Development of Automatic Transplanter for Plug Seedling

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Abstract: Transplanting is one of the most important operations during vegetable and flower production. Because of the higher labor intensity and lower efficiency for the operation by hand, it is difficult to enlarge production scale. So, it has become an urgent task to achieve automation of plug seedling transplanting for Chinese horticulture industry. In this paper, on the basis of knowing the development of transplanting technology and transplanter both domestic and abroad, a simple, practical and automatic transplanter for plug seedling, including manipulator, conveyor system for plug tray and flowerpots, overall structure and control system based on PLC was designed. Finally, Prototype was manufactured and performance tests were conducted. Results showed that the automatic transplanter had reliable transplanting performance.

Keywords: Automatic transplanter; Plug seedling; Manipulator; End-effector; PLC.

1. INTRODUCTION

Greenhouses have been used in agriculture widely all over the world. In recent years, facilities-based vegetables and flowers industry, such as solar greenhouse and vegetable greenhouse, has developed rapidly, and more plants now use automatic seeders and seedling growth monitoring systems to produce uniform seedlings with reduced time and labour requirements in greenhouse. Transplanting is one of the most important operations during vegetable and flower production, but plug seedling transplanting is waste of workforce and is a labor-intensive and low-efficient operation, which is still operated by hand and the environment is terrible, where it is always wet and foggy, so it constrains development of seedling nursing technology in China. In order to achieve industrialization production, plug seedling transplanting operation of mechanization and automation is necessary.

Research for the development of a transplanter began several years ago. Hwang and Sistler (1986) developed a commercial pepper transplanter using a basic robotic manipulator. Kutz et al. (1987) studied the feasibility of seedling transplanting by utilizing a Puma 560 articulated robot with a parallel-jaw-type gripper. Ting et al. (1990) developed a plug transplanting work cell based on an AdeptOne selective compliance assembly robot arm type robot. Sylvester and Tesch (1993) invented a seedling array transplanter, which consisted of a transplant head, a pneumatically mechanical linkage, a carriage, and a computer controller. Onosaka and Okuno (1996) developed a transplanter, which can be operated rapidly and has been used commercially. Ryu et al. (2001) used Cartesian coordinate axes to develop a robotic transplanter for bedding plants, produced good transplanting performance. In China, Fan et al. (1996) developed an air-pruning and air-suction type of automatic thansplanter in Jilin University of Technology; Lv et al. (2003) studied an air pressure type of adjustable transplanter for plug seedlings in Taiwan, but it had low productivity; Qiang and Zhang (2005) designed an automatic transplanter for lettuce in China Agricultural University, but it can transplant one kind of vegetable and had low level of intelligence.

The purpose of the present study is to develop a simple, efficient, practical and automatic transplanter for plug seedling in greenhouse, which is important to promote development of production automation of seedling nursing and transplanting in China. The main objectives of this study were: (1) to develop a structurally simple end-effector which can grip and release seedlings reliably; (2) to develop an overall structure of automatic transplanter; (3) to design an control system of automatic transplanter; and (4) evaluate the performance of the transplanter by experiment.

2. MATERIALS AND METHODS

The automatic transplanter developed consisted of four end-effectors, gantry-gate arm, conveyor systems of plug tray and flowerpots and control system. Gantry-gate arm was designed to move the end-effectors to the desired position. After the end-effectors were located to the desired position, each end-effector gripped a seedling from the plug tray and released it in a flowerpot. The trays and flowerpots were carried by the conveyor systems of plug-tray and flowerpots to the predefined working space of the end-effectors.

2.1 End-effector

Based on comparative analysis of current status of transplanting end-effectors, the shovel-shaped needle and pneumatic-driven end-effector was used. First, some experiments of physical properties of plug materials such as gravity (G) and adhesion force (K) were conducted. Adhesive force is defined as the force that wall of tray sticks to plug when plug seedling being gripped from tray cell. There are three needles on each end-effector, so one needle can be loaded adhesive force that is $K/3$. Secondly, the forces between plug and one needle of end-effector were analyzed when the needle penetrating the plug (Fig. 1). The definition of α is the angle between the needle and vertical central line of plug. N is the normal load that the needle obtained when plug seedling being gripped from tray cell, and Ff is friction force between needle and plug. Finally, a mathematic model (1) describing relation between the forces and penetrating angle was developed along y axis, which provided a basis for structural design of end-effector.

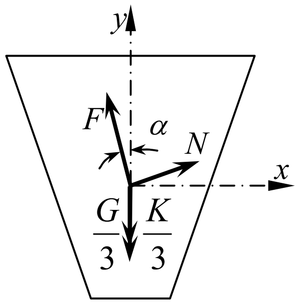

Fig. 1 Force analysis diagram between plug and one needle

According to Fig. 1, the equations are obtained as following:

$$F_f \cos\alpha + N \sin\alpha = G/3 + K/3 \qquad (1)$$

$$F_f = \mu N \qquad (2)$$

Then, the relation of the loaded forces of plug and penetrating angle can be derived from (1) and (2), which is as following:

$$N = \frac{G+K}{3(\mu\cos\alpha + \sin\alpha)} \qquad (3)$$

Finally, the suitable penetrating angle of needle (α=10°) was determined by calculation from equation (3) after the value of the parameters including G, K, N, and constant friction coefficient (μ) of plug having been given.

With the help of software of Solid Works and ADAMS, the three different kinds of structure of sliding block-lever type, connecting bar-needle type and sleeve-needle type transplanting end-effector (Fig. 2) were designed and manufactured. It was observed that the sleeve-needle type was the best design and this type of end-effector was used in a prototype of the transplanter. By comparison between the dynamic simulation of left needle movement trajectories and real track taken by a high-speed digital imaging camera (Fig. 3), they are proved to be consistent.

1) Sliding block-lever type 2) connecting bar-needle type 3) sleeve-needle type

Fig. 2 Photographs for three kinds of end-effector

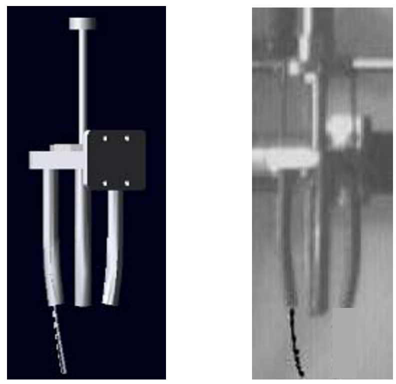

Fig. 3 Comparison simulation movement trajectory and trajectory taken by high speed digital imaging camera for needle of end-effector

2.2 Gantry-gate type arm and Conveyor system

A parallel conveyor system of plug trays and flowerpots with a gantry system (vertical and horizontal transmission structure of mechanical arm and guide mechanism) was manufactured after conducting an optimization design by using Solid Works and ADAMS software. Four end-effectors were able to be attached or detached by a detachment and attachment guide mechanism. The whole automatic transplanter including all mechanisms was designed successfully including hands detachment and attachment guide mechanism, vertical and horizontal transmission structure of mechanical arm and guide mechanism, conveyor systems of plug seedling and flowerpots and their driving device based on a virtual prototype theory (Fig. 4).