Design and test of tray-seedling sorting transplanter

Feng Qingchun, Zhao Chunjiang, Jiang Kai, Fan Pengfei, Wang Xiu*

(*Beijing Research Center of Intelligent Equipment for Agriculture, Beijing 100097, China*)

Abstract: In order to improve the automatic sorting and transplanting of tray-seedling and reduce labors strength, a new sorting transplanter was designed. According to the feature of normal seedling tray and manual grading method, the mechanical sorting procedure was defined. The key parts of sorting transplanter are as follows: an efficient transfer mechanism with aerodynamic buffer, a seedling identifying and measuring unit based on linear-structured vision, the extendible multi-grasper with wireless technology and the system controller. The experiments were conducted and showed that the transplanting success rate was 90.0% on the tray of 6×12 holes under the speed of 700 cycles per hour. The vision unit's failed identifying rate for the superior pepper seedlings on five different trays was less than 10%, and the measurement error of seedling height was about 5 mm.

Keywords: transplanter, tray seedling sorting, grasper, machine vision, wireless technology

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1 Introduction

The strong and unified seedling is expected for vegetable (or flower) cultivation to reduce managing cost, as well as desired for the automatic machine to graft and transplant[1-3]. However, the trays with uneven seedlings are universally existing because of limited seed germination rate and regional environment variance, the rate of missing and inferior seedlings is averagely 5%-10% in China[4]. On the other hand, partly agricultural resource (water or space) will be wasted until bad seedlings could be removed. Thus, sorting operation, classifying the tray seedling into different grade to cultivate accordingly and removing inferior and missing seedlings, are apparently important for improving the commercial seedling quality and encouraging the usage of automatic machine. Considering the annual quantity of vegetable seedlings in China (800 000 billion), high labor costs in manual sorting is hardly meet the need of intensive seedling production.

Since 1990s, seedling sorting machine had been developed and applied in commercial products for flower seedlings[5-9], the efficiency could reach to 20 000 seedlings per hour (or 800-1 000 operating cycles per hour). But the price is too high for Chinese small-scale nursery, and the domestic tray also could not fit perfectly with the imported machine. Therefore, the Chinese researchers begun to design a cheaper and more appropriate seedling sorting machine these years[5,10-16]. However, there is still a great gap in industrial application, especially in seedling grasping, seedling evaluating and versatility improving.

A new seedling sorting transplanter is presented in this paper, which is redesigned and improved based on the model of Urbinati RW8 transplanter made in Italy. The key parts including the transfer unit, grasper, vision unit and controller were introduced in detail in Section 3. The performance of machine was evaluated by a series of

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Biographies: Feng Qingchun, Assistant Professor, research interest: agricultural robot, Email: fengqc@nercita.org.cn. **Zhao Chunjiang**, Professor, research interest: agricultural information, Email: zhaocj@nercita.org.cn. **Jiang Kai**, Assistant Professor, research interest: agricultural machinery, Email: jiangk@nercita. org.cn. **Fan Pengfei**, Assistant Professor, research interest: agricultural machinery, Email: fanpf@nerciat.org.cn.

***Corresponding author: Wang Xiu**, Professor, research interest: agricultural machinery, Beijing Research Center of Intelligent Equipment for Agriculture, Beijing 100097, China; Tel: +86-10-51 503686; Fax: +86-10-51503886. Email: wangx@nercita.org.cn.

experiments.

2 System design specifications

2.1 Feature analysis of tray seedling

As shown in Figure 1, the pepper seedlings grow in a tray with 6×12 holes, which is widely used for vegetable and flower seedling in China, and the square tray-hole is 35 mm wide. The seedlings after 30 d sowing are suitable for sorting: at this time the root developed enough to hold the soil which could be integrality drawn out from tray-hole. Moreover, the seedlings are lower than 15 cm, the leaves assemble in a cylinder of 50 mm diameter, and not spread to overlap with each other, which made it possible to assess quality automatically and grasp seedling without damage.

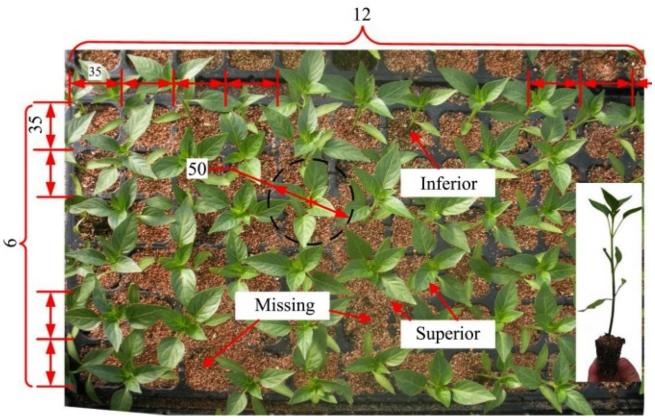


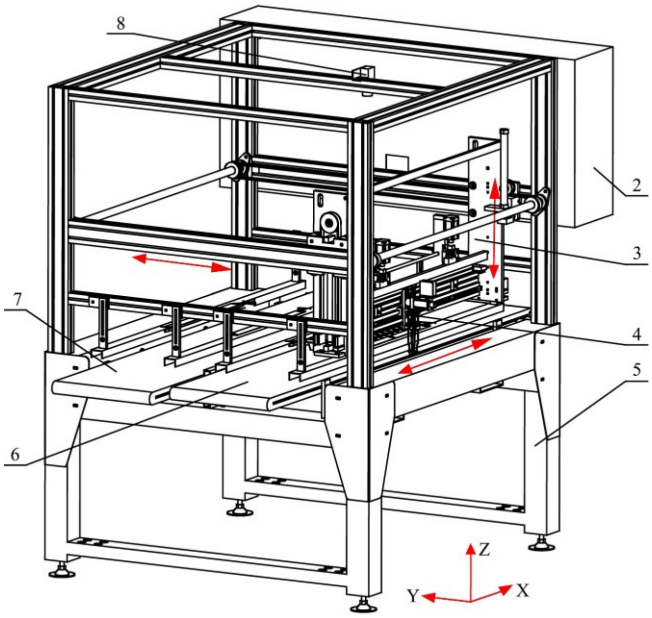
Figure 1 Tray seedlings

2.2 Working process

The working process of the sorting transplanter is as follows: Step 1, set operating parameter according to the trays size (original and objective). Step 2, load the original seedling tray and the empty objective tray. Step 3, classify the seedling quality, and locate tray-holes with none and inferior seedling. Step 4, mechanically draw the superior seedling out of the original tray-hole, then transfer and insert into the objective tray-hole. The step 4 is usually defined as a single transplanting cycle, and generally, the number of cycles completed in one hour represents the machine's efficiency. Furthermore, the number of grasper load by machine represents the number of seedling transplanted in one work cycle, which is an important determinant of machine performance.

3 Modular grading transplanter

A functional model of the seedling grading transplanter is shown in Figure 2. It consists of several major components: the base, frame, two conveyors for carrying the original and destination tray, controller box, transfer unit, vision unit and graspers. The base and frame support the whole transplanter. The grasper, carried between the original and destination tray by the transfer of two degrees of freedom or move independently, could be positioned at every hole in the same row to grasp (or release) the seedling.



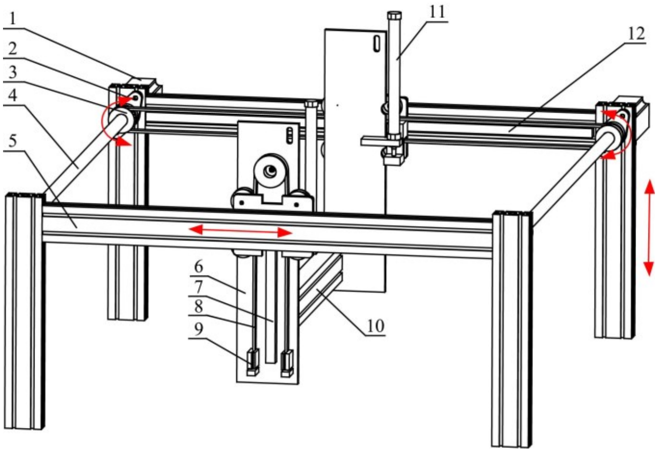
1. Frame 2. Controller box 3. Tansfer unit 4. Grasper 5. Base 6. Organal conveyor 7. Destination conveyor 8. Vision unit

Figure 2 Model of seedling grading system

3.1 Transfer mechanism

The transfer unit, supported by the frame, is installed above two conveyors as shown in Figures 2 and 3. The beam for fixing the graspers could move back and forth between the original and objective tray. Two synchronous belt transmission-mechanisms symmetrically installed, which connected by the axles and the meshing between the belt and the pulley, driven by the servo motor, transformed rotary motion of the motor into linear motion of the belt. Two pressing plats fixed on the vertical plate, hold both end of the belt, and two vertical plates are connected through the beam. Besides, the rails for the horizontal and vertical motion are fixed on the frame and vertical plates.

When the servo motors rotate in the same speed and direction, the belts pull vertical plates and beam to move horizontally, while rotate in the same speed and opposite direction, they move up and down vertically. Thus, in order to relieve the inertial impact and insure the high-speed transplanting operation runs smoothly, two pneumatic buffers are designed. The buffer cylinders stretch out as the transfer unit moved upward, and draw back as moved downward. As shown in Figure 4, because of the reducing and overflow valves linked into the pneumatic circuit, the cylinders are aerated with constant-pressured air. When components (vertical plates and beam) rise up, the air inflows from the reducing valve and the cylinders stretch out as a driver to reduce the motor’s dynamic load from accelerating. When descend down, the air exhausts from the overflow valve, and the cylinders draw back as a buffer to reduce the load from braking.



1. Servo motor 2. Bearing 3. Synchronous pulley 4. Axle 5. Frame 6. Vertical plate 7. Vertical rail 8. Synchronous belt 9. Pressing plate 10. Beam 11. Buffer cylinder 12. Horizontal rail

Figure 3 Transfer unit

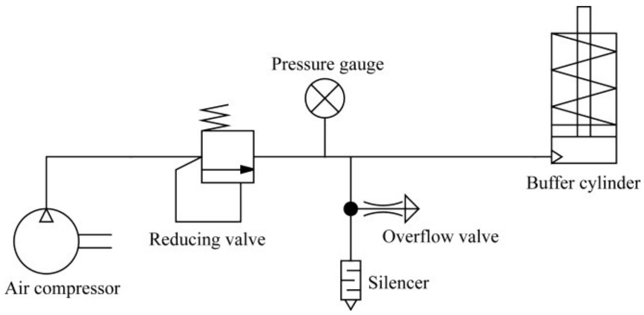
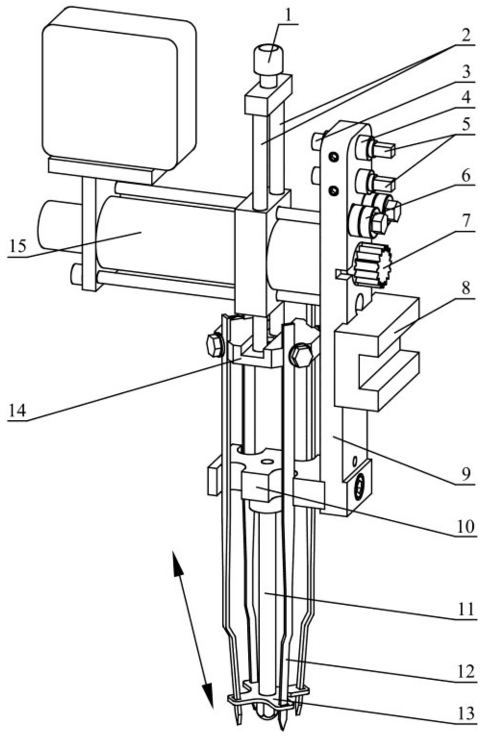


Figure 4 Pneumatic buffer

3.2 Grasper

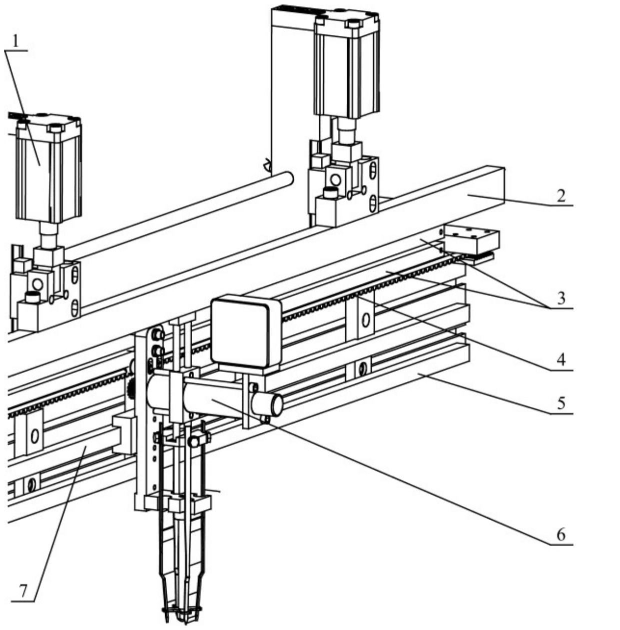
The seedling grasper model is shown in Figure 5. The four needle-shaped fingers are constrained by deflector, when the fingers slide upward and out of the seedling root soil, they swing away from each other and the fingertips open to release the seedling; when the fingers slide downward and into the root soil, they swing together with each other and the fingertips close to grasp the seedling. The fingers link with handle through the poles and fixer, and the handle is pulled (pushed) by the grasping cylinder trough the draw bar. Hence, the graspers installed with draw bar, could be opened or closed through controlling the grasping cylinder to stretch out or draw back. In particular, the handle is not totally fixed with the draw bar, in which it could slide straightly.



1. Handle 2. Pole 3. Motor terminal 4. Nealon pipe 5. Electrical brush 6. Roller 7. Gear 8. Slider 9. Vertical plate 10. Horizontal plate 11. Rod 12. Needle-shaped finger 13. Deflector 14. Finger fixer 15. Motor

Figure 5 Grasper

In order to get each seedling into the same row of tray holes, the grasper need to move along the beam, as shown in Figure 6. A belt and rail is installed on the beam, and the rail matched with the slider of grasper to linearize sliding. Furthermore, the belt meshed with the gear driven by the motor of grasper, and the rollers rolled on the other side of the belt to insure meshing tightly. The grasper can be precisely positioned along the beam through controlling the motor. In addition, double electrical brushes, set on the grasper and connect with motor, are pressed on the electrical slides linked with the power source of 24 V DC. In this study, wireless power supplying for the multi-grasper is implemented, which could solve the problem of connecting messes cable perfectly.

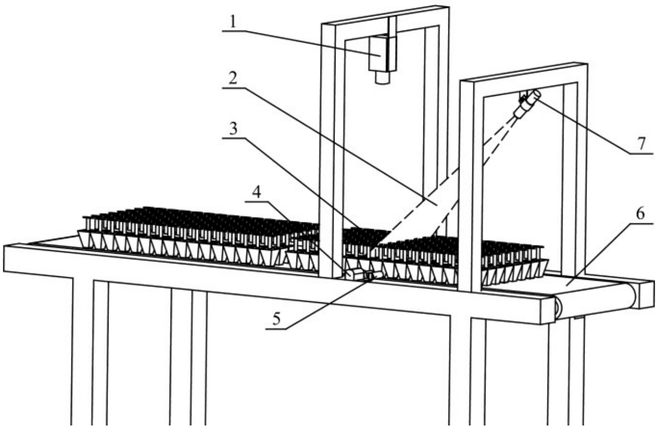


1. Grasping cylinder 2. Draw bar 3. Electrical slide 4. Belt 5. Beam 6. Grasper 7. Rail

Figure 6 Drive component of grasper

3.3 Vision unit

A linear structured-light vision unit in Figure 7 is used to measure the leaf size and stem height, and to assess the seedling quality. The unit has been particularly introduced on the previous researches[17,18], the principle of stereo measure is as follows: If the laser line project on the objects of different distance from the camera, it will show as the discontinuous segments in the image acquired from the camera. In other word, the information of 3D position between the seedling leaves and the camera can be calculated by pixel coordinate of laser on leaves area.



1. Color camera 2. Linear-laser plane 3. Tray seedling 4. Electromagnet 5. Photoelectric sensor 6. Conveyor belt 7. Linear laser

Figue 7 Model of seedling feature measuring unit

The laser is obliquely arranged on the seedling at the middle of the camera field. The seedling tray moved with conveyor belt below the camera and laser, photoelectric sensor is used for detecting the seedling line. Once one line pass the sensor, the camera will be triggered and acquire two images of the seedling line under its center. One image, taken when the laser is closed, processed to recognize leaf size information, and the other one, taken when laser is opened, processed to measure seedling height.

3.4 Controller

The control aspect as Figure 8, the transplanter employed a two-stage control structure, among which the top computer, as the core part, receives the camera information and manual interface settling; executes the seedling measure algorithm; then sends the position and count data to the lower PLC. According to the data, PWM signal from PLC transmitted to servo drivers of transfer unit and switching signal transmitted to control the grasping cylinder and conveyor belt.

A wireless mini-driver for the grasper motor is adopted to receive the control signal from computer, as well as the wireless power supplying in Section 3.2. It can greatly enhance expansibility of multi-graspers in sorting machine.

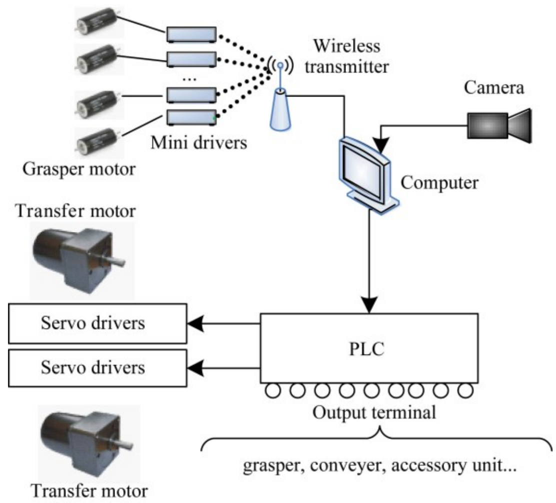


Figure 8 Controller constitution

4 Experiments and analyses

4.1 Experimental description

The performance tests for the key parts of the sorting transplanter were conducted in May, 2014 (Figure 9). Five different size trays with the random number of superior pepper seedlings were selected; the height of seedlings was measured by human. The transplanter with one grasper sorted these seedlings under the speed of 700 cycles per hour, the results showed as Table 1.

Figure 9 Physical prototype

Table 1 Test results on different trays

Tray size	Quantity of good seedlings	Quantity of ones identified	Average measurement error of height /mm	Transplant cycles (Successful cycles/Total cycles)
8×16	80	88	5.80	65/80
7×15	80	85	5.20	70/80
6×12	60	62	5.13	55/60
5×10	45	45	5.04	45/45
4×8	25	25	4.96	25/25

Five trays of 6×12 holes with 60 good seedlings were transplanted in different speed, the results showed as Table 2.

Table 2 Test results on different efficiencies

Efficiency /cycles·h^{-1}	Rate of successful transplanting/%	Transplant cycles (Failure cycles /Total cycles
700	90.0	6/60
750	81.7	11/60
800	75.0	15/60
850	70.0	18/60
900	58.3	25/60

4.2 Results and analysis

The sorting transplanter could apply to five different trays with common specifications at speed of 700 cycles per hour; successful transplanting rate was more than 80.3%, the failed identifying rate for the superior seedlings was less than 10%. The measurement error of seedling height was about 5 mm. In this condition, the controller unit could logically respond the input and output components at speed between 700 and 900 cycles per hour. Under the speed of 700 cycles per hour, the successful rate was up to 90.0% on the tray of 6×12 holes, which is acceptable for practical use.

However, the misjudgment and measurement error of the vision unit are particularly obvious in the dense tray (more than 72 holes). The main reasons are: (1) In the dense tray, the same age seedlings much easily occluded the adjacent holes (Figure 10), which could be considered as seedling holes and led to empty holes. (2) When the seedling was not sowed in the center of tray hole, the linear laser will not be projected on the peak area of seedling, the height may be measured lower. The same phenomenon occurred when the seedling deviated (Figure 11). Above all, the earlier transplanting and more accurate sowing could hopefully reduce the misjudging rate of the vision unit.

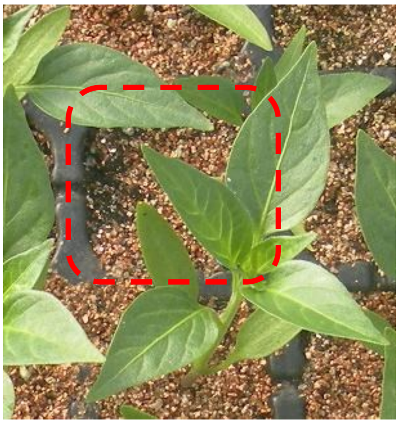


Figure 10 Occluded empty hole

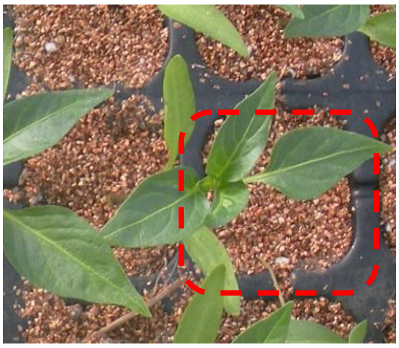


Figure 11 Deviated seedling

All failed transplanting cycles caused by unsuccessful grasping and releasing of the grasper, the main reasons are: (1) As more holes of tray is that smaller holes needs. However, the tray has 6×12 holes, and the distance between fingers is appreciably longer than holes in denser tray. So when using the denser trays under the same precision of the transfer unit, the needle of grasper is much easier to insert into adjacent holes, which cause the failed operation. (2) High transplanter working speed could increase unsuccessful grasping and releasing rate, because of the action of lagging grasper. Thus, to improve the performance of the machine, different type of graspers should be specially designed and optimized according to the tray size and work efficiency in the future work.

Figure 12 Successful grasping

5 Conclusions

A new automatic tray-seedling sorting transplanter has been developed, which includes transfer mechanism, grasper, vision unit and controller. The machine can identify superior seedlings in the tray and measure their height, and selectively transplant the good seedlings from the original tray to the destination. Results of this study show that the successful rate of transplanting was 90.0% on the tray of 6×12 holes under the speed of 700 cycles per hour; the failed identifying rate was less than 10%. The measurement error of seedling height was about 5 mm. The machine has better performance with sparse trays with less holes. How to achieve tray density or operating speed is a problem to be solved in the future work.

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