Design and test of self-propelled citrus seedling pots filling and placing machine

Qinchao Xu[1,2,3], Shanjun Li[1,2,3*], Jian Zhang[1,2,3], Jiating Zhu[1,2,3], Haibing Pan[1,2,3]

(1. *College of Engineering, Huazhong Agricultural University, Wuhan 430070, China*;
2. *Key Laboratory of Agricultural Equipment in Mid-lower Yangtze River, Ministry of Agriculture and Rural Affairs, Wuhan 430070, China*;
3. *Citrus Mechanization Research Base of the Ministry of Agriculture and Rural Affairs, Wuhan 430070, China*)

Abstract: In order to address the problem of citrus seedling pot filling and transporting which is time-consuming and labor-intensive in China, a scheme for seedling pot filling and placing was proposed, and a self-propelled citrus seedling pot filling and placing machine was designed which can fill and place 48 pots at one time. Firstly, the rotary hopper door mechanism was designed, the movement of the hopper door was analyzed, and the connection between the opening size and the movement time of the hopper door was determined. Then, the transmission system of the machine was designed, the power consumption of the hopper movement and substrate stirring were calculated, and the power requirement of the transmission system was determined. The lifting structure of the seedling pots frame was analyzed, the size of the flipping structure of the cover plate was calculated, and the seedling pots frame was designed. After that, the substrate flow rate curve was measured through the substrate flow rate experiments, and the hopper-controlled movement speed was calculated. Furthermore, the experimental prototype was manufactured and tested. The test results indicate that the filling number of pots was 48 one time, the filling time was 30 s, and the seedling pots were fully filled and placed in order. The average filling mass of the seedling pots was 2.23 kg, and the average mass variation coefficient was 2.70%. The substrate mass which is scraped out is 0.81 kg, accounting for 0.76% of the total filling mass at one time. This designed machine had a reasonable structure and high filling efficiency. The research can provide a reference for the development and optimization of the citrus seedling pots filling and transporting machine.

Keywords: agricultural machinery, design, experiments, filling machine, placing machine
DOI: 10.25165/j.ijabe.20231601.7817

Citation: Xu Q C, Li S J, Zhang J, Zhu J T, Pan H B. Design and test of self-propelled citrus seedling pots filling and placing machine. Int J Agric & Biol Eng, 2023; 16(1): 104–110.

1 Introduction

Citrus seedling cultivation is an important part of citrus planting. Because of its advantages of convenient transplanting and high survival rate, the container seedling method has become a main seedling cultivation method in the process of citrus seedling cultivation[1-3]. At present, the substrate filling and placement of citrus seedling containers in China mostly rely on manual operation, which is high labor intensity and low production efficiency. These seriously restrict the development of the citrus industry in China. In view of these problems, it is urgent to develop a type of filling and placing machine for citrus seedling pots, so as to improve the filling and placing efficiency and promote the citrus industry development.

The research and application of container seedling technology began in the 1950s and developed rapidly in countries such as the Netherlands, Canada, and Sweden[4-6]. These countries also developed high automation corresponding machines[7-10]. Container seedling technology developed early in China. In the 1950s, southern China began to cultivate *Pinus massoniana*, eucalyptus, and other trees through container seedling technology, with good results[11-13]. However, the corresponding machines developed late, which had the advantages of simple structure and low costs but also had the disadvantages of low automation, and poor versatility[14-17]. Mayer TM 2020 flowerpot substrate filling machine produced by Mayer company in Germany has a high degree of automation and intelligence, which can automatically take out pots, fill pots, punch holes, and send pots to the next transplanting step. The plus M2.0 flowerpot substrate filling machine developed by Javo company in the Netherlands has a filling efficiency of 1240-1340 pots/h. It is very convenient to adjust the machine to adapt to different diameter flowerpots. Kappa65c Line plug tray filling machine produced by Urbinati company of the United States has a filling efficiency of 2400 trays/h, and is mainly composed of trays taking part, filling part, punching part, and substrate covering part. Shunyi Science and Technology Co., Ltd. in China had developed a kind of automatic seedling pot filling machine, which has a high degree of automation, and the filling efficiency can reach 1500 pots/h. However, this machine has the disadvantages of manual pot feeding and adapting to one type of flowerpot. TLZ-400 filling machine developed by Wei et al.[18] adapts to the plug tray, with a filling efficiency of 50-400 trays/h. This machine is simple in structure and easy to operate. It is suitable for vegetable tray seedlings. In general, substrate filling machines in developed

Received date: 2022-07-23 **Accepted date:** 2022-11-03
Biographies: Qinchao Xu, PhD, Associate Professor, research interest: orchard machinery, Email: hlxqc@mail.hzau.edu.cn; **Shanjun Li**, PhD, Professor, research interest: orchard machinery, Email: shanjunlee@mail.hzau.edu.cn; **Jian Zhang**, MS, research interest: orchard machinery, Email: 836173714@qq.com; **Jiating Zhu**, Master, research interest: orchard machinery, Email: 3252605113@qq.com; **Haibing Pan**, PhD, Associate Professor, research interest: orchard machinery, Email: phb@mail.hzau.edu.cn.
***Corresponding author: Shanjun Li**, PhD, Professor, research interest: orchard machinery, College of Engineering, Huazhong Agricultural University, Wuhan 430070, China. Tel: +86-27-87288638, Email: hlxqc@mail.hzau.edu.cn.

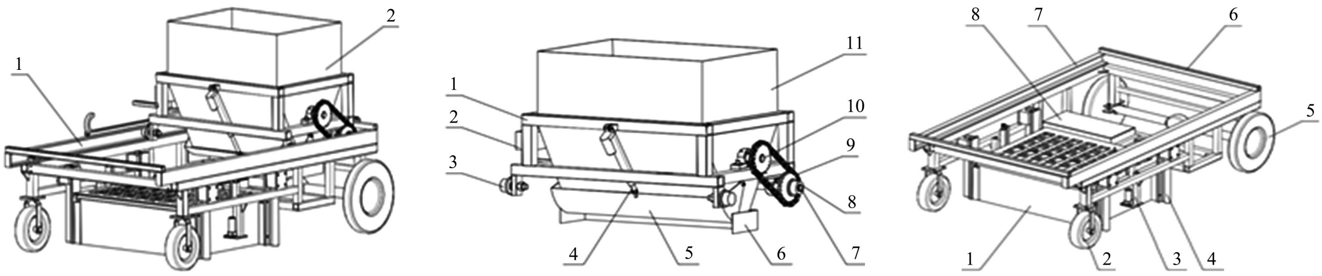
countries have the characteristics of large size, high price, and difficult maintenance[19-22], while the machine in China has the characteristics of simple structure, low price, and low degree of automation[23-26].

At present, there are mainly two kinds of pots used as citrus seedling pots in China, and few types of mechanical equipment were developed for the citrus seedling. So, a scheme for seedling pot filling and placing was proposed, and a self-propelled citrus seedling pot filling and placing machine which fills and placed 48 pots at one time was designed. The structural parameters of the key components were determined, the filling control circuit of the whole machine was designed, and the test prototype was manufactured. This designed machine has a reasonable structure and high filling efficiency which can provide reference for the development and optimization of the citrus seedling pots filling and transporting machine.

2 Structure and working principle of filling and placing machine

2.1 Machine structure

The self-propelled citrus seedling pots filling and placing machine is mainly composed of the filling part and placing part. The filling part is composed of a frame, a hopper, a hopper door mechanism, and a scraper mechanism, while the placing part includes a frame, a pots frame lifting mechanism, a steel track, and a movement mechanism. The machine structure is shown in Figure 1, and the performance parameters of the machine are listed in Table 1.



1. Placing part 2. Filling part
a. Self-propelled filling and placing machine for citrus seedling pots

1. Frame 2. Motor 3. Driven track wheel 4. Linear actuator 5. Curved hopper door 6. scraper 7. Driving shaft 8. Driving track wheel 9. Chain 10. Transmission shaft 11. hopper
b. Filling part

1. Pots frame 2. Universal wheel 3. Linear actuator 4. Sliding guide rail 5. Driving wheel 6. Frame 7. Steel track 8. Battery box
c. Placing part

Figure 1 Structure of self-propelled filling and placing machine for citrus seedling pots

Table 1 Main performance parameters of self-propelled filling and placing machine for citrus seedling pots

Items	Parameters
Size	2300 mm×1230 mm×1200 mm
Total mass	500 kg
Filling number	48 pots (8 pots×6 lines, 98.4 kg)
Moving speed	1.2 m/s
Filling time	30 s
Driving mode	Motor-driven

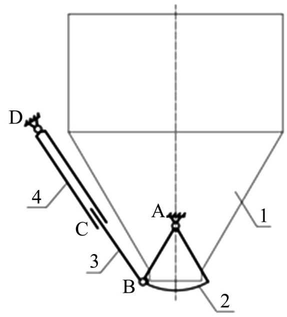
2.2 Working principle

The self-propelled citrus seedling pots filling and placing machine is placed in the seedling nursery. Then, the pots are manually placed into each compartment of the pot frame, and the substrate is filled into the hopper by feeding machine or manually. After the filling preparation, the filling part starts to move forward along the track to the first row of the pot frame when the start button is pressed, and then the hopper door opens, while the substrate falls into the seedling pots in the pot frame. The filling part continues to move forward at a controlled speed, and the scraper mechanism scrapes excess substrate above the pots. When the filling device completes the filling of the last row, the hopper door rotates to the closing position at the same time, and the filling process is finished. After filling, the filling part moves back to the initial position, and then the pot frame lifting by a linear actuator, and the filled pots stay in place as gravity. Finally, the machine moves backward at a certain distance for the next filling process.

3 Design of key components

3.1 Design of hopper door mechanism

The main function of the hopper door mechanism is to control the falling of the substrate in the hopper which is mainly composed of a curved hopper door, oscillating block, guide rod, etc, as shown in Figure 2. The guide rod retracts to drive the carved hopper door to rotate clockwise around the revolute joint A to open the hopper, and the guide rod extends to drive the curved hopper door close.



1. Hopper 2. Curved hopper door 3.Guide rod 4. Oscillating block
Note: A, B, and D are revolute joints; C is a sliding pair.

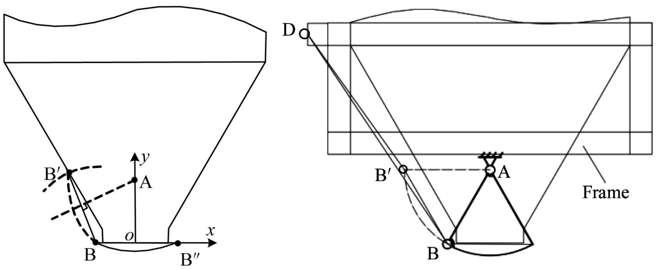
Figure 2 Hopper door mechanism

3.1.1 Structural dimensions of the hopper door mechanism

The structural dimensions of the hopper door mechanism mainly contain the rotation center, rotation radius, and rotation angle of the hopper door, the length of the guide rod, and the length of the oscillating block. In order to calculate the dimensions of the hopper door mechanism, a coordinate system *oxy* is set up in Figure 3a. The chord length of the arc-shaped hopper door BB'' is 190 mm to cover the hopper. In order to ensure no interference between the hopper door and the hopper wall, the hopper door can rotate to the extreme position BB' where point B″ rotates to the position of point B. The angle of the ∠B′BB″ was measured as 110°. The coordinates of point A are calculated as follows:

$$\begin{cases} x_A = 0 \\ y_A = \dfrac{\mathrm{BB''}}{2}\tan\left(\dfrac{\angle \mathrm{B'BB''}}{2}\right) \end{cases} \tag{1}$$

where, y_A was calculated as 135.5 mm. In order to ensure no interference between the hopper door and hopper wall and the suitable installation site for joint A, the angle of ∠B′BB″ was taken as 120°, y_A was calculated as 165 mm and the length of AB was calculated as 190 mm.



a. Schematic diagram of curved hopper door b. Schematic diagram of guide rod

Figure 3 Diagram of hopper door mechanism

The stroke of the guide rod is determined by the position change of the oscillating block and the guide rod. As shown in figure 3b, DB is the state of the guide rod at full extension, and DB′ is the state of the guide rod at retracted. Because the angle of ∠BDB′ is less than 2°, the stroke of the guide rod can be as the length of BB′ approximately.

When the hopper door is closed, the hopper door is under the pressure of the substrate above. The guide rod drives the hopper door to rotate. The force of the guide rod acting on the hopper door can be calculated as follows:

$$G_s = V_s \cdot \rho_s \cdot g \tag{2}$$

$$F_s = f_s \cdot G_s \tag{3}$$

$$F_s - F_r \cdot \cos(\angle BDB')=0 \tag{4}$$

where, G_s is the pressure of the substrate above, N; V_s is the volume of the substrate above, m^3; ρ_s is the density of the substrate, kg/m^3; g is gravity acceleration, m/ s^2; f_s is the friction coefficient between the hopper door and the substrate; F_s is the friction force between the hopper door and the substrate, N; F_r is the force acting on the hopper door by guide rod, N.

F_r was calculated as 117.67 N. Because the opening speed of the hopper door is related to the extension speed of the guide rod, the suitable speed of the guide rod was chosen as 48 mm/s. Refereeing to the specification of the linear actuator, the guide rod stroke was chosen as 200 mm, the guide rod thrust was 200 N.

3.1.2 Kinematic analysis of hopper door mechanism

In the hopper door mechanism, the guide rod moves in a line at a constant speed relative to the oscillating block, and the hopper door rotates at a variable angular speed. In order to obtain the connection between the hopper door opening size and time, the angular velocity change of the hopper door was analyzed by ADAMS software[27-29]. The hopper door mechanism was modeled by SolidWorks software and imported into ADAMS software, which is shown in Figure 4. Kinematic pairs between connected parts were set up, and JOINT_3 was set as the driving part, as listed in Table 2.

The angular velocity curve of the hopper door was obtained by simulation, as shown in Figure 5. The opening size of the hopper door can be calculated based on the angular velocity curve of the hopper door, as shown in Figure 6.

$$l_d(t) = \mathrm{OB}' - \mathrm{AO} \cdot \tan(\frac{\pi}{6} - \alpha_h) - s_h \tag{5}$$

$$\alpha_h = \int_0^t \omega_h(t)\mathrm{d}t \tag{6}$$

where, $l_d(t)$ is the hopper door opening size, m; OB' is the half of the chord length of the hopper door, m; AO is the height of joint A from the bottom of the hopper, m; s_h is the length from hopper side to hopper door side when the hopper is closing, m; $\omega_h(t)$ is the angular velocity of the hopper door, rad/s; α_h is the angular in which the hopper door rotated, rad; t is the time, s.

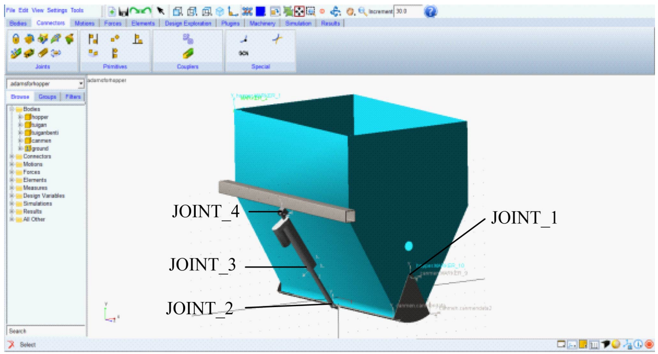


Figure 4 Hopper door mechanism in ADAMS

Table 2 Kinematic pairs of hopper door mechanism

Name	Part 1	Part 2	Kinematic pair	Point
JOINT_1	Curved door	Hooper	Revolute pair	A
JOINT_2	Guide rod	Curved door	Revolute pair	B
JOINT_3	Oscillating block	Guide rod	Sliding pair	C
JOINT_4	Oscillating block	Frame	Revolute pair	D

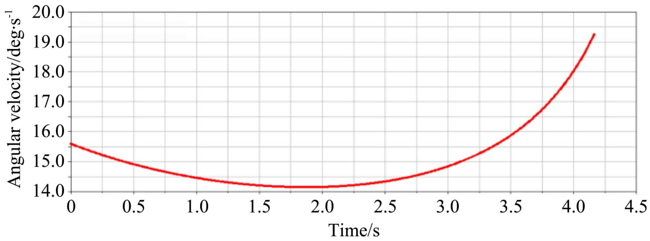


Figure 5 Angular velocity of hopper door

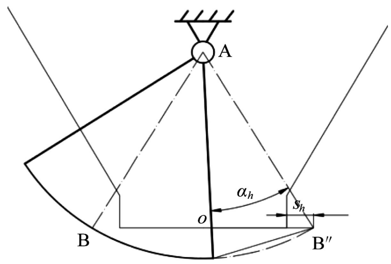


Figure 6 Diagram of hopper door opening

The hopper door opening size was calculated by Equations (5) and (6), and the result is shown in Figure 7.

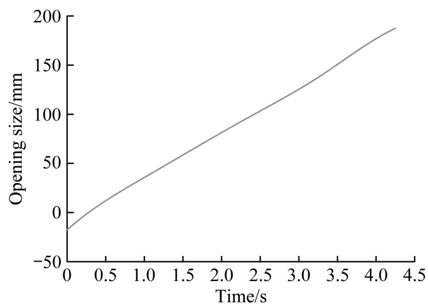
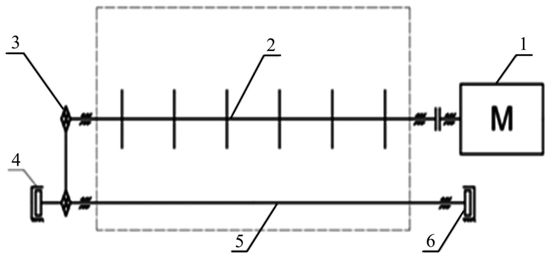


Figure 7 Diagram of the hopper door opening size and time

3.2 Design of transmission system

The movements of the filling part include back-and-forth movement and the rotation of the mixing shaft. The transmission system shown in Figure 8 was designed, which was driven by a motor.



1. DC motor 2. Mixing shaft 3. Chain 4. Steel rack 5. Driving shaft 6. Driving wheel

Figure 8 Transmission system of filling part

The output power of the motor can be calculated as follow.

$$P_f = 1.5 \times \left(\frac{P_{f1}}{\eta} + P_{f2} \right) \quad (7)$$

where, P_f is the output power of the motor, kW; P_{f1} is the movement power of the filling part, kW; η is the efficiency of the transmission system, η= 0.816; P_{f2} is the rotation power of the mixing shaft, kW.

The movement power of the filling part is calculated as follows:

$$n_w = \frac{60 \cdot v_w}{2\pi \cdot r_w} \quad (8)$$

$$T_w = F_w \cdot r_w \quad (9)$$

$$F_w = f m_f g \quad (10)$$

$$P_{f1} = \frac{T_w \cdot n_w}{9550} \quad (11)$$

where, n_w is the rotating speed of the driving steel wheel, r/min; v_w is the moving speed of the filling part, m/s; r_w is the radius of the steel wheel, m; T_w is the working resistance torque of the steel wheel, N·m; F_w is the driving force, N; f is rolling friction coefficient between steel wheel and track, f=0.1; m_f is the total mass of the filling part, kg.

The substrate in the hopper is stirred by mixing rods which are evenly arranged on the mixing shaft. The resistance torque on the mixing shaft mainly comes from the resistance effect of the mixing rods. The rotation power of the mixing shaft is calculated as follows:

$$T_M = N_l \cdot F_r \cdot \frac{l_r}{2} \quad (12)$$

$$P_{f2} = \frac{T_M \cdot n_M}{9550} \quad (13)$$

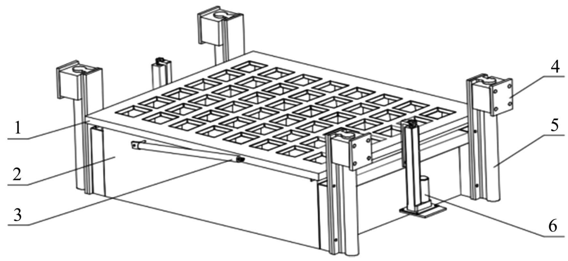
where, T_M is the resistance torque of the mixing shaft, kW; N_l is the number of the mixing rod; F_r is the resistance force on the mixing rod which is measured by experiment, N; l_r is the length of the mixing rod, m; n_M is the rotating speed of the mixing shaft, r/min.

Through calculation, the motor output power is 1.32 kW, so the driving motor with 1.5 kW was selected.

3.3 Design of pot frame

The function of the pot frame is to keep the pots stable when the seedling pots are been filling, as shown in Figure 9. The pot frame is lifted along the guide rail by linear actuators which are installed on both sides.

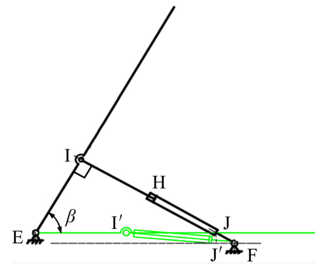
The pot frame is lifted by four linear actuators, so the performance parameters of the linear actuator need to be determined. The extension distance of the linear actuator should be longer than the height of the seedling pots by 300 mm, and the propulsive force must be bigger than the gravity of the pot frame. Considering the standard of linear actuator, the extension distance is chosen to be 350 mm, the propulsive force is 500 N and the extension speed is 48 mm/s.



1. Pot frame cover 2. Pot frame 3. Damper spring 4.Connecting plate 5. Guide rail 6. Linear actuator

Figure 9 Structure of seedling pot frame

In order to facilitate the pots placing, a cover plate mechanism was designed, as shown in Figure 10. The length of the cover plate is 940 mm, the length of J′F is 40 mm to ensure the space of the installation, and the length of the IE is chosen as one-third of the cover plate. When the cover plate is in the condition of opening, the rotating angle β is 60°, and when the cover plate is in the condition of closing, the cover plate is horizontal.



Note: E, I, and F are revolute joints, IJ is a damper spring, H is a sliding pair, J is the fixed joint of the damp spring and rod JF, β is the rotation angle, I′J′ is the damp spring when the cover plate is horizontal.

Figure 10 Structure of cover plate mechanism

When the cover plate is fully opened (β=60°), the damper spring is subjected to the least pressure in the condition of the damper spring is perpendicular to the cover plate. When the damper spring is fully extended, the length of IF is calculated as follows:

$$\mathrm{IF} = \mathrm{IE} \cdot \tan\beta + \frac{\mathrm{J'F}}{\cos\beta} \quad (14)$$

The length of IF was 622 mm. Because of the specification of the damper spring, the CT-QC200 damper spring with a maximum stroke of 300 mm and a maximum supporting force of 950 N was selected.

4 Design of control system

4.1 Measurement of the substrate flow rate

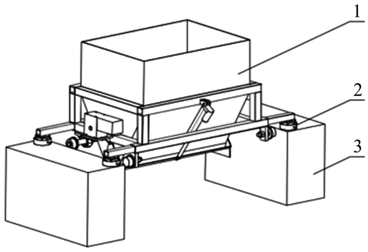
Due to the influence of the operating parameters of the machine and material characteristics, the flow rate changes greatly during the substrate-filling process. It is necessary to measure the curve of the substrate flow rate during the filling process. In tests, the opening width of the hopper is 40 mm, the moisture content of the substrate is 13.6% and the rotation speed of the stirring shaft is 69.2 r/min[30-33].

The testing device is shown in Figure 11. The filling part is placed on four weighing sensors which were placed on the frame. The weighing sensors can measure the change in weight in real-time, and transmit the combined four-channel data to the computer through the A/D conversion module.

Before the test, the hopper was filled with substrate. Then, the hopper door started to open while the starting button was pressed. The weighing data were recorded by computer at the beginning of the hopper door opening to the flowing out of substrate in the hopper completely. The flow rate of the substrate can be obtained by differentiating of mass variation of the hopper.

$$Q_s = \frac{\mathrm{d}m_s}{\mathrm{d}t} \tag{15}$$

where, Q_s is the flow rate of substrate, kg/s; m_s is substrate mass, kg; t is the time, s.



1. Hopper 2. Weighting sensor 3. Frame

Figure 11 Testing device of substrate flow rate

Tests were repeated 12 times, and the average flow rate was obtained from the arithmetic mean of 12 groups of testing results. The average flow rate curve is shown in Figure 12.

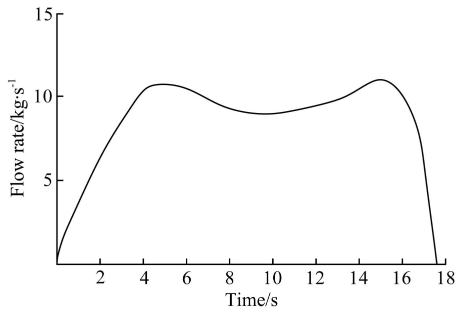


Figure 12 Flow rate of sunstrate

4.2 Moving speed of filling part

According to the flow rate of the substrate, the moving speed of the filling part was calculated as follows:

$$M_L = \int_{t_{i-1}}^{t_i} Q_s \mathrm{d}t \tag{16}$$

$$\Delta t_i = t_i - t_{i-1} \tag{17}$$

$$v_i = \frac{l_L}{\Delta t_i} \tag{18}$$

where, m_L is the mass of substrate needed for filling a row of pots, kg; t_{i-1} is the time when the i-th row of pots starts to be filled, s; t_i is the time when i-th row of pots ends to be filled, s; Δt_i is the time needed for filling i-th row of pots, s; v_i is the moving speed of the filling part when filling i-th row of pots, m/s; l_L is the width of a row of pots, m.

A group of the discrete moving speeds of the filling part was obtained through calculation. After fitting the discrete moving speed, the moving speed curve of the filling part was obtained as shown in Figure 13.

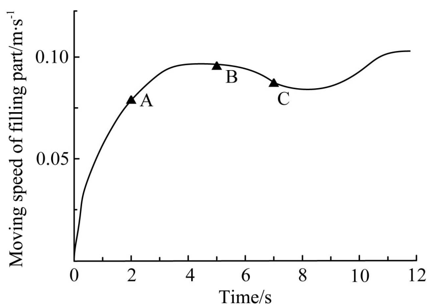


Figure 13 Moving speed of the filling part

In order to lower the cost and reduce the control requirements of hardware, the moving speed was simplified according to the characteristics of the speed curve in Figure 13. According to the kinematic simulation in Figure 7, it takes 1.30 s for the hopper door to open totally to the width of the required 40 mm. But it needs 1.96 s for the first row of pots to be filled fully according to the calculation. Therefore, the filling time of the first row is determined to be 2.00 s, and the moving speed of the filling part is calculated as follows:

$$v_1 = \frac{l_L}{2} \tag{19}$$

The moving speed of the filling part when filling the first row of pots was calculated as 0.0585 m/s. When filling the last row of pots, the hopper door rotating process is the reverse of that in the first row. So, the moving speed of the filling part when filling the last row of pots was the same as the first row.

The mass of falling substrate from 2 to 7 s was calculated as 65.6 kg which is the required filling mass of the pots of row 2 to row 5. As shown in Figure 14, the time is 2 s, and the moving speed of the filling part is 0.0745 m/s at point A, while the time is 7 s and the moving speed of the filling part is 0.0891 m/s at point C. The moving speed of the filling part is variable from 2 to 7 s and reaches a peak of 0.0945 m/s at point B. Therefore, the moving speed of the filling part was chosen as uniform motion from 2 to 7 s, and the controlling moving speed in the total process is listed in Table 3.

Table 3 Moving speed of filling part

Parameter	Row 1	Rows 2-5	Row 6
Moving speed/m·s^{-1}	0.0585	0.0936	0.0585
Moving time/s	2	5	2

4.3 Composition of control system

The hardware of the control system mainly includes the main control chip (Acer STC89C52, Shenzhen, China), DC motor driver (Shidai Chaoqun ZM-6650, Beijing, China), linear actuator (Noah Zhike a0064, Chongqing, China), 5 V electromagnetic relay (risym srd-05vdc-sl-c, Shenzhen, China), limit switch (Chint yblx-me-8180, Shenzhen, China), etc. the hardware of control system is shown in Figure 14[34,35].

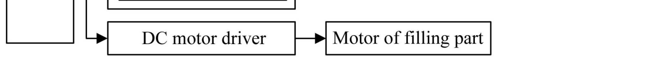


Figure 14 Hardware of control system

The working principle of the control system is as follows: the main control chip controls the DC motor driver and electromagnetic relay. When the start button is pressed, the main control chip sends PWM signals to the DC motor driver[36] to control the rotating speed of the motor, and the moving speed of the filling part is changed as the change in the rotating speed of motor. When it is time to control the movement of the pot frame or hopper door, the main control chip controls send control signals to the corresponding 5 V electromagnetic relay to control the linear actuators.

The program is compiled on Keil software based on C language, and the control flow chart is shown in Figure 15. In the program flow chart, M1 represents the motor of the filling part, B1 represents the linear actuator of the hopper door mechanism, B2 and B3 represent the two linear actuators of the pot frame mechanism, SB1 represents the rising button of the pot frame, SB2 represents the falling button of pot frame, SB3 represents the start button, SB4 represents the stop button, X1 represents the limit switch 1, X2 represents the limit switch 2, and X3 represents the limit switch 3.

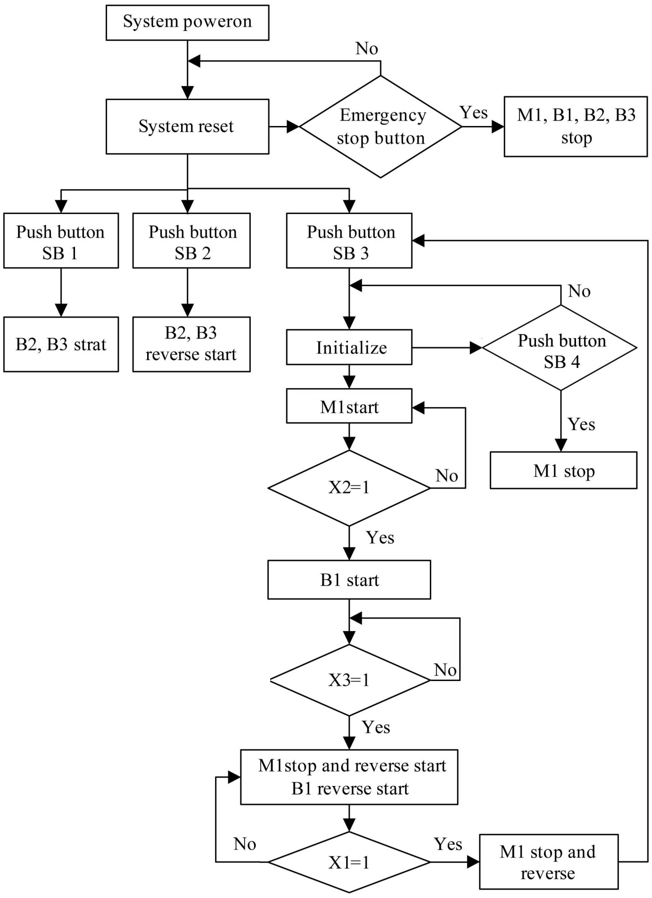


Figure 15 Control flow diagram of control system

5 Prototype tests

5.1 Material and methods

After the design was completed, the prototype of a type of self-propelled citrus seedling pot filling and placing machine was manufactured, as shown in Figure 16.

Figure 16 Prototype of the self-propelled citrus seedling pots filling and placing machine

There are four index parameters were used to evaluate the performance of this filling and placing machine. 1) Filling mass and filling uniformity. Filling mass is evaluated by comparing the weight of the pot filled by the machine to that manually. Filling uniformity is evaluated by the coefficient of variation; 2) Number of the unnormal placing pots. The number of unnormal placing pots is evaluated by observing the unnormal pots after the filling and placing process; 3) The substrate mass scraped by the scraping plate. The substrate mass scraped by the scraping plate is evaluated by weighing the substrate scraped off after the filling process. 4) Working efficiency. Working efficiency is evaluated by time in the total working process cycle.

5.2 Testing results

The prototype tests were repeated 3 times, and the filling and placing effects are shown in Figure 17. The average mass of the seedling pots at the same position in three tests was calculated, as listed in Table 4. The results of the performance parameters of the filling and placing machine are listed in Table 5.

a. Filling effect of test b. Placing effect of test

Figure 17 Filling and placing effect of prototype test

Table 4 Average mass of pots at same position in three tests (g)

Seedling pot column number	Seedling pot row number							
	1	2	3	4	5	6	7	8
1	2.27	2.25	2.26	2.24	2.26	2.27	2.21	2.25
2	2.23	2.24	2.23	2.23	2.23	2.21	2.22	2.20
3	2.25	2.24	2.24	2.26	2.27	2.26	2.21	2.27
4	2.26	2.28	2.26	2.27	2.23	2.22	2.27	2.21
5	2.24	2.25	2.24	2.24	2.24	2.27	2.29	2.22
6	2.24	2.23	2.13	2.22	2.12	2.26	2.24	2.23

Table 5 Test results of performance parameters

Items	Result
Average mass of one filled pot/kg	2.24
Mean mass coefficient of variation	2.70
Number of the unnormal placing pots	0
Average scraped substrate mass/g	0.81
Working efficiency/s	119

5.3 Discussion

1) As shown in Figure 17, there is no overturned pot and no failure-separated pot in tests. The filling and placing function of the prototype is normal.

2) As listed in Table 4, the maximum mass of the filled pot is 2.28 kg, and the minimum mass of the filled pot is 2.12 kg. The average mass of one filled pot is 2.24 kg. Compared with the mass of a manually filled pot 2.22 kg, the mass difference is 0.02 kg, accounting for 0.9%. The mean mass coefficient of variation is 2.7 as listed in Table 5, and the filling uniformity is acceptable.

3) The average substrate mass scraped off by the scraping plate in each process is 0.81 kg as listed in Table 5. It is known that the total amount of substrate required for each filling process is 106.56 kg. The substrate mass scraped off by the scraping plate account for 0.76% of the substrate mass needed for each filling

process. This shows that the moving speed of the filling part is well controlled.

4) The main steps in each filling process contain the placing seedling pots step, the filling step, the pot frame rising step, and the machine moving backward stage. The total time of the filling process is 119 s as listed in Table 5.

6 Conclusions

1) A self-propelled filling and placing machine for citrus seedling pots were developed, which has high filling efficiency and filling quality.

2) The structure design of the machine is reasonable and the prototype can run stably. There are 48 pots that can be filled and placed in one working process, and the substrate in the hopper is enough for twice the working process.

The research can provide a reference for the development and optimization of citrus seedling pot filling and placing machines.

Acknowledgements

The authors acknowledge that this work was financially supported by the Chongqing Research and Development Project 'Key Technology Research and Equipment Development of Intelligent Management for Citrus Seedling Plant' (cstc2019jscx-gksbX0095).

[References]

[1] Qi C J, Gu Y M, Zeng Y. Progress of citrus industry economy in China. Journal of Huazhong Agricultural University, 2021; 40(1): 58–69. (in Chinese)

[2] Wu F B, Yan C F. Container seedling development overview and direction. South China Agriculture, 2014; 8(30): 66–67. (in Chinese)

[3] Shan Y. Present situation, development trend and countermeasures of citrus industry in China. Journal of Chinese Institute of Food Science and Technology, 2008; 8(1): 1–8. (in Chinese)

[4] Coker R, Posadas B, Langlois S, Knight P, Coker C. Current automation practices among greenhouse and mixed nursery/greenhouse operations in selected Gulf South States. Mississippi Agricultural & Forestry Experiment Station, 2014. Available: https://www.mafes.msstate.edu/publications/bulletins/b1208.pdf.

[5] Yulianto D, Raibhu S. Design of semi-automatic plant media bagging machine for container plant nursery. Journal of Advanced Agricultural Technologies, 2018; 5(1): 36–40.

[6] Singh R R, Meena L K, Singh P. High tech nursery management in horticultural crops: a way for enhancing income. International Journal of Current Microbiology and Applied Sciences, 2017; 6(6): 3162–3172.

[7] Gu S, Yang Y L, Zhang Y F. Development status of automated equipment systems for greenhouse potted flowers production in Netherlands. Transactions of the CSAE, 2012; 28(19): 1–8. (in Chinese)

[8] Liu N H, Jiang X P, Cheng J F, Li H L, Li W, Xue K P, et al. Current situation of foreign organic greenhouse horticulture and its inspiration for sustainable development of Chinese protected agriculture. Transactions of the CSAE, 2018; 34(15): 1–9. (in Chinese)

[9] Yang Y T, Chen Y S, Hu H, Guan C S. Experience of development of pot filling machine at home and abroad. Journal of Chinese Agricultural Mechanization, 2013; 34(1): 47–50. (in Chinese)

[10] Meerburg B G, Korevaar H, Haubenhofer D K, Blom-Zandstra M, Van Keulen H, et al. The changing role of agriculture in Dutch society. Journal of Agricultural Science, 2009; 147(5): 511–521.

[11] Ryu K H, Kim G, Han J S. AE—Automation and emerging technologies: Development of a robotic transplanter for bedding plants. Journal of Agricultural Engineering Research, 2001; 78(2): 141–146.

[12] Hwang S J, Nam J S. Development of automatic accumulating equipment for Roller-Type onion pot-seeding machine. Applied Sciences, 2019; 9(10): 2139. doi: 10.3390/app9102139.

[13] Hwang S J, Lee J Y, Nam J S. Irrigation system for a Roller-Type onion pot seeding machine. Applied Sciences, 2019; 9(3): 430. doi: 10.3390/app9030430.

[14] Hwang S J, Nam J S. Optimization of roller shape for roller-type onion pot-seeding machine. Int J Agric & Biol Eng, 2020; 13(1):111–119.

[15] Lantin R M. Agricultural mechanization in the Philippines, Part I: Brief history. AMA-Agricultural Mechanization in Asia Africa and Latin America, 2016; 47(2): 80–86.

[16] Juliano P, Barbosa-Cánovas G V. Food powders flow ability characterization: theory, methods and applications. Annual Review of Food Science and Technology, 2010; 1: 211–239.

[17] Choi W C, Kim. D C, Ryu. I H, Kim K U. Development of a seedling pick-up device for vegetable transplanters. Transactions of the ASAE, 2002; 45(1): 13–19.

[18] Wei Y Y, Lu J, Sheng K C, Qian X Q, Shen J F. Design and performance investigation for substrate filler in protected horticulture. Journal of Zhejiang University (Agriculture and Life Sciences), 2013; 39(3): 318-324. (in Chinese)

[19] Meena L K, Bairwa S L, Kumari M, Wadhwani M K. Performance of onion in Bihar - An economic analysis. Economic Affairs, 2016; 61(2): 299–304.

[20] Singh R C, Singh G, Saraswat D C. Optimisation of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. Biosystems Engineering, 2005; 92(4): 429–438.

[21] Kocher M F, Lan Y, Chen C, Smith J A. Opto-electronic sensor system for rapid evaluation of planter seed spacing uniformity. Transactions of the ASAE, 1998; 41(1): 237–245.

[22] Karayel D, Wiesehoff M, Özmerzi A, Müller J. Laboratory measurement of seed drill seed spacing and velocity of fall of seeds using high-speed camera system. Computers & Electronics in Agriculture, 2006, 50(2): 89–96.

[23] Xu Q C, Li S J, Zhang Y L, Meng L, Lu H A, Xie L. Design and test of seedling pot filling and transporting machine for citrus. Transactions of the CSAE, 2020; 36(18): 66–72. (in Chinese)

[24] Yang Y T, Hu H, Chen Y S, Guan Q S. Design and experiments of pot filling machine. Journal of Chinese Agricultural Mechanization, 2014; 35(1): 170–175. (in Chinese)

[25] Zhang L, Cui X F, Zhang M B, Fan H L, He J C. Structure design and key component simulation analysis of preparation machine based on nursery bag raising method. Journal of Fujian Agriculture and Forestry University (Natural Science Edition), 2019; 48(4): 539–545. (in Chinese)

[26] Zhang S B. Construction of *E.coli* displaying S.aureus trap on its surface by red recombination and its immunogenicity. Master dissertation. Daqing: Heilongjiang Bayi Agricultural University, 2014; 69p. (in Chinese)

[27] Guan X Q, Zhao Q Z, Gao Y W, Wang X. Simulation analysis of planner guide mechanism based on Solidworks and ADAMS. Coal Mine Machinery, 2014; 35(10): 273–275.

[28] Wei B D, Zhang M L. Optimal design of mechanism based on simulation result data of ADAMS. Machinery, 2004; 31(12): 44–45. (in Chinese)

[29] Wang S Y, Hu Z C, Peng L, Wu H C, Gu F W, Wang H O. Simulation of auto-follow row detection machanism in beet harvester based on ADAMS. Transactions of the CSAM, 2013; 44(12): 62–67. (in Chinese)

[30] Cheng H. Study on the optimization model and algorithm for the complex cutting stock problem. Doctoral dissertation. Hefei: Hefei University of Technology, 2015; 126p. (in Chinese)

[31] Lin J C, Luo S, Yuan Q X, Cao H L. Flow properties of vermicompost particle with different moisture contents. Transactions of the CSAE, 2019; 35(9): 221–227. (in Chinese)

[32] Sun D, Lu H F, Cao J K, Wu Y T, Gao X L, Gong X. Solid flow rate prediction in hoppers with complicated flow channels. CIESC Journal, 2020; 71(3): 974–982. (in Chinese)

[33] Zhao W, Lu H F, Guo X L, Gong X. Application of CPFD in hopper discharge of fine granular material. CIESC Journal, 2015; 66(2): 512–521. (in Chinese)

[34] Wang H, Zhang J F. Design and experimental research of jujube core-removing machine based on a single chip microcomputer. Food and machinery, 2020; 36(2): 115–118. (in Chinese)

[35] Xu L M, Liu X D, Zhang K L, Xing J J, Yuan Q C, et al. Design and test of end-effector for navel orange picking robot. Transactions of the Chinese Society of Agricultural Engineering, 2018, 34(12): 53–61. (in Chinese)

[36] Qu J W, Guo K Q, Gao H, Song S J, Li X N, Zhou W. Experiments on collaborative characteristics of driving and steering for agricultural flexible chassis based on PWM signal. Transactions of the CSAE, 2018, 34(7): 75–81. (in Chinese)