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Structural design of a pit type chili seedling transplanter

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Abstract: *In order to solve the problems of high labor consumption and low efficiency in the process of transplanting chili seedlings. This article designs a pit type chili seedling transplanter, which innovatively adopts pit type planting technology. By integrating a four-wheel walking device, a seedling tray rotating seedling conveying device, a pit type drilling device, and a duckbill type transplanting device, the entire process of digging holes, picking seedlings, dropping seedlings, transplanting, and covering soil is unmanned, ensuring a stable and efficient chili transplanting process. This design provides a feasible solution for the automation of chili pepper transplantation.*

Keywords: *Chili sprouts; Duckbill transplantation; Cellar style planting; automation*

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I. Introduction

As a globally cultivated cash crop of significant economic importance, pepper plays a vital role in food processing, pharmaceuticals, and agroecology. In China, pepper cultivation spans extensive areas and serves as a primary income source for farmers in many regions. However, the transplanting stage of pepper seedlings faces persistent challenges. The development of mechanized transplanting technologies has drawn considerable attention, as traditional manual methods—reliant on labor-intensive hole-digging, seedling extraction, and planting—exhibit low efficiency (approximately 200 seedlings/hour) and high physical demands [1－3].

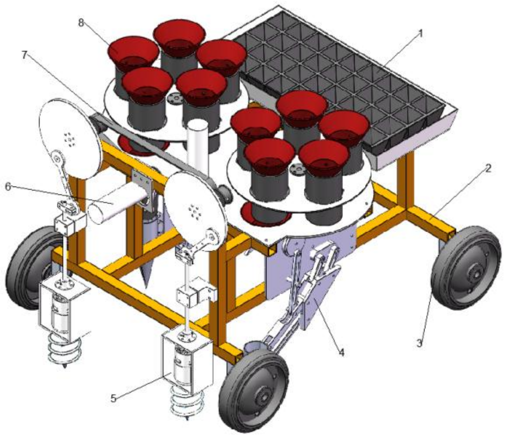
In recent years, diverse solutions have been proposed by researchers worldwide. For instance, the fully automated high-speed transplanter developed by Visser Horti Systems in the Netherlands achieves an operational efficiency of 2,000 seedlings/hour [4], yet its prohibitive cost and stringent terrain requirements hinder its adoption in small-to-medium farms. Domestically, Li Hongbin et al. [6] designed the 2ZB-2 Hanging Cup Transplanter, which employs a cup-shaped seedling-dropping mechanism to enhance transplanting standardization in Xinjiang, though its performance in sandy soils remains suboptimal.

Innovations in core components have also emerged. Zhang Ni[2] developed an automatic pepper plug seedling transplanter utilizing a modular seedling delivery system for precise extraction, yet its application is confined to flat terrains. Jia Tibing[4] further optimized the seedling extraction device with a mechanical clamping mechanism, achieving a separation accuracy of ±3 mm, but still requiring manual positioning assistance. A review of existing literature reveals that cellar-type transplanting technology addresses complex terrains through borehole stabilization design, effectively maintaining root zone spatial stability and improving seedling survival rates by 25% compared to conventional methods [1, 10]. This technology demonstrates promising applicability in pepper cultivation.

II. Overall structure and working principle of transplanting machine

2.1 Overall Design

The pit type chili seedling transplanting machine designed in this article mainly consists of four core modules: four-wheel walking device, seedling tray rotating seedling conveying device, pit type drilling device, and duckbill type transplanting device. Each module cooperates with each other to complete the automated transplanting of chili seedlings. Its overall three-dimensional structure is shown in Figure 1.



1. Seedling tray; 2. Rack; 3. Walking device; 4. Transplanting device; 5. Drilling device; 6. Drive motor; 7. Synchronous belt; 8. Seedling transportation device

Figure 1 Overall three-dimensional structure

2.2 Working principle

The pit type chili seedling transplanter mainly completes actions such as walking, drilling, seedling transportation, transplanting, and soil covering. The functional modules are shown in Table 1.

Table 1 Function Module Table

functional module	Drive mode
walk	DC deceleration motor drives four-wheel walking device
drill	Eccentric wheel mechanism drives spiral drill bit
Seedling transportation	Synchronous belt driven seedling tray rotates and separates seedlings
transplant	Cam linkage mechanism controls duckbill opening and closing
earthing	Combination of wall dumping and natural backfilling

Before starting work, the transplanting machine is in its initial state. After the power is turned on, the controller starts the collaborative operation of various modules. The steps are as follows:

1) Walking positioning: The four-wheel walking device moves at a constant speed along the ridge, and the front wheel steering mechanism adapts to the curved path of the ridge.

2) Drilling in the cellar: The motor drives the eccentric wheel mechanism, which drives the spiral drill bit (with a speed of 200 rpm) to drill vertically downwards; The shape of the hole is fixed on the cylinder wall, and the U-shaped soil outlet guides the soil to both sides, forming a pit type hole with a depth of 15 cm and a diameter of 5 cm.

3) Seedling tray transportation: Manually place seedling trays (6 × 8 matrix arrangement of chili seedlings) in a rotating trough; The synchronous belt wheel drives the turntable (with a speed of 5 rpm), and the gap structure separates individual seedlings. The seedling protection bowl guides the seedlings to fall vertically into the seedling transport channel.

4）. Duck billed transplantation: The cam mechanism controls the duck billed to move down to the bottom of the hole (10-15 cm deep), triggers the push rod to pull the rope, and opens the duck billed to release the seedlings; The duckbill is closed and lifted, and the tube wall is naturally backfilled with soil to complete the covering.

5）. Cycle operation: Repeat the drilling seedling transportation transplanting process for every 30 cm advance of the walking device until the entire field ridge operation is completed.

III. Design and Implementation of Main Devices for Transplanter 3

3.1 Four wheel walking device

In order to adapt to complex ridge terrain, the four-wheel walking device adopts wear-resistant rubber wheels. This type of rubber wheel has good grip and flexibility, and can stably drive on uneven ridges, reducing the impact of bumps on transplanting accuracy. The walking speed is designed to be 0.1-0.3m/s, with a general transplanting row spacing of 0.4-0.6cm and a plant spacing of 30cm [5], which can be adjusted according to actual planting needs. At a slower speed, it can ensure the accuracy of transplanting operations; In the case of large-scale planting with relatively low precision requirements, the speed can be appropriately increased to improve work efficiency (as shown in Figure 2).

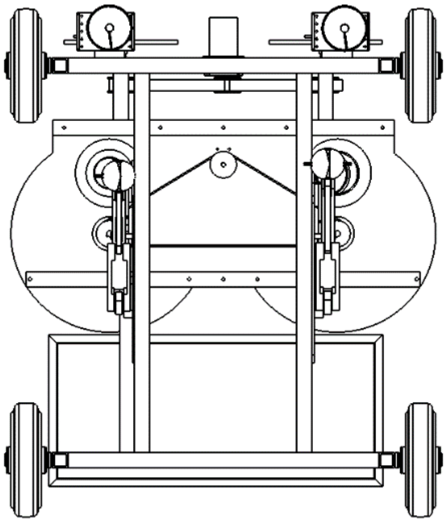
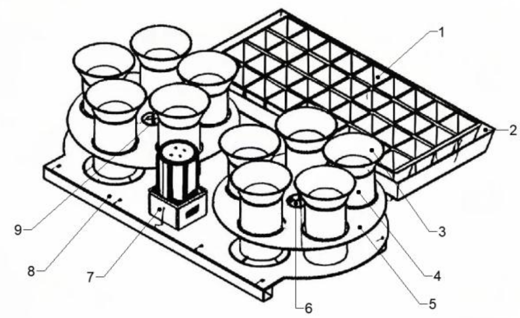


Figure 2 Four wheel walking device

3.2 Rotating seedling conveying device for seedling tray

The device drives the synchronous pulley through a motor, which in turn drives the turntable to rotate. The turntable's speed is set to 5 rpm. There is a special notch structure designed on the turntable. When the turntable rotates, the position relationship between the notch and the chili seedlings in the seedling tray is utilized to achieve automatic separation of individual chili seedlings [4,7,8,9]. This design ensures the accurate number of chili seedlings separated each time, avoiding the occurrence of multiple seedlings being taken out at the same time and ensuring the precision of seedling transportation (as shown in Figure 3).

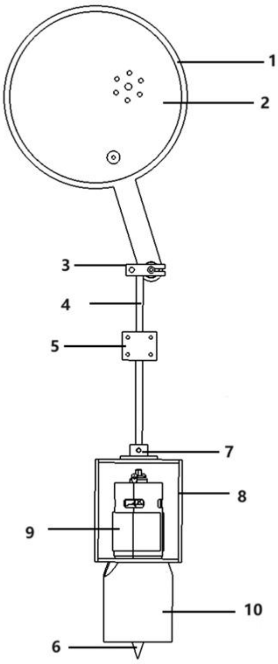


1. Seedling tray trough; 2. Seedling tray trough; 3. Seedling protection bowl; 4. Cylinder; 5. Rotary table; 6. Drive the optical axis; 7. Motor; 8. Bottom plate; 9. Flange coupling

Figure 3 Rotating seedling conveying device for seedling tray

3.3 Well cellar drilling device

The drill bit is driven by an eccentric wheel mechanism, with a rotation speed of 200rpm. The diameter of the drill bit is designed to be 5cm, the depth of the drilling hole is 15cm, the thickness of the cylinder wall is 2mm, and the material used is high-density and high-precision resin material. This material has high strength and corrosion resistance, and is fire-resistant and waterproof, ensuring that the drill bit will not easily deform or be damaged during long-term drilling operations. The diameter and depth of the drill bit have been determined through multiple experiments and optimizations to be 12cm and 15cm, which can provide suitable growth space for chili seedlings while ensuring the stability of the pit. The thickness of the cylinder wall is 2mm, which reduces the weight of the device as much as possible while ensuring the structural strength. During the drilling process, the eccentric wheel mechanism provides stable power, allowing the drill bit to quickly and efficiently penetrate the soil. The fixed design of the cylinder wall is achieved through special structures and processes, effectively preventing hole collapse and ensuring smooth transplantation.



1. Cam outer ring; 2. Cam; 3. Optical axis cross connector; 4. Connecting rod; 5. Linear bearing slider; 6. Drill bit; 7. Flange coupling; 8. Motor placement rack; 9. Motor; 10. Cylinder wall

Figure 4: Well cellar drilling device

3.4 Duck billed transplanting device

The design of the duckbill transplanter is directly related to the quality and survival rate of pepper seedling transplantation (as shown in Figure 5). By precisely controlling the angle of the cam, the duckbill can be opened and closed within the range of 45 ° -135 °. When the cam rotates to 45 °, the duckbill begins to gradually open, ready to receive chili seedlings; When rotated to 90 °, the duckbill is fully opened, and the chili seedlings are accurately placed into the duckbill; As the cam continues to rotate to 135 °, the duckbill gradually closes, accurately transplanting the chili seedlings into the pit. This precise control method can avoid damage to the root system of chili seedlings during transplantation and improve the success rate of transplantation [6].

1. Rack; 2. Cam; 3. Push rod; 4. Push rod extension rod; 5. Rope; 6. Execution agency; 7. Duckbed; 8. Connecting rod; 9. Install bolts; 10-12. Components; 13~16. Constraint mechanism of transmission system

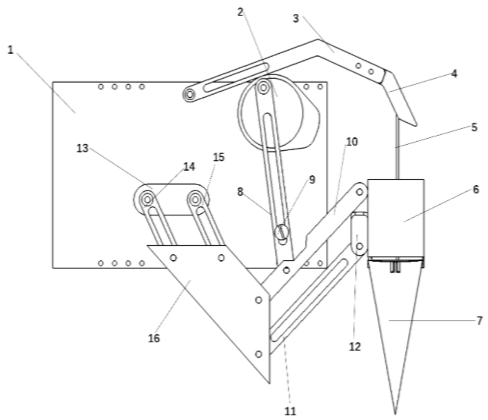


Figure 5 Duck billed Transplanter

IV. Design and Implementation of Electronic Control System

This project uses Arduino Uno R3 as the main controller. It is based on the ATmega328p microcontroller with a main frequency of 16MHz, 32K ROM, 2K SRAM, 1K EEPROM. The working voltage is 5V, with 14 digital IO pins, including 6 supporting PWM output and 6 analog inputs. pin configuration

This article uses the PWM output function of three digital IO pins, D9, D10, and D11, to drive three L298N drivers. The pin configuration is shown in Figure 6.

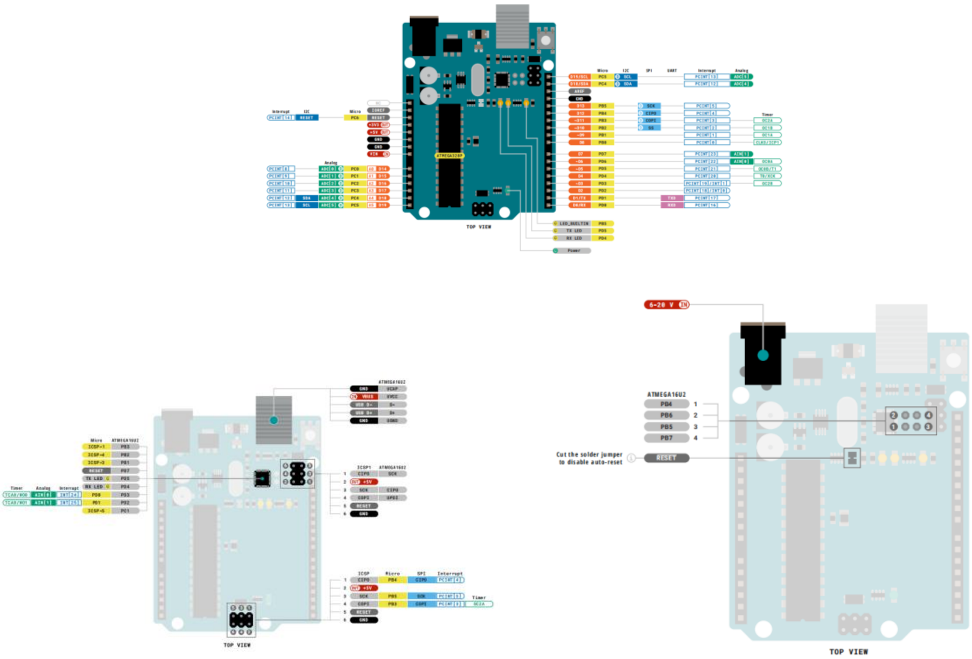


Figure 6 Pin Configuration

The system operation process is as follows: at the beginning of the program, the digital IO pins are initialized, and then the chassis wheelset is driven. After reaching the working position, it stops. Then turn the turntable and place the chili seedlings. Finally, the drill bit and duckbill part are driven to descend for drilling and planting. After reaching the working position to complete drilling and planting, the mechanical structure design will start to return to the reference position.

V. Prototype Implementations

According to the design, verify the development prototype as shown in Figure 7. The test experiment shows that the transplanting machine has a 3-fold increase in transplanting efficiency compared to manual labor in deep sandy soil environments, with a transplanting success rate of ≥ 95%, making it suitable for deep sandy soil environments.

VI. Innovative Points

6.1 Structural Innovation

The chili transplanter in this article adopts an integrated design concept, integrating multiple functional modules such as walking, seedling transportation, drilling, and transplanting. Compared with similar models, the volume has been reduced by 40%. This integrated design not only reduces the footprint of the equipment and facilitates operation in narrow planting environments, but also simplifies the overall structure of the equipment, reducing manufacturing and maintenance costs. At the same time, the close coordination between various functional modules improves the overall operational efficiency of the equipment and reduces the time loss during the transplanting process.

6.2 Technological Innovation

In the pit drilling device, an innovative eccentric wheel mechanism is adopted, which can provide stable and efficient power for the drill bit, making it smoother when drilling into the soil and ensuring the stability of the pit hole. Compared with traditional drilling methods, this design greatly reduces the risk of hole collapse and provides a better environment for the growth of chili seedlings.

The precision of seedling tray gap separation technology has reached ± 2mm. By precise control of the gap structure and turntable movement, precise separation and delivery of chili seedlings have been achieved. This high-precision seedling separation technology effectively improves the accuracy of transplanting and reduces the problem of transplanting failure caused by inaccurate seedling separation.

6.3 Application Innovation

This transplanter is specifically designed for sandy soil environments, filling the market gap for miniaturized transplanters in this field. In the past, sandy soil environment has always been a difficult point for the application of transplanting machinery due to its special soil properties. This transplanting machine has successfully achieved stable operation in sandy environments by optimizing key components such as the walking device and drilling device, providing an effective mechanized solution for farmers planting chili peppers in sandy areas.

VII. Conclusion

This article designs and develops a pit type chili seedling transplanter, which achieves full automation of the entire process of digging holes, picking seedlings, dropping seedlings, transplanting, and covering soil during chili seedling transplantation through a series of innovative designs and experimental verifications. Through the demonstration and verification of a physical prototype, the transplanting efficiency and success rate of the transplanting machine are significantly better than traditional manual transplanting methods in deep sandy soil environments, achieving the expected goals of the project. This not only provides an efficient and convenient transplanting equipment for chili growers, but also offers new ideas and practical experience for the development of smart agricultural equipment.

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