J. agric. Engng Res. (2001) **78** (2) 141–146
doi:10.1006/jaer.2000.0656, available online at http://www.idealibrary.com on IDEAL®
AE—Automation and Emerging Technologies

Development of a Robotic Transplanter for Bedding Plants

K. H. Ryu; G. Kim; J. S. Han

Department of Agricultural Engineering, Seoul National University, Suwon, Korea 441-744;
e-mail of corresponding author: Giyoungkim@hotmail.com

(Received 1 November 1999; accepted in revised form 21 September 2000; published online 6 December 2000)

This study was carried out to develop a robotic transplanter for bedding plants. The transplanter consisted of a manipulator, an end-effector, plug tray conveyors and a vision system. The manipulator consisted of two electrical linear motors. It was used to move the end-effector to the desired working position. The end-effector, which picks up a seedling from a high-density plug tray and moves it to a low-density growing tray, comprises two air cylinders and fingers. The conveyors, which move the plug trays to the desired position, were driven by servomotors. The vision system was used to identify empty cells and to reduce transplanting time. The transplanter developed in this research was tested with a range of seedling type, growth stage, growing medium and moisture content, and produced good transplanting performance.

1. Introduction

Labour shortage in greenhouse production systems has made growers become interested in automating greenhouse operations. More growers now use automatic seeders and seedling growth-monitoring systems to produce healthy and uniform seedlings with reduced time and labour requirements. However, seedling transplantation, which is a labour-intensive task, is still performed manually. In a greenhouse production system, seeds are germinated in the high-density trays. At a certain growth stage, the seedlings are transplanted into low-density growing trays for further growth and development. During transplantation, seedlings are handled many times to replace bad or missing plants with healthy ones. Using a robotic transplanter could reduce the labour requirement of seedling transplantation by carrying out repetitive tasks in an accurate and reliable manner.

The robotic transplanter needs to be designed differently from an industrial robot because it manipulates biological seedlings of variable size, shape, colour, position and orientation. These non-uniform working conditions are quite different from those of the industrial robot, which deals with uniform objects in a defined spatial configuration. When designing a robotic transplanter, the important variables which must be considered for each crop are: the species of crop, growth stage, type of seedling plug tray and growth media used.

Research for the development of a robotic transplanter and its components began several years ago. Hwang and Sistler (1986) developed a commercial pepper transplanter using a basic robotic manipulator. Simonton (1991) developed an end-effector for the handling and manipulating of geranium cuttings. He controlled the position, velocity and force of the end-effector to minimize damage to the petioles and main stem. An end-effector which utilized a rack and pinion mechanism was developed by Kim *et al.* (1995). The end-effector converted rotational motion of the stepping motor to the clipping motion of the finger.

Computer simulation was utilized to design a robotic transplanter. Kutz *et al.* (1987) used a computer graphics system to simulate the transplanting operation of an industrial robot. In this paper, the feasibility of using a robot for transplanting bedding plants was evaluated by validating the results of simulated transplanting operation by the actual performance of the robot. Computer modelling was also used to improve an end-effector design. Brewer (1994) modelled a conceptual transplanter on a computer to correct the deficiencies of the automated field transplanter, which transferred seedlings from tray to module.

Developing a robotic transplanter requires specialized gripping fingers. Ting *et al.* (1990) developed a needle type of end-effector operated by pressurized air that could be used for a wide range of seedling shapes and sizes. A robotic transplanter often requires a machine vision system to identify and locate empty positions in the seedling trays. Beam *et al.* (1991) used a machine vision system to inspect the results of seedling transplanting to detect unsuccessful operations. Tai *et al.* (1994) developed a machine-vision-assisted robotic transplanting system to improve the quality of transplanted seedling trays. The machine vision system was able to locate empty cubes and guide a robotic transplanter to re-transplant healthy plugs into empty cubes.

The purpose of the present study was to develop an efficient robotic transplanter for bedding plants in a greenhouse. The main objectives of this study were: (1) to develop an efficient robotic transplanter; (2) develop a structurally simple end-effector which can pick and place seedlings reliably; and (3) evaluate the performance of the transplanter with respect to handling seedlings.

2. Materials and methods

The robotic transplanter developed consisted of an end-effector, a manipulator, a vision system and plug-tray transfer units. The manipulator was designed to move the end-effector to the desired position. After the end-effector was located to the desired position, the end-effector picked up a seedling from a plug tray and placed it in a growing tray. The trays were carried by the plug-tray moving units to the predefined working space of the manipulator. The vision system was used to identify empty cells and cells missed in the transplanting process.

2.1. *Manipulator*

The manipulator used Cartesian coordinate axes, labelled X and Y, to specify the position of the end-effector and seedlings. Linear motion along the two axes was performed using slide actuators. Linear-motion guides were attached to ensure the linear motion along the axes and to reduce vibration of the actuators. The linear-motion guides and the actuators were supported and connected by an aluminium frame. Since the end-effector was attached to the low end of the vertical Z axis, of the manipulator, the manipulator also anchored the air pipes that provided pressurized air to the actuators of the end-effector.

The control of the slide actuators in the manipulator was performed by a microcomputer. Based on the information from the vision system, the moving distance and the speed of the slide actuators were calculated by the microcomputer. The calculated results were transferred to a control unit to operate the slide actuator driver units. Finally, an electrical signal from the slide actuator-driver units controlled the direction and speed of the slide actuators. *Figures 1* and *2* show the schematics of the manipulator and the manipulator assembly with the end-effector, respectively.

2.2. *End-effector*

An end-effector mechanical design using a pneumatic system was developed to successfully grip, hold and release a seedling plug during transplanting. Two types of end-effectors were developed and tested.

One end-effector (type A) consisted of a stepping motor, an air cylinder, an air chuck and gripping fingers. The type A end-effector, which could be rotated by the stepping motor, responded to the orientation of the plant to avoid damaging the leaf. The air cylinder enabled the

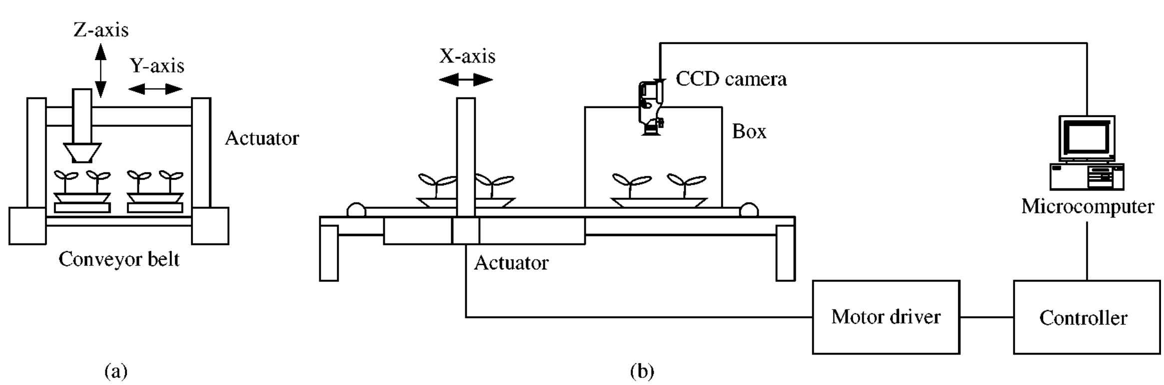

Fig. 1. The schematics of the robotic transplanter: (a) the front view of the manipulator; (b) the side view of the manipulator, the tray moving system and the vision system

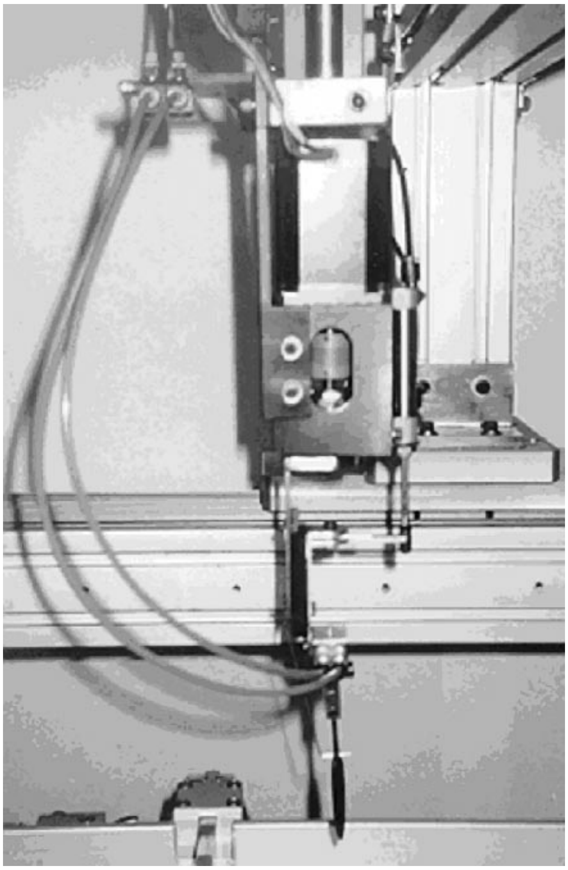

Fig. 2. *Photograph of the manipulator assembly with type A end-effector*

fingers (attached at the air chuck) to penetrate into the soil. The end-effector could grasp and hold a seedling by the opening and closing motion of the air chuck. *Figure 3* shows the schematics of the type A end-effector operating parts. The transplanting mechanism of the type A end-effector is shown in *Fig. 4*.

Specifications for end-effector components were determined based on their task. The stroke and size of the air chuck were determined by the required stroke for transplantation and the size of the plug tray cell, respectively. The inner diameter and size of the air cylinder were determined based on the cylinder load applied and the depth of the plug tray, respectively. The total load was equal to the weight of the air chuck, fingers, a seedling and attached growth media. A linear-motion guide was installed near the air cylinder to prevent rotation of the air cylinder rod and to guide the motion of the gripping fingers. To determine the specifications for the air cylinder, operating air pressure and airflow rate were used. Solenoid valves controlled the operation of the air cylinder and the air chuck by regulating the direction of the airflow.

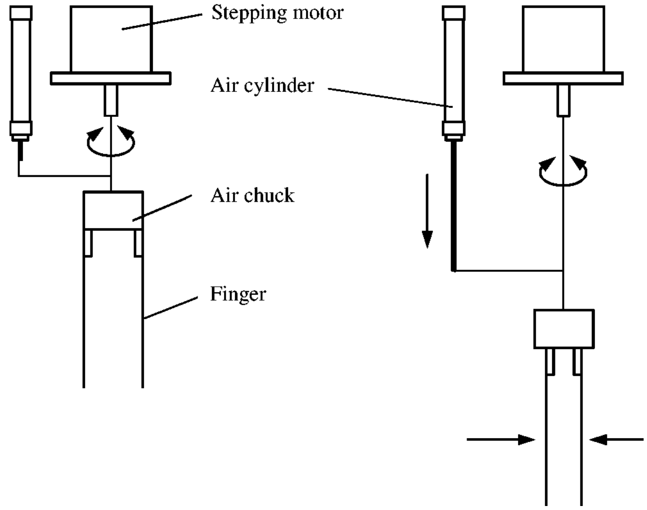

Fig. 3. Schematics of the type A end-effector operating parts

The length of the gripping finger that picked up the seedlings was determined by the depth of the plug tray. Four types of fingers were designed and tested (*Fig. 5*).

Results of performance tests showed that using the type A end-effector could result in an unacceptable transplanting performance when the moisture content of the growth media was low. To overcome this limit, the type B end-effector was developed. The design of the type B end-effector consisted of two air cylinders and gripping fingers. The air cylinder enabled the fingers to penetrate into the soil. The type B end-effector could grasp and hold a seedling by sliding the two fingers, which were attached to the two separate cylinders and, mounted at an angle of 15°, as depicted in *Fig. 6*. Press-plates were

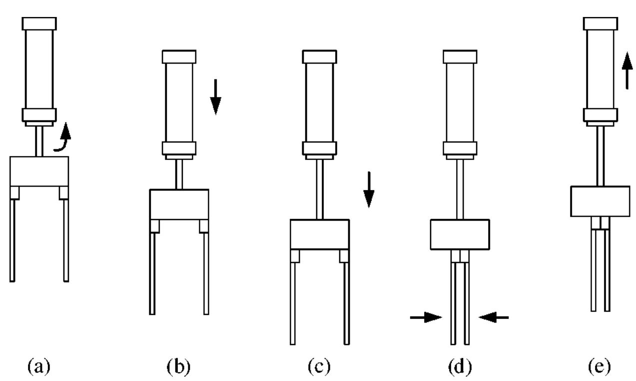

Fig. 4. Mechanisms of the seedling transplanting by type A end-effector: (a) fingers are first rotated according to the leaf direction; (b) and then the end-effector is lowered by the manipulator; (c) the fingers are penetrated into the growth media by pushing the air cylinder; (d) the fingers, actuated by the air chuck, grip the root portion of the seedling; and finally; (e) the seedling is pulled out by retracting the air cylinder rod

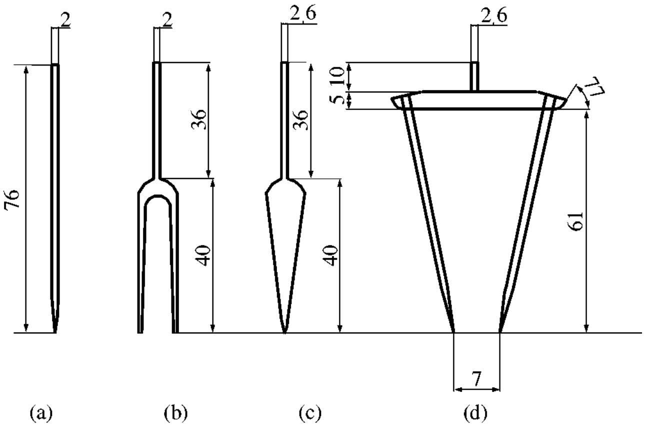

Fig. 5. Shape and dimensions of the fingers developed: (a) needle I; (b) fork; (3) shovel; and (4) needle II; all dimensions in mm

attached to the end of the end-effector and so improve the reliability and performance of the release mechanism. *Figure 7* shows all steps of the type B end-effector transplanting.

2.3. *Machine vision system*

A vision system was used to monitor seedling transplanting. The system consisted of a colour charge coupled device (CCD) camera, a frame grabber and IBM compatible 486 DX66 computer. To identify empty cells, information about the seedling leaves was analysed. The vision system detected empty cells in high-density plug trays by counting and comparing the number of white pixels representing the seedling leaves with a pre-defined value. If a cell was identified as empty it was omitted from transplanting to reduce the transplanting time.

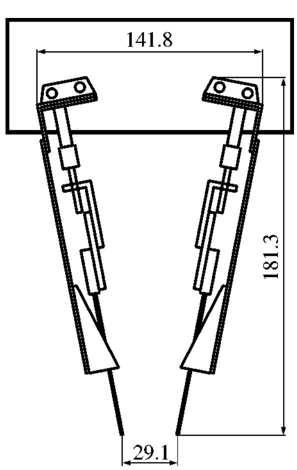

Fig. 6. Schematic diagrams of the gripper operating parts; all dimensions in mm

The vision system was also used to determine the leaf direction of the seedlings. The type A end-effector was rotated according to the leaf orientation in order to minimize damage to the seedlings.

Performance of the vision system was evaluated by identifying empty cells in 72-cell trays and 128-cell trays. Cucumber seedlings (16 days after planting) were used to evaluate the performance of the vision system. The seeds had been sown in trays that contained peat moss as growth media and were grown in a greenhouse until ready for transplanting.

2.4. *Seedling-tray transfer units*

The seedling-tray transfer unit was designed to move a high-density plug tray and a low-density plug tray to the manipulator working space. The system consisted of two conveyors and several photo-sensors. The photo-sensors detected the front-edge of a plug-tray in the manipulator working space. After the entire row of seedlings was transplanted, the conveyors were moved forward to place the next seedling-row into the working space. This procedure was repeated until all seedlings in the plug tray were transplanted.

3. Results and discussion

The accuracy of the end-effector positioning was controlled within $\pm 1{\cdot}0$ mm for the specified planar coordinates. The positioning accuracy of the end-effector was adequate for the transplanting task that requires less than $\pm 3{\cdot}0$ mm of distance error from the centre of the plug cell.

To evaluate the performance of the robotic transplanter prototype, several consecutive tests were conducted. The first test examined the performance of the vision system. The second test was conducted to select an appropriate gripping-finger type. The third test examined the end-effector mechanism. Finally, overall system performance of the final design was evaluated.

To test the vision system, six trays were used for each of the tray types. Trays were prepared to have about 10% of empty cells for each tray by removing some seedlings randomly. The identification of empty cells in the 72-cell trays and the 128-cell trays had a 99 and 95% success rate, respectively. All identification failures were caused by an occluded leaf image that originated from tilted seedlings and extruding leaves from neighbouring cells.

To test the performance of the gripping fingers, 50 seedlings in each of 72- and 128-cell trays were transplanted to 50-cell growing trays using the type A end-effector mechanism. Test results showed that the

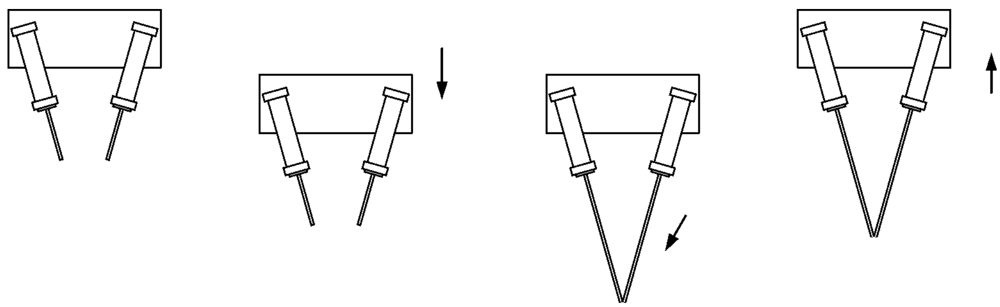

Fig. 7. Procedure of the seedling-transplanting by type B end-effector: (a) initial position; (b) the manipulator first lowers the end-effector; (c) the air cylinder pushes the fingers to penetrate into the growth media and to grip the root portion of the seedling; and finally, (d) the seedling is pulled out by retracting the end-effector

shovel-type fingers had the best transplanting success rate which was 96 and 98% for 72- and 128-cell plug trays, respectively. Other finger types produced a transplanting success rate of less than 90%. Transplants failed because: (a) a seedling was stuck to the tray cell; (b) a seedling was dropped when the manipulator was moving; (c) a seedling was stuck to the fingers and failed to plant; and (d) fingers damaged a seedling. The fork-type fingers damaged seedling leaves occasionally. Needle-type fingers resulted in the lowest transplanting success rates because of their poor gripping and holding capability. Based on these results, the shovel-type fingers were finally selected for the robotic transplanter.

Further tests revealed that the transplanting performance of the robotic transplanter with the type A end-effector was affected by the condition of growth media. When moisture content of the growth media was below 48%, the transplanting success rate dropped to 80%. Furthermore, finding the leaf orientation and rotating the end-effector according to leaf direction slowed the transplanting task. The task of determining the leaf orientation and rotating the end-effector required an average 2 s per seedling. To improve the end-effector design, the type B end-effector was developed as previously described.

The performance of the improved end-effector was tested with cucumber seedlings at different levels of soil moisture content. The difference in soil moisture content among seedling trays was created by controlling the irrigation rate artificially. Watering was stopped at 3, 2 and 1 day before the performance test. Moisture content ranges were 28–48, 44–59 and 55–66% for 3, 2 and 1 day, respectively.

To test the type B end-effector, three 72-cell trays for each of the different moisture levels were used. The best transplanting result was achieved at a medium level of soil moisture content. The success rates of transplanting for the different moisture content level were 92, 99 and 90% for 28–48, 44–59 and 55–66%, respectively. The success rate at the medium level of soil moisture content was significantly better than other levels with 95% confidence level.

The performance of the final version of the robotic transplanter was evaluated with various seedlings at the medium level of soil moisture content. Similar quantities of different seedling types were used: 225 of 16-day-old cucumber seedlings; 214 of 13-day-old cucumber seedlings; and 217 of 26-day-old tomato seedlings. Seedlings in 72-cell trays were transplanted to 50-cell trays to test the performance of the robotic transplanter. The success rates of transplanting were 97·8, 97·7 and 98·2% for 16-day cucumber seedlings, 13-day cucumber seedlings and 26-day tomato seedlings, respectively.

4. Conclusions

A robotic transplanter for bedding plants was developed and evaluated. The prototype transplanter was evaluated by performing transplanting operations with cucumber and tomato seedlings. The use of a vision system to monitor transplanting seedling was also evaluated. The overall robotic transplanter success rate in transplanting operation was around 98%. The vision-assisted robotic transplanter developed in this study could be used to reliably transplant seedlings into growing trays, to reduce labour requirements of the transplantation process.

References

Beam S M; Miles G E; Treece G J; Hammer P A; Kutz L J; Richey C B (1991). Robotic transplanting: simulation, design, performance tests. ASAE Paper No. 91-7027. St. Joseph, MI, USA

Brewer H L (1994). Conceptual modeling automated seedling transfer from growing trays to shipping modules. Transactions of the ASAE, **37**(4), 1043–1051

Hwang H; Sistler F E (1986). A robotic pepper transplanter. Applied Engineering in Agriculture, **2**(1), 2–5

Kim K D; Ozaki S; Kojima T (1995). Development of an automatic robot system for a vegetable factory. I. Transplanting and raising seedling robot in a nursery room. Proceedings of ARBIP95, Vol. 1, pp 157–163. Kobe, Japan

Kutz K C; Miles G A; Hammer P A; Krutz G W (1987). Robotic transplanting of bedding plants. Transactions of the ASAE, **30**(3), 586–590

Simonton W (1991). Robotic end-effector for handling greenhouse plant material. Transactions of the ASAE, **34**(6), 2615–2621

Tai Y W; Ling P P; Ting K C (1994). Machine vision assisted robotic seedling transplanting. Transactions of the ASAE, **37**(2), 661–667

Ting K C; Giacomelli G A; Shen S J; Kabala W P (1990). Robot workcell for transplanting of seedlings. Part II: end-effector development. Transactions of the ASAE, **33**(3), 1013–1017