Computers and Electronics in Agriculture 147 (2018) 131–145

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Design of seedlings separation device with reciprocating movement seedling cups and its controlling system of the full-automatic plug seedling transplanter

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ARTICLE INFO

Keywords:
Vegetable plug seedling
Automatic transplanting machine
Seedling separating device
Gear rack mechanism
Test

ABSTRACT

In this paper, it is described the design of seedling separation device with reciprocating movement of seedling cups and control system of the full automatic plug seedling transplanter. The analysis of the research indicates that the specific strategic path seedling is plane and corresponding control system is formulated. It is put forward special intention on the specific designing of the main components (transplanting device, seedling device and seedling cup) of the seedling separation device. The linear driving motor and driving cylinder are used to control the reciprocating motion, open and close mechanism of mobile seedling cups. The control schemes of the seedling picking, seedling transmission and seedling dropping are designed in detail. It is assured the control program of picking of seedling in the fixed position and the transmission of seedling rapidly and dropping of seedling in the fixed position. The positioning accuracy tests of the linear transmission device and the success rate tests of the seedling device are carried out separately. It is found that the positioning accuracy of a linear transmission device decreased gradually with the increase of seedling speed, especially when the motor pulse frequency exceeds 20,000 Hz. The motor gets out of steps and the precision will drop rapidly. After that it is optimized the motor by setting different pulse frequencies, and fix the range of error values between 0.2 mm and 0.8 mm which is according to the requirement of seedling location. The results of seedling tests of seedling device indicate that the qualified rate of seedling decreases gradually with the increase of seedling speed and the success rate of 70 working cycles/min is 95.03%. This demonstrates that the structure of mechanical components of seedling separation device meets the sub-seed movement requirements. The optimization of the control system could increase the position accuracy according to requirements and achieve the goal of automated sub seedlings.

1. Introduction

With the development of agricultural machinery automation, agricultural economic level increases gradually, many industries are manufacturing automatic planters to plant evenly grown seedlings, which greatly reduces the time and labor requirements (Tian et al., 2010). Transplanting plantation area is quarter of the total vegetable plantation area of China, transplanting plantation will be the future direction of national agricultural production. (Lu et al., 2011; Zhang et al., 2012). However, automation of vegetable transplanting plantation is not yet universal, the seedling device is one of the most important part of transplanter and seedling process is done manually in domestic. (Zhang et al., 2009), The higher labor intensity and lower efficiency of the operation by hand make it difficult to apply on large scale production so, it is urgent need of time to achieve automation of plug seedling transplanting in china (Tian et al., 2010).

The seedling transplanting technique was studied firstly in the United States and Japan. Hand-feeding seedlings planting machinery had emerged in the beginning of the last century, a variety of semi-automatic transplanting machines and different hand-planted devices were developed around 1950, at the end of the previous century, semi-automatic transplanting machine has been widely applied in agriculture production. In 2002, Choi et al. developed a new catching seedling device for transplanting vegetable composed of a clip pointer, a track generator and a pointer driver, based on experiment of 23 days tomato seedlings, the transplanting rate of this device was 30 seedlings per minute and transplant success rate was high as 97%. (Zhang et al., 2013); With the method of catching seedling on negative pressure,

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https://doi.org/10.1016/j.compag.2018.02.004
Received 24 August 2017; Received in revised form 20 December 2017; Accepted 5 February 2018

automatic vegetable transplanter based on air the whole seedling plate for seedlings nurtured on special inverted conical hard seedling plate was developed by American company Renaldo in 2003 (Han et al., 2011); With higher operating speed and better degree automation, Hd144 four and six rows of automatic transplanter in Australia adopted advanced needle-type catching seedling robot to take out 4 to 6 seedlings in plug plate placed vertically for one time, then the seedlings was transferred to transporting cup for the second cast seedlings(Cui et al., 2015). A global positioning system guided automated rice transplanter was developed by Nagasaka Y and his team from National Agriculture and Food Research Organization, it was guided with only tilt corrected GPS position data during straight driving and had advantages of a lower cost system and more precise operation in August 2013 (Nagasaka et al., 2013).

In the present age, the researchers in China began to realize the commercial value and advantages of automatic transplanter, therefor researchers from different fields have worked together to develop efficient automatic transplanter. (Jiang et al., 2009). Inverted tray type automatic seedling fetching and seedling separating device developed by professor Luo and his team from Shihezi University was driven by the motor and the reducer together, which could reduce the damage of the bowl seedlings, improve the production efficiency and easy operation and achieve efficient and continuous automation operation in June 2010. (Cheng et al., 2012). Li pole machine divided cutting seedling pick-up device proposed by professor Shu from Huazhong Agricultural University could realize the function of seedling fetching in a row and seedling separating in a single row and correct the stalk posture, reduce the damage of the seedling in November 2012 (He et al., 2013). Longitudinal seedling feeding mechanism proposed by professor Zhao from Northeast Agricultural University, it had a simple structure, and damage the seedling plate relatively small in November 2013, (Na et al., 2015). Seedling method of seedling fetching in a row and seedling separating in interval row proposed by professor Guo from Jiangsu University could catch seedlings indirectly and separate seedlings according to parity, seedlings fall from two seedling mouth in August 2015 (Guo, 2016). The method of interval of seedlings, seedling separating mechanism of paper row bowl seedling transplanter proposed by professor Hu from Heilongjiang Bayi Agricultural University, it was able to separate the paper seedling plate quickly and it had stable cutting speed, cutting evenly, high efficiency, (Song et al., 2016).

Characteristics of photoelectric sensor are quick response, strong positioning ability and others. With function of automatic control, PLC can improve operating efficiency and automated degree of the automatic transplanting system effectively when it applies to the automatic transplanting system of plug seedlings. (Tian et al., 2017). In this study, the automatic transplanting system is based on photoelectric sensor and PLC, the photoelectric sensors are installed at both ends of the frame, the stepper motor begins to perform straight round trips according to the instructions, the cylinder waits for the photoelectric sensor signal and then reacted, the wiring of each part are connected to the PLC for unified control to achieve automated seedling of seedling device.

The seedling device is a very important component of a transplanting machine. The structure of the seedling device directly determines the seedling rate and the planting speed. Therefore, it has a very broad market application prospect to develop a seedling device caring reciprocating mobile seedling cup with a simple structure, rapid reaction and easy driving. In this paper, the restricted movement route and control scheme of the seedling device are designed and analyzed. The transplanting device, seedling dropping device and seedling cup are designed specially. The control system of the seedling device is developed in detail. The experiments are conducted to test the positioning error and the success rate of seedling separation.

2. Materials and methods

2.1. Design of overall program

According to requirements that seedlings separation needs to meet, the overall seedling separation device is designed with a automatic program including catching seedlings at a fixed position、fast separating seedlings and casting seedlings at a fixed position. The specific seedlings separation step is analyzed to develop a matching control system.

2.2. Design of specific mechanical structure

According to overall program, seedling separation device designed involves following major components: rack, linear transmission device, opening and closing device of cylinder and seedling cup. Linear transmission device is responsible for transporting seedlings to the designated place; Opening and closing device of cylinder is responsible for casting seedlings at a fixed position to provide convenience for subsequent transplanting; Seedling cup is responsible for picking, transporting and dropping seedling. Structures of all components is designed in detail.

2.3. Design of electrical control system

For fulfilling requirements of positioning accuracy of linear transmission device、 linear speed and other related parameters, the appropriate PLC, stepper motor and drive, cylinders and magnetic switches, photoelectric sensors are selected to assemble hardware components of control system. In order to improve positioning accuracy and stability of control system, PLC ladder program of XC series is used to repeated correction and optimization of operation of each part.

2.4. Development and test of prototype

A prototype is established after process and assembly of parts and components. The positioning accuracy test and the seedling separation success rate test of linear transmission device are carried out on the prototype to explore factors that affect positioning accuracy and success rate.

3. Operation principle and control scheme analysis of seedling device

3.1. Design of separating seedlings route

Seedlings separation device is installed on rack, seedling cups are driven by linear transmission device to separate seedlings reciprocally, a single operating cycle of linear transmission device as follows:

1. Catching seedlings device reaches at the designated position firstly and waits for seedling cups to reach catching seedlings position point A;
2. Four seedling cups on linear transmission device start to move into separating seedlings path after catching seedlings, which means the first round of seedlings separation is started;
3. When four seedling cups reach at position B and C then two seedling cups open and fall seedlings down;
4. The two seedling cups close and return to separating seedlings path where another two seedling cups prepare for starting the second round of seedlings separation;
5. When four seedling cups reach at position B and C again, another two seedling cups open and fall seedlings down;
6. Four seedling cups on linear transmission device returns to point A to wait for the next round of separating seedlings when one round of separating seedlings have been finished.