seedling tray in the seedling storage mechanism into the conveyor belt. The composition of the organization is shown in Fig. 4. Through the sensor set on the mechanism to monitor the related mechanism action signal, the feedback was sent to the controller. The controller processed the signal and sent the results to the user interface. At the same time, the controller guides the timing of each driving mechanism, drives the motor to perform the action, and completes the loading and unloading steps.

4.1.1 Loading and unloading monitoring

The loading and unloading detection system mainly detects the position change of the seedling plate from the seedling storage mechanism to the seedling plate conveyor belt and obtains the position signal as the action control signal of loading and unloading. The system includes PVDF pressure sensor, travel switch, limit sensor, and a single lamp. The PVDF pressure sensor is arranged in the middle of the slot wheel-type seedling storage tray and is in the same vertical plane with the push rod mechanism, which is used to detect whether the seedling storage tray is empty or not. It also lights the single lamp and instructs the start of the sprocket drive motor. The stroke switch mainly detects the displacement of the sprocket drive of the seedling storage

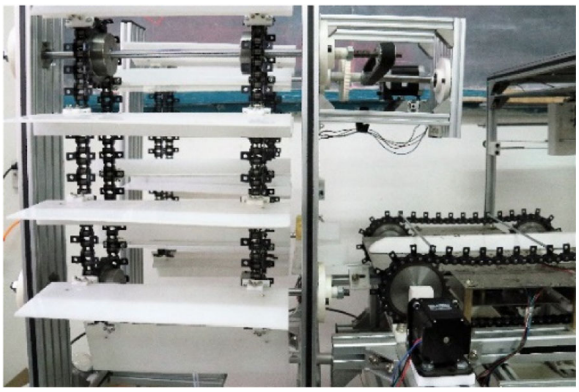

Fig. 4 Automatic loading and unloading system

tray and determines whether the seedling storage tray reaches the feeding position. Its signal is used to instruct the push rod mechanism to push the seedling tray to the conveyor belt. The limit sensor is installed at the starting position of the conveyor belt, and its signal is used to control the reset action of the pushing mechanism.

4.1.2 Loading and unloading action control

According to the signal indication of the loading and unloading system, the controller completes the transport of the seedling storage tray, the pushing action by the push rod, and receiving action by the conveyor belt. A series of operations from the seedling storage mechanism to seedling tray conveyor belt is completed. The loading and unloading control sequence is shown in Fig. 5. When the PVDF pressure sensor detects that the seedling disk mechanism is not stored, the controller lights up the single lamp and prompts the packing plate. When the seedling tray is placed on the seedling storage mechanism, the PVDF pressure sensor is triggered, and the sprocket wheel drives the motor operation. The seedling tray is conveyed to the top of the push rod mechanism to trigger the stroke switch, and the push rod mechanism drives the motor operation. The seedling tray is pushed to the conveyor belt to trigger the limit switch. The push rod mechanism drives the motor in reverse direction to perform the reset action and waits for the next seedling disk push action command.

4.2 Hanging cup-type cycle conveying system

The hoisting cup-type circulation transportation system is composed of the executive mechanism and the monitoring module. The executive mechanism includes a seedling plate guiding mechanism, a lifting combination mechanism, a lifting cup conveying vehicle, and a driving motor. The monitoring module includes CCD sensors and pressure sensors. The hoist circulating conveying mechanism is shown in Fig. 6.

4.2.1 Seedling conveying monitoring

The detection of seedling transportation mainly includes the detection of the position of the sampling seedling, the detection of the conveying status, the acquisition of the position and the state information, and the provision of indication signals for the control of the conveying action. The pressure change during the seedling pushing is detected by the pressure sensor to detect whether the pushing action is executing normally. It is used to prevent the positioning error caused by the conveyer belt and damage of the potted seedlings during the pushing. The potted vegetable seedling was put into the conveying cup after the pushing operation was completed, and the transportation state information was obtained by the CCD camera set above the cup conveying mechanism.

4.2.2 Conveying movement control

The main conveying action is to move the individual seedlings from the seedling tray and put them into the cup in the transportation mechanism. The potted vegetable seedlings will be conveyed to the delivery position to complete the individual transportation. The control flow chart is shown in Fig. 7. When the pressure sensor detects the picking action, the signal is transmitted to

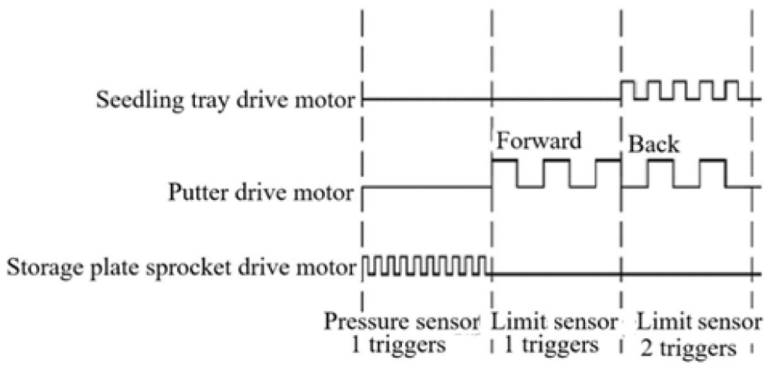

Fig. 5 Timing diagram of loading and unloading control

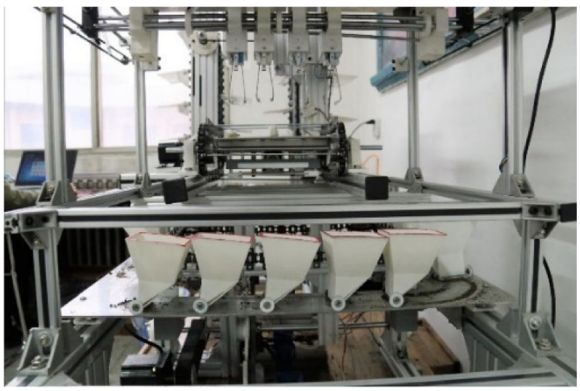

Fig. 6 Hanging cup circulation system

the controller to judge whether it is abnormal or not, and the controller instructs the seeding claw to take and throw the seedling. The conveying information is obtained by CCD camera, and the image information is processed by the controller to judge whether the seedling missed or not [17] and indicates the circulation transportation to act.

4.3 User interface design

The user interface of the automatic conveying system of potted vegetable seedlings includes the functions of state monitoring, identification of transportation status, setting of transportation parameters, system control, and fault alarm. They were implemented through the microcomputer and software.

4.3.1 Microcomputer terminal

Microcomputer is the hardware base for user interface. A microcomputer with integrated monitoring and industrial control functions has been developed for the system for automatic control of vegetable seedling transportation. The computer is equipped with L-GS530QC industrial touch screen and Intel four-generation i3 processor with 32 G solid-state hard disk. It has a 00RLT8111C 10/100/1000 Mb/s network interface that supports multiple device interfaces such as VGAB 3.0 RS232/485. The running state data of the conveying system monitored by PLC controller can be connected with the host computer (microcomputer) through a serial port [18–20].The monitoring of loading and unloading operations, the display of system running speed, the video monitoring of transmission status, and the recognition of missed seedlings are realized, and the relevant working data are stored in the disk. The operating system is Microsoft WIN 7, which supports VB development environment. The whole machine is easy to operate and has a rich configuration. It can meet the requirements of the connection with the PLC controller.

4.3.2 Software design

The system software includes sensor data collection and display, working state display, transmission speed setting, transportation status identification, data storage and serial port setting, and other functional modules. The software is written with Visual Studio software and OpenCV function library [21]. The software interface is shown in Fig. 8. Through the start/stop button on the software interface panel, the system works or stops. By inputting the speed parameter, the control subprogram sends the instructions to the I/O port of the PLC controller through the serial port. The control command is sent by PLC to the hardware of the executer (including drive motor of the storage mechanism, the driving

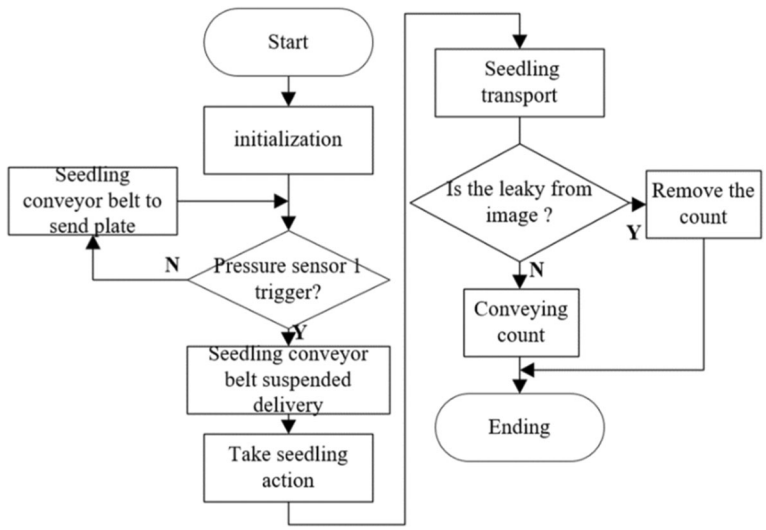

Fig. 7 Flow chart of conveying control

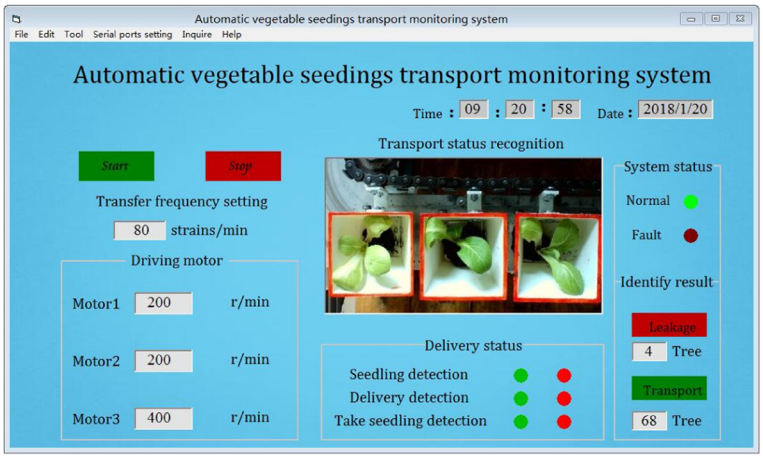

Fig. 8 Software interface of monitoring system

motor of seedling tray conveyor, and the drive motor in transportation mechanism), to control the working state. After the sensor monitoring data is processed by the PLC module, the information is transmitted to the system software data interface through the RS485 communication protocol, and the status information is displayed on the software interface.

5 Experiment and analysis

In order to verify the stability and monitoring reliability of the designed automatic conveying system for potted vegetable seedling, an experiment was carried out in the Agricultural Information Laboratory of Henan University of Science and Technology in 20 January 2018. The experiment setup is shown in Fig. 9.

5.1 Test of seedling automatic conveying

The purpose of this experiment is to investigate the reliability of the feeding function of the automatic conveying system of vegetable seedling. The whole machine transportation includes seedling tray loading and unloading and transportation of individual potted vegetable seedling. After repeated operation of the vegetable bowl seedling transportation system, it happened that the seedling may be damaged during the pushing action or be dropped during the placing action. Therefore, this experiment investigated the individual delivery process in the transportation system to evaluate the reliability of the conveying function. The successful ejection of the seedling was taken as the test index, and the error rates of the seedling transportation and the seedling pushing were investigated. The successful rate was investigated by successfully placing the seedling into the cup-type conveying vehicle. The test material was cabbage seedling, and variety is Shanghai green. The size of the seedling tray is 3.5 cm × 2.8 cm × 4 cm, length × width × height, with 32 rectangle holes. The conveying speed of the system is set at 80/min. The opening and closing range of the seedling clip was 30 mm (minimum when closing) to 40 mm (maximum when opening). Six groups of experiments were carried out. The number of successful seedling pushings was recorded, and the accuracy of seedling pushing and placing was analyzed. The experimental results are as shown in Table 2. It can be seen from Table 2 that the average error rate of seedling pushing is 2.08%, and the average success rate of seedling placing is 97.91%.

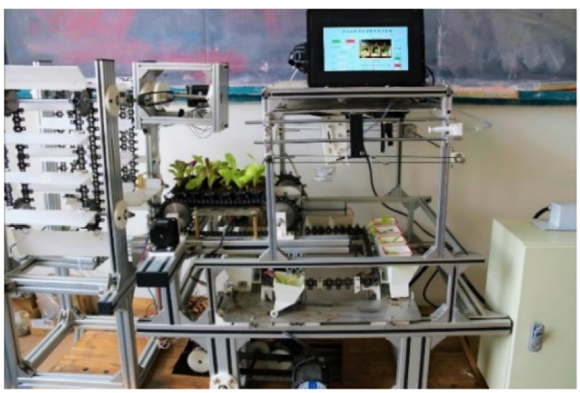

Fig. 9 Experiment of vegetable seedling conveying

6 Discussion

Through the observation of the test process, it is found that the reason for the breakage of the seedling ejection in the bowl is that the contact area between the push rod mechanism and the bowl seedling tray is too small. The uneven force the seedling plate bears in the process of transporting the pushing disk leads to a certain degree of inclination on the conveyor belt, which affects the positioning accuracy of the seedling during the process of

Table 2 Results of vegetable seedling placing

Test number	Number of damage	Numbers of successful placing	Error rate of pushing (%)	Success rate of placing (%)
1	0	32	0	100
2	0	30	0	93.75
3	1	31	3.12	96.87
4	0	32	0	100
5	2	32	6.25	100
6	1	31	3.12	96.87

ejection. It can be considered to increase the effective contact area between the push rod and the seedling plate and to improve the stability of the pushing process to reduce the breakage rate of pushing seedlings. The reason of the failure seedling dropping is that the contact area between the grafted claw and the bowl seedling is too small, which leads to large clamping pressure, resulting in the collapse of the pot and dropping failure. Therefore, the seedling claw should be designed according to the characteristics of the substrate. The clamping force is matched with the mechanical characteristics of the seedling, which can increase the success rate of seedling feeding and impugn and rove the conveying efficiency.

7 Conclusions

(1) An automatic conveying system for vegetable seedling is designed. The system functional execution component consists of a tank-wheel storage seedling mechanism, a seedling plate conveyor belt, and a hanging cup-type circulating transport mechanism. The sensor is used in combination with PLC control technology. Combined with the communication technology between host computer and PLC, the user interface software of automatic vegetable seedling conveying system was developed by using Visual Studio. The software system integrated the monitoring and control function of transportation status. Monitor the transport status by the CCD camera through the PLC controller combined with the sensor feedback to control the various components of the implementation of timing. The device can complete the automatic transfer process of potted vegetable seedlings according to the user instructions.

(2) The test results show that the system can realize the automatic conveying function for potted vegetable seedlings. The seedling tray transport is stable, and the supply is timely. The averaged error rate of pushing seedling was 2.08%, and the averaged success rate of seedling throwing was 97.91%. It can provide technical support for the design of automatic transplanting machine for vegetables.

Abbreviations

ADC: Analog to digital converter; CCD: Charge-coupled device; CPU: Central processing unit; I/O: Input/output; MCU: Microcontroller unit; PLC: Programmable logic controller; PVDF: Polyvinylidene fluoride; RAM: Random access memory

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Authors' contributions

JX, LD, and PJ were responsible for the mechanical design, installation, and commissioning of the device. LM, WJ, and PL were responsible for the design and implementation of the device control system, as well as the test work. JJ was responsible for the data check and manuscript review work. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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