Design and experiment of intelligent sorting and transplanting system for healthy vegetable seedlings

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Abstract: Healthy vegetable seedlings are surviving seedlings with good biological characteristics. Selective planting of healthy seedlings in the mechanized transplanting process can effectively avoid the reduction in yield caused by missed planting. Aiming at the current transplanting machinery that cannot achieve the selective planting of healthy seedlings, a healthy seedling intelligent sorting and transplanting system was proposed. The system consisted of a seedling delivery mechanism, sorting mechanism, photoelectric sensor, image sensor, PLC control system, and computer control system. It can realize automatic transmission of seedling trays, automatically identify the information of healthy seedlings in the trays and selectively transplant them. Also it can reduce the missed planting rate caused by the poor quality of plug seedlings after planting and the lack of seedlings in the hole. A sorting test of plug seedlings was carried out for the age-appropriate pepper plug seedlings cultivated in the factory. The results showed that the system had an average recognition accuracy rate of 89.14% and an average sorting success rate of 93.20% in the process of sorting suitable age pepper plug seedlings. The whole system can identify, sort and transplant the plug seedlings of appropriate age according to healthy information, and effectively avoid missing planting. This research can provide technical support for the intelligent upgrade of transplanting equipment.

Keywords: intelligent agriculture, sorting and transplanting system, healthy vegetable seedling, design, experiment, image, sensor

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1 Introduction

The missing planting in the transplanting of plug seedlings is the main factor causing the yield reduction[1]. There are two main reasons for missed planting: 1) There are holes and lack of seedlings in the plug seedlings cultivated in the factory, and the subsequent mechanical transplanting process cannot identify and avoid the holes and missed plants[2]; 2) Poor quality plug seedlings are produced due to diseases and transportation damage, and the occurrence of diseases and dead seedlings after transplantation causes missed planting[3]. At present, the problem of missing planting mainly relies on manual inspection and timely replenishment of seedlings, but this method is easy to damages the growth consistency of transplanted seedlings and causes subsequent mechanized production problems[4-6]. Limited by the cost of factory seedlings, the factory seedlings are directly transplanted by transplanter after leaving the factory, and the cavities and diseased seedlings cannot be removed by transplanter. Therefore, in the process of mechanized transplanting, it is necessary to improve the intelligent level of transplanting equipment, independently identify and select healthy seedlings for transplanting, avoid the problem of missing planting, and improve the quality of transplanting[7-11].

With the rapid development of modern agricultural technology, the intelligentization of transplanting plug seedlings has attracted more and more attention[12-14]. The feature recognition and selective transplanting of plug seedlings have become a research hotspot. Some scholars have simplified the visualization model to improve recognition accuracy. Combining computer vision algorithms and color features to cultivate, identify and detect plug seedlings[15-19]. For example, Rahul et al.[20] designed a four Degree of freedom (DOF) parallel robot arm, which was used to grasp the pot seedlings. The dual-core function of MCU was used to solve the kinematics equation, which improves the operation speed. The period of picking and dropping seedlings was 3.5 s, which improved the efficiency of transplanting. Khadatkar et al.[21] developed a set of automatic seedling picking end-effector based on machine vision technology, which could position seedlings through vision and improve the grasping accuracy and speed of the end-effector. Samiei et al.[22] used a deep learning algorithm to analyze the characteristics of seedling emergence and early development, providing a complete image processing and machine learning method for the image monitoring of early seedlings. Fabiyi et al.[23] used RGB image to extract the appearance features of rice seeds, and fused the spectral data to establish the quality classification algorithm of rice seeds, which could effectively remove the poor-quality seeds. Liu et al.[24] used the color characteristics of vegetable seedlings to propose a rapid

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plant seedling identification method based on machine vision, which could quickly and accurately identify seedlings from a complex soil background; Jiang et al.[25] proposed a machine vision system that detects the growth status of vegetable seedlings during the process of moving seedlings. The watershed algorithm based on morphology was used to segment the edge of the vegetable seedlings and extract each hole. The leaf area and leaf perimeter of the seedlings were used as the judging unit to determine whether it is suitable for transplanting; Yang et al.[26] used monocular vision to comprehensively evaluate the suitability information of the transplanted pot seedlings, such as the erection and height, and screened the pot seedlings that meet the requirements of transplanting. The visual detection algorithm designed was between the results of manual measurement. The deviation rate was 6.67%, and the response time was 0.35 s, which met the needs of real-time screening of pot seedling transplanters; Sun et al.[27] established a multi-scale feature fusion convolutional neural network recognition model using the combination of hole convolution and global pooling. Provide a theoretical basis for the exploration of weed identification under complex field backgrounds and the development of weed and seedling identification devices; Zhang et al.[28] took the color image of pepper seedlings as samples, and used machine vision technology to extract the diameter features of the seedlings. Using Harris corner detection algorithm combined with the weighted least squares method to fit the key points. Line comprehensive evaluation of the verticality and height of pepper seedlings to select pepper seedlings that meet the transplanting requirements to improve the survival rate of seedlings after transplantation; Huang et al.[29] developed an image processing algorithm through segmentation and classification of the components of phalaenopsis tissue culture seedlings (PTCP). First, the skeleton node of the plant was used to generate the cutting line. Secondly, the Bayesian classifier based on the combination of color and shape was used to classify each section of the plant into leaf or root sections. Finally, the root segment with the highest decision value was selected based on Bayes' theorem, and the midpoint of its skeleton was designated as a suitable grab point for automatic transplantation. In this way, the operation of automatic transplanting was realized, and the test results showed that the image processing algorithm can realize automatic machine vision transplantation of small plants.

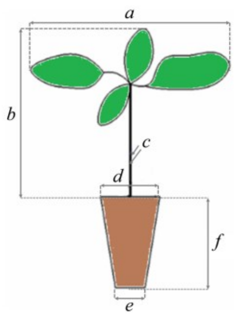
In order to improve the intelligence of transplanting equipment, and avoid the problem of missing seedlings caused by lack of seedlings and dead seedlings after planting, the idea of intelligent sorting and transplanting system for healthy vegetable seedlings was put forward, and the sorting and transplanting mechanism and a healthy seedling identification system were developed for transplanting equipment. The selection and transplanting of healthy vegetable seedlings refer to the selective planting of plug seedlings cultivated in the factory during the transplanting process, effectively avoiding the transplanting of poor-quality plug seedlings due to seedling shortage, disease and transportation damage. Combining mechanical design, photoelectric sensor, image recognition, PLC control and computer programming technology, the intelligent sorting and transplanting system for healthy vegetable seedlings was designed, which can identify the health information of plug seedlings, and sort out the lack of seedling holes and poor-quality seedlings. The system obtains the image information of the plug seedlings through a CCD camera, and combines the photoelectric sensor on the conveying mechanism to position and transport the plugs. The healthy information recognized by the plug seedling image is sent to the PLC control system to guide the seedling manipulator to selectively transplant, so as to achieve the purpose of robust seedling sorting and transplanting.

2 Materials and methods

2.1 Overall structure and principle design

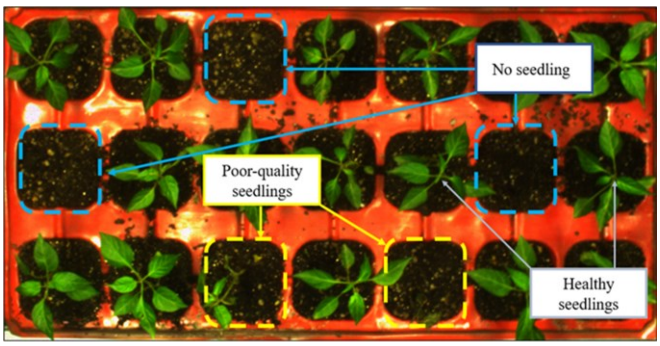
2.1.1 System operation object

Pepper as an economic crop has edible and medicinal value and is widely planted in China. Therefore, this study selected Pepper Plug Seedlings as the system operation object and designed a healthy seedling sorting and transplanting system. 601 type pepper seedlings were selected to cultivate pot seedlings, the plug tray size of factory seedling usually includes 21, 50, 72, and 128 holes, among which the seedling tray size of 21 holes has wider seedling spacing and less leaf crossing, which is conducive to image detection. Therefore, the 21-hole seedling tray was selected to cultivate pepper seedlings, and the three were uniformly mixed according to the volume ratio of 3:1:1. And then put the plug tray after sowing into the automatic seedling incubator to control the temperature, humidity, and light. When the seedlings reach the age-appropriate transplanting requirements (the seedling age was 35-45 d). At this time, the seedlings are 4-6 leaves. As shown in Figure 1a. Due to the biological differences between individual seedlings, there are three conditions for individual seedlings in the same batch of plug seedlings: 1) The lack of seedling holes due to ungerminated seeds; 2) After the seed emerges, seedlings with poor resistance to stress, diseased seedlings, dead seedlings, and other poor quality seedlings are produced; 3) There are more healthy seedlings that can be transplanted. The pepper plug seedlings to be transplanted under factory cultivation conditions are shown in Figure 1b.



Note: *a* is the width of a seeding, mm; *b* is the height of a seeding, mm; *c* is the stem diameter of a seeding, mm; *d* is the top of bowl width, mm; *e* is the bottom of bowl width, mm; *f* is the bowl height, mm.

a. Morphology of potted seedlings



b. Seedlings under factory cultivation conditions

Figure 1 Different characteristics of pepper seedlings transplanted at appropriate ages

2.1.2 Analysis of individual biological differences of plug seedlings

The differences between individual organisms of plug seedlings cause the different quality of pot seedlings to be transplanted in the same plug. The mature seedlings after germination are prone to appear healthy seedlings and poor-quality seedlings, and there is no seedling hole at the same time, as shown in Figure 1b. At present, the distinction between healthy seedlings and poor-quality seedlings is mainly made by manually distinguishing their individual appearance, size and growth status. In order to establish the criteria for distinguishing healthy seedlings and poor-quality seedlings, an individual difference test of plug seedlings was carried out. Because the growth form of seedlings is affected by the age of seedlings, therefore, the judgment basis of different seedling ages should be established when judging healthy seedlings and poor-quality seedlings according to individual morphology.

Test object and method: The test objects used pepper plug seedlings under the cultivation conditions in Section 2.1.1 (the seedling age was 35 d, 40 d and 45 d), the test instrument is a vernier caliper with an accuracy of 0.01 mm. The appearance parameters of the artificially identified healthy seedlings and poor-quality seedlings are counted, mainly including the information of seedling width, seedling height and stem diameter. The statistical results of individual biological differences of pepper plug seedlings are shown in Table 1.

Table 1 Individual biological differences of pepper plug seedlings

Seedling age/d	Parameters	Healthy seedlings					Poor-quality seedlings				
		Max value	Min value	Average value	Standard deviation	Coefficient of variation/%	Max value	Min value	Average value	Standard deviation	Coefficient of variation/%
35	Width/mm	85.41	78.26	80.37	3.98	4.95	60.01	51.35	56.48	4.41	7.80
	Height/mm	111.72	105.21	107.54	3.20	2.97	84.34	75.56	78.39	4.08	5.20
	Stem diameter/mm	2.130	2.070	2.090	0.031	1.483	1.890	1.820	1.840	0.035	1.902
40	Width/mm	93.14	86.50	91.04	3.07	3.37	72.99	55.74	61.32	8.50	13.86
	Height/mm	131.59	112.46	123.35	9.51	7.70	92.31	86.17	89.43	3.07	3.43
	Stem diameter/mm	2.310	2.200	2.260	0.045	1.991	1.940	1.860	1.900	0.033	1.736
45	Width/mm	107.53	99.84	102.12	3.39	3.31	86.52	60.38	70.15	12.22	17.41
	Height/mm	138.61	121.37	130.83	8.72	6.66	101.02	93.51	96.29	3.60	3.73
	Stem diameter/mm	2.390	2.280	2.310	0.060	2.597	2.010	1.910	1.950	0.048	2.461

It can be seen from Table 1 that under the condition of 35 d seedling age, the coefficient of variation of seedling width of the healthy seedling is greater than that of seedling height, the results showed that the seedling width of healthy seedlings was different, the seedling height difference was small, the seedling width difference of poor-quality seedlings was more obvious than that of seedling height, and the difference of stem diameter was small; At 40 d and 45 d of seedling age, the variation coefficient of the seedling height of healthy seedlings was significantly greater than that of seedling width and stem diameter, which indicated that the difference of seedling height of healthy seedlings was more obvious than that of seedling width and stem diameter, in poor-quality seedlings, the variation coefficient of seedling width was significantly greater than that of seedling height and stem diameter, indicate that the difference of seedling width was significant.

From the above analysis, it can be seen that the difference in seedling height of healthy seedlings is more significant than that of seedling width, and the distribution of seedling width is relatively uniform. While the difference in seedling width of poor-quality seedlings is more significant, and the distribution of seedling height is relatively uniform. The characteristic parameters of seedling width and height of healthy seedlings are usually higher than those of poor-quality seedlings, and the difference in seedling width is significant in poor-quality seedlings. The characteristics of typical healthy seedlings and poor-quality seedlings are shown in Figure 2. Therefore, seedling width (i.e., leaf stretch area) is the most important factor for the plug seedlings classified by machine vision.

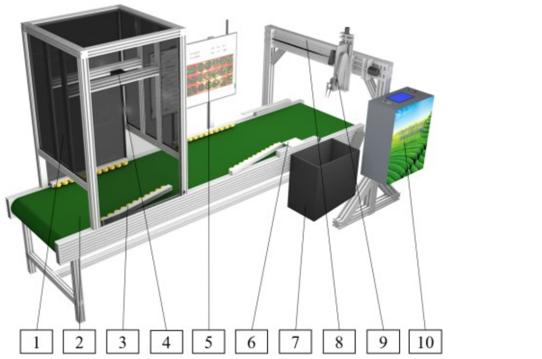
Figure 2 Characteristics of healthy seedlings and poor-quality seedlings

2.1.3 Overall design of transplanting device

The intelligent sorting and transplanting device for healthy vegetable seedlings mainly consists of a plug seedling conveying unit, a visual inspection unit, and a sorting and transplanting unit. The whole set of devices adopts modular installation and coordination, with a reasonable layout and compact structure, as shown in Figure 3. The plug seedling conveying unit mainly transported the plug seedlings. It was powered by a stepping motor to send the plug seedlings to the visual inspection unit and the sorting and transplanting unit at a fixed point. Each complete seedling transport includes two stop times to complete the sorting and transplanting actions. The visual inspection unit mainly acquires image information such as the biological characteristics and appearance size of the seedlings in the plug. It consists of a light box, a fill light, a camera, an industrial computer, and a support frame. The camera is installed on the support frame in the light box, and the viewing angle is perpendicular to the conveyor belt to ensure that the image information of the plug seedlings collected within the field of view is accurate and effective. The sorting and transplanting unit mainly sorts and transplants the individual identification and detection results of the pot seedlings in the plug seedlings. It is composed of a gantry mechanism, a cross slide, and an End-effector. The end-effector is installed vertically at the lower end of the cross slide, which can increase the Z-axis operation space of the End-effector. The cross slide and the gantry slide rail can realize the movement of the X-axis. The conveyor belt can be controlled according to the hole size to realize the relative movement of the Y-axis. The sorting and transplanting unit can realize XYZ three-way positioning adjustment, and with the visual recognition unit, it can effectively carry out the sorting and transplanting of plug seedlings.

2.1.4 System working principle

The working principle of intelligent sorting and transplanting system for healthy vegetables is shown in Figure 4. It uses PLC control technology, computer communication technology combined with the functions of the plug seedling conveying unit, visual inspection unit, sorting and transplanting unit to complete the intelligent sorting and transplanting work of plug seedlings.



1. Light box 2. Plug seedling conveying unit 3. Limiter 4. camera 5. Industrial computer 6. photoelectric sensor 7. Poor-quality seedling recovery box 8. Gantry slide rail 9. End-effector 10. PLC control cabinet

a. Structure design

b. Whole machine

Figure 3 Intelligent sorting and transplanting device for healthy vegetable seedlings

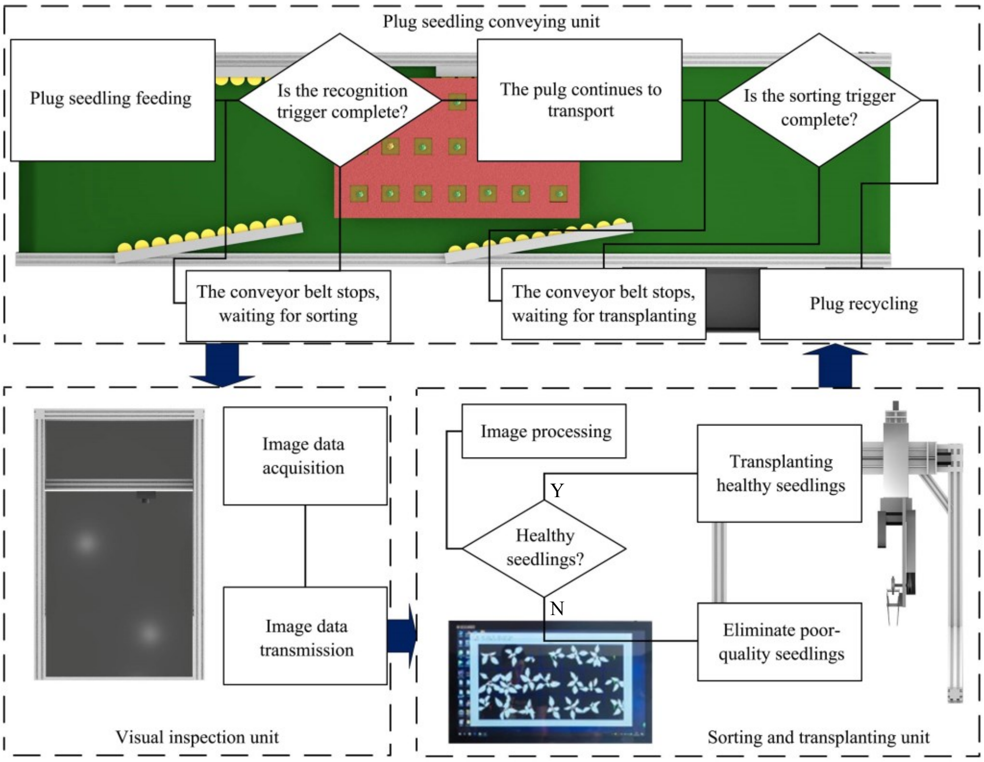


Figure 4 Intelligent sorting and transplanting system working principles

The operation of plug seedling sorting and transplanting mainly includes three parts: 1) The conveying and positioning of plug seedlings, which are mainly completed by conveyor belt mechanism and photoelectric sensor system; 2) The health information detection and classification of plug seedlings, which are mainly completed by the visual detection unit and computer system; 3) The transplanting of healthy seedlings and the elimination of poor-quality seedlings, which are mainly completed by the sorting mechanism and the end effector. The plug seedling conveying unit transported the seedlings tray by means of stepping motor and chain transmission. In order to extract the individual information of seedling with the visual detection unit, the photoelectric sensor installed on the conveyor belt provides the trigger signal for the movement control of the conveyor belt, when the plug seedling was transported to the vision detection unit, the photoelectric sensor was triggered to detect the vision acquisition position. When it reached the acquisition position, the conveyor belt stopped running for 1 s, and the vision detection unit was instructed to collect the image information of the plug seedling. After the visual detection unit completed the detection, the image information of plug seedlings was transmitted to the industrial control computer, and the industrial control computer carried out the image processing operation to identify the individual state of plug seedlings, and selected the healthy seedlings, poor-quality seedlings and no seedling holes. After identifying and locating the holes of poor-quality seedlings and the hole of no seedling, the conveyor belt continued to transport the plug seedlings to the sorting and transplanting position, triggered the photoelectric sensor to detect the sorting position, and the PLC controller controlled the End-effector to complete the sorting and transplanting.

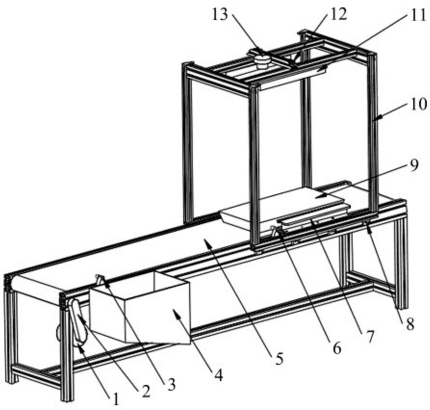
3 Key function design

3.1 Plug seedling sorting mechanism

The plug seedling sorting mechanism is mainly responsible for the position movement of the plug seedlings, which facilitates the detection and sorting operations of healthy seedlings. The sorting mechanism was composed of a conveyor belt and a frame. The conveyor belt was installed on the frame, and the belt was driven by a stepping motor. The visual inspection unit was installed above the conveyor belt. In order to ensure that the visual inspection unit can collect the effective image information of the plug seedlings, a guide rail was installed on the side of the conveyor belt, and a guide wheel was installed on the guide rail. When the plug seedling passes the guide rail area, the horizontal position of the plug seedling should be automatically corrected. The edge line of the plug seedlings after the corrected was kept level with the edge line of the conveyor belt, which ensured the accuracy of the image information of the plug seedlings collected by the camera. The side of the conveying mechanism was provided with a low-quality seedling recovery box, and when the conveying mechanism transported the plug seedlings to the sorting position, it was convenient to reject and recover the poor-quality seedlings. As shown in Figure 5.

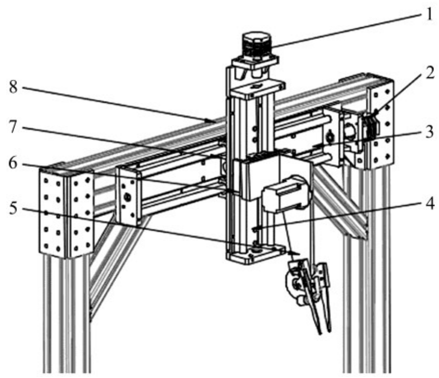
3.2 Plug seedling transplanting mechanism

The plug seedling transplanting mechanism is mainly to perform the transplanting operation of the healthy seedlings and the poor-quality seedlings after the image processing and recognition of the plug seedlings. As shown in Figure 6, the transplanting mechanism is composed of a gantry and an End-effector. The identified plug seedlings are sent to the transplanting position by the conveyor belt. After the gantry controls the positioning of the End-effector according to the recognized plug seedling information, the clip needle of the End-effector is inserted into the hole to grab, and the plug seedling transplanting mechanism is shown in Figure 6. In order to meet the transplanting requirements of plug seedlings, the height of the gantry is 1020 mm and the width is 1100 mm. The End-effector is installed on the Z-axis arm of the gantry, and the distance between the end of the End-effector clip needle and the upper surface of the conveyor belt is 400 mm. Combined with the physical size information of the plug seedlings, the movable distance of the gantry Z-axis is 395 mm, and the movable distance of the gantry X-axis is 900 mm. The Y-axis movement is realized by the relative movement of the conveyor belt, which ensures the End-effector operation space; when the End-effector grips the pot seedlings, the thickness of the clip, the opening and closing angle and other factors will affect the effect of the seedling. In order to avoid the inability to grasp the seedling, the maximum opening and closing distance of the clip needle is set to 30 mm, and the thickness of the clip needle is 4 mm, which meets the requirements for the size of the plug seedling.



1. Drive motor 2. Chain box 3. Front photoelectric sensor 4. Poor-quality seedling recycling box 5. Conveyor belt 6. Rear photoelectric sensor 7. Limiting plate 8. Light box fixed foot material 9. Plug seedling 10. Light box frame 11. Light source 12. Camera mounting frame 13. Industrial camera

Figure 5 Plug seedling sorting mechanism



1. Z-axis stepper motor 2. Y-axis stepper motor 3. Y-axis part of cross slide 4. X-axis part of cross slide 5. End-effector 6. Slider 7. End-effector mounting bracket 8. Gantry

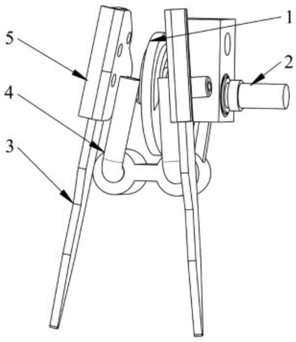
Figure 6 Plug seedling transplanting mechanism

3.3 Design of the End-effector

The End-effector is an important executive part for plug seedling transplanting, which can cooperate with the plug seedling sorting mechanism and transplanting mechanism to realize the action of seedling picking and dropping, as shown in Figure 7. The End-effector mainly relies on the cam and clip needle to achieve the action of picking and dropping plug seedlings, the internal spring structure of the rotating shaft ensures the close connection between the clip needle and the cam. The cam is divided into stroke section and push section, which respectively controls the opening and closing action of the clip needle. When the PLC control system receives the signals of picking up and dropping seedlings, the driving motor of the End-effector is connected with the cam through the transmission shaft to control the opening and closing of the clip needle, so as to realize the picking up and dropping of the seedlings.

3.4 Healthy seedling identification scheme

The healthy information identification of plug seedlings is usually based on observing their dimensions and growth status. Therefore, in the identification of healthy seedlings, it is necessary to obtain the biological characteristics of plug seedlings. In order to realize the identification of healthy seedlings, machine vision was used to sort the health information of plug seedlings. The identification process is shown in Figure 8. In this study, an intelligent recognition algorithm for plug seedlings was developed based on the Heal multi-operator compound algorithm. The Heal multi-operator compound algorithm improves the quality of the collected images through image preprocessing such as vegetable bowl seedling image color enhancement, threshold image segmentation, morphological image processing, and connected region image de-noising. Reduce noise interference and enhance the image characteristics of the target part. The pre-processed vegetable plug seedling images were feature-extracted, and two interesting feature information of the leaf area threshold *F* and the green degree per unit leaf area *Y* of the pot seedlings are extracted. According to the established grading standards, the seedlings of the plug vegetables were divided into three levels: healthy seedlings, poor-quality seedlings, and no seedling holes, and record the coordinates of the poor-quality seedlings and the no seedling holes. The coordinates of poor-quality seedlings and no seedling hole were sent to the intelligent sorting control system via the USB data bus through the Modbus protocol.



1. Cam 2. Transmission shaft 3. Clip needle 4. Rotating shaft
5. Clip mounting bracket

Figure 7 End-effector for plug seedling transplanting

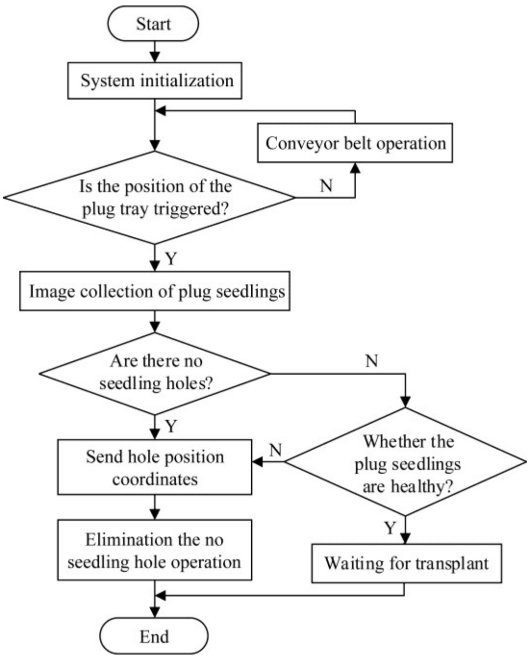


Figure 8 Process of identifying the healthy information of plug seedlings

3.5 Design of intelligent transplanting control system

In order to realize the selective transplanting of healthy vegetable seedlings, using a PLC processor combined with a computer to realize an intelligent sorting control function. The block diagram of the intelligent sorting and transplanting control system for vegetable seedlings is shown in Figure 9.

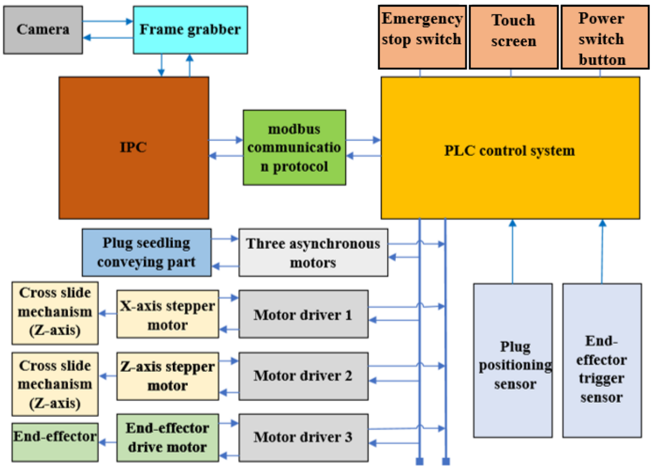


Figure 9 Block diagram of the intelligent sorting and transplanting control system for vegetable seedlings

The main functions of the intelligent sorting and transplanting control system, including the perception of the conveying status of plug seedlings, the coordination of conveying and sorting actions, and the fusion of healthy seedling information and manipulator positioning control. The conveying status of plug seedlings was realized using an SYM18J-D5ON1 diffuse reflection photoelectric sensor (Xinshe Electric Co., Ltd., China). The working voltage is DC10-30 V, the load current is 200 mA, the working temperature is −25°C to 55°C, the detection distance is less than 50 cm, and the response time is less than 0.005 s. The conveying and sorting actions required the controller to control one three-phase asynchronous motor and two-stepping motors (*X*-axis stepping motor, *Y*-axis stepping motor) to achieve, the conveyor belt was driven by three asynchronous motors. In order to realize the positioning of the End-effector, the sorting mechanism acted as a mechanical arm, and the sorting mechanism was designed by the gantry structure, The End-effector is mounted on the cross slide of the gantry. The *X*-axis stepper motor and *y*-axis stepper motor are respectively responsible for driving the cross slide to drive the End-effector to move on the *X*-axis and *Z*-axis so that the End-effector moves to the hole. The driving motor of the End-effector was responsible for the rotation of the cam, which can control the opening and closing action of the clip needle, and completing the picking and dropping action of seedlings. The controller used a Mitsubishi FX3U-80MT PLC controller (Mitsubishi Co., Ltd, Japan), rated voltage AC100-240 V, 40 I/O points, and can independently control three-axis single-speed positioning or reciprocating positioning. The maximum output pulse train can reach 100 kHz, which can meet the requirements of sensor input points and coordinated control of three motors. The image information processing of healthy seedlings used an industrial computer, i7-6200U processor, 8GB memory, 64GB storage, RS485/232 communication interface. The communication between the host computer and the PLC adopts the Modbus communication protocol, which can meet the needs of image processing and information transmission of plug seedlings.

3.6 Design of automatic identification system for plug seedling health information

In order to realize the automatic identification of the health information for the plug seedlings, an automatic identification system for the health information of the plug seedlings was developed. The system was mainly based on Matlab 2016b and Visual Studio 2013 as the basic configuration. The human-computer interaction interface was written by Visual Basic

6.0 language, and the image processing algorithm developed by Matlab was nested using VB language to realize the image recognition and feature processing of plug seedlings. The system interface is shown in Figure 10.

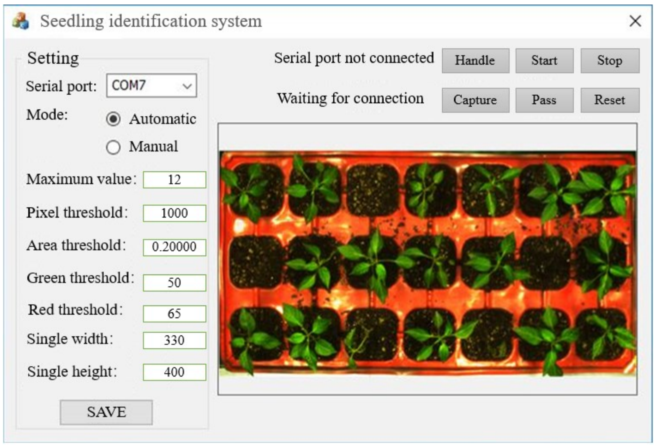


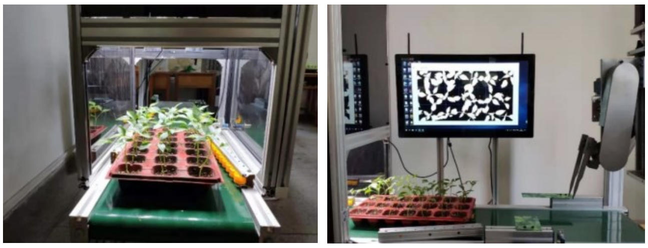
Figure 10 Automatic identification system for plug seedling health information

The system includes serial communication setting, image threshold parameter setting, and plugs seedling characteristic value setting. The camera communicated with the industrial computer through the serial communication protocol and transmitted the collected plug seedling information to the interactive interface for display. It can select automatic processing mode and manual processing mode on the interface to realize the processing of plug seedling image information, and the acquisition of health information of plug seedlings.

4 Results and discussion

4.1 Plug seedlings sorting and transplanting test

The intelligent sorting and transplanting system for healthy vegetable seedlings aimed to identify and sort the quality problems of plug seedlings, and to ensure the quality of transplanter. In order to test the effects of the designed system, an indoor experiment was carried out. The test scene is shown in Figure 11.



a. Image acquisition of seedling b. Image processing of seedling

Figure 11 Indoor test of intelligent sorting and transplanting system for healthy vegetable seedlings

1) Test conditions

The plug seedlings used in the experiment were cultivated under factory conditions, the seedling plugs were 21 holes, and the variety was pepper. The specific cultivation method was the same as in Section 2.1. Six plug seedlings of 35 d, 40 d and 45 d were randomly selected. In order to verify the effects of machine sorting, the number of inferior seedlings (the number of poor-quality seedlings and the number of no seedling holes, collectively referred to as the number of inferior seedlings) and the number of healthy seedlings were manually recorded before the test. And control the number of inferior seedlings to be less than 30% (The total number of holes in the plug tray was 21, that is, the maximum number of poor-quality holes was 6). After putting the plug seedlings on the conveyor belt, connect the position trigger sensor, CCD camera and the industrial computer through the serial port, and set the photo trigger to the serial command trigger mode. The light source of the system was a light-emitting diode (LED) strip light source. In order to ensure the uniformity of light, double light sources were installed on the top of the collection box. Startup the power supply and set the speed of seedling collection to 20 plants/min. Turn on the power, divided the test into three groups according to different seedling ages, and repeat each group of tests 6 times. Record the number of true positives, false positives, true negatives, and false negatives identified each time, and count the number of identified poor-quality seedlings and the number of successful transplanting.

2) Test index

In order to verify the reliability of the intelligent sorting and transplanting system for healthy vegetable seedlings, a statistical analysis was carried out with the recognition accuracy rate R and the sorting success rate D as performance indicators. The specific definitions are as follows:

$$R=\frac{C}{C_0}\times 100\% \tag{1}$$

where, R is the recognition accuracy rate, %; C is the true recognition number of plug seedlings; C_0 is the total number of plug seedlings.

$$D=\frac{T}{T_0}\times 100\% \tag{2}$$

where, D is the transplanting success rate, %; T is the transplanting success number; T_0 is the total identification number of inferior seedlings.

4.2 Test results

Table 2 shows the classification and recognition results of plug seedlings by the intelligent sorting and transplanting system for healthy vegetable seedlings. Among them, the number of inferior seedlings is the sum of the number of no seedling holes in the plug and the number of poor-quality seedlings. The number of true positives is the number of seedlings that no seedling holes or poor-quality seedlings are judged as inferior seedlings during the identification process. The number of false positives refers to the number of healthy seedlings identified as poor-quality seedlings. The number of true negatives refers to the number of healthy seedlings that are distinguished as healthy seedlings. The number of false negatives refers to the number of seedlings that no seedling holes or poor-quality seedlings are judged as healthy seedlings. The sorting identification number refers to the number of inferior seedlings identified by the machine. The successful transplanting number refers to the number of inferior seedlings successfully removed by the End-effector.

4.3 Discussion

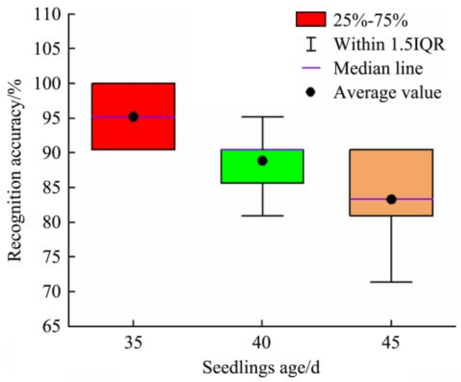
In order to explore the influence of various factors on the recognition accuracy rate and transplanting success rate. The results of the test were compared and analyzed, as shown in Figure 12.

It can be seen from Figure 12 that when the seedlings of three ages are sorted, the recognition accuracy rate is quite different, and the transplanting success rate is relatively close. The recognition accuracy rate of plug seedlings with 35 d seedlings is relatively high. The median value of the recognition success rate in the test was 95.23%, and the maximum value was 100%. The recognition accuracy rate of plug seedlings with 40 d seedlings has declined.

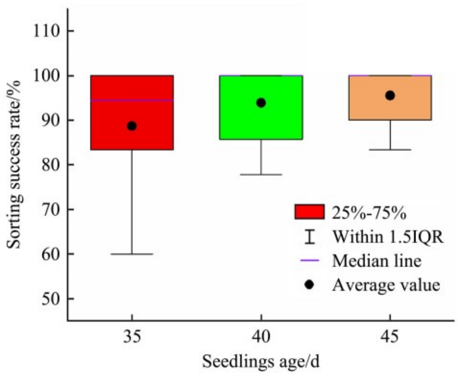
In the test, the median value of the recognition accuracy rate was 90.47%, and the maximum was 95.23%. The recognition accuracy rate of plug seedlings with 45 d seedlings was significantly reduced. The median value of the recognition accuracy rate in the test was 83.33%, and the maximum was 90.47%. With the increase of seedling age, the recognition success rate of plug seedlings gradually decreases. The main reason was that the seedling leaves increase with the increase of seedling age, and the machine has a cross-blocking phenomenon during recognition, which causes the recognition success rate to decrease. In the test of plug seedlings with 35 d, the median value of transplanting success rate was 93.5%, and the maximum was 100%. In the test of plug seedlings with seedling ages of 40 d and 45 d, the median value of transplanting success rate was 100%, and the maximum was 100%. As the seedling age increases, the transplanting success rate gradually increases. This is because the roots of the plug seedlings are better wrapped with the increase of seedling age, which in the process of transplanting seedlings, it is not easy to appear scattered. The sorting and transplanting test for healthy seedlings showed that the average recognition accuracy rate was 89.14%, and the average transplanting success rate was 93.20%. The system can effectively identify the healthy information of the age-appropriate plug seedlings and sort out the poor-quality seedlings.

Table 2 Statistics of the test results of the sorting and transplanting of plug seedlings

Seedling age/d	Test number	True positives	False positives	True negatives	False negatives	Recognition accuracy rate/%	Sorting identification number	Successful transplanting number	Transplanting success rate/%
35	1	4	0	17	0	100	4	4	100
	2	5	1	14	1	90.47	6	5	83.33
	3	2	0	19	0	100	2	2	100
	4	6	2	13	0	90.47	8	7	87.50
	5	4	1	16	0	95.23	5	3	60.00
	6	6	1	14	0	95.23	7	7	100
	Average value					95.23			88.47
40	1	5	1	14	1	90.47	6	6	100
	2	5	2	12	2	80.95	7	6	85.71
	3	2	0	18	1	95.23	2	2	100
	4	4	2	15	0	90.47	6	6	100
	5	8	1	10	2	85.71	9	7	77.77
	6	4	0	15	2	90.47	4	4	100
	Average value					88.88			93.91
45	1	6	0	11	4	80.95	6	6	100
	2	3	0	15	3	85.71	3	3	100
	3	5	1	12	3	80.95	6	6	100
	4	5	1	10	5	71.42	6	5	83.33
	5	5	2	14	0	90.47	7	7	100
	6	4	1	15	1	90.47	5	5	100
	Average value					83.32			97.22



a. Result of seedlings recognition test



b. Result of seedlings sorting test

Note: IOR: Inter-quartile range.

Figure 12 Results of the sorting and transplanting test for plug seedlings

In the test, it was observed that two cases caused the identification and transplanting failure:

1) There are poor-quality seedlings in the holes, but the End-effector device has not eliminated them. The reason for this problem is that the poor-quality seedlings have different morphology, the phenotypic characteristics are not obvious, and there were leaf cross-shading, which led to the system's misjudgment, and the poor-quality seedlings are recognized as healthy seedlings.

2) In the process of picking up the poor-quality seedlings, after the manipulator removes the poor-quality seedlings, there is still a residual matrix in the hole, which led to the failure of the poor-quality seedling eliminated. This is due to the poor growth of seedlings due to nutritional and other factors that led to poor root

development. The roots were poorly encapsulated to the substrate, which made it easy to scatter when picking up the seedlings. Residual matrix adheres to the hole, causing poor-quality seedlings to fail to be removed. No seedling holes were also prone to this problem.

Aiming at the problem above, the state of the plug seedlings can be disturbed by increasing the seedling leaf combing mechanism (pressure plate rod, seedling leaf blocking rod) to reduce the occurrence of lodging, leaf-crossing and other phenomena. At the same time, improve the seedling collection method (the ejection method can be used) to reduce the residual matrix during the removal of inferior seedlings, and improve the success rate of healthy seedling sorting.

5 Conclusions

1) Aiming at the problem of missed planting in mechanized transplanting, an intelligent sorting and transplanting system was proposed for healthy vegetable seedlings. The system included a plug seedling conveying mechanism, plug seedling sorting mechanism, photoelectric sensor, image sensor, stepping motor, PLC controller and computer. It realized the operation of healthy seedling sorting and poor-quality seedling removal of the factory cultivated plug seedlings, avoiding missed planting.

2) The sorting and transplanting test of plug seedlings showed that the intelligent sorting and transplanting system for healthy vegetable seedlings designed for transplanting pepper seedlings of suitable age (seedling age 35-45 d) can effectively distinguish healthy seedlings from poor-quality seedlings, the average recognition success rate was 89.14%. The system can sort and remove the identified healthy seedlings and poor-quality seedlings. The average transplanting success rate was 93.20%.

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