Proceedings of the International Conference for Agricultural Machinery & Process Engineering
October 19-22, 1993, Seoul, Korea

A Robotic System for Transferring Tobacco Seedlings

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ABSTRACT

Germination and early growth of tobacco seedings in trays containing many cells is increasing in popularity. Since 100% germination is not likely, a major problem is to locate and replace the content of those cells which contain either no seeding or a stunted seeding with a plug containing a viable seedling. Empty cells and seedlings of poor quality take up valuable space in a greenhouse. They may also cause difficulty when transplanting seedlings into the field. Robotic technology, including the implementation of computer vision, appears to be an attractive alternative to the use of manual labor for accomplishing this task. Operating AGBOT, short for Agricultural ROBOT, involved four steps: (1) capturing the image, (2) processing the image, (3) moving the manipulator, (4) working the gripper

This reseach was designed and constructed a robotic system specifically tailored to transfer seedings within a cell-grown environment. The configuration of the cell-grown seedling environment dictated the design of a Cartesian robot suitable for working over a flat plane. Experiments of AGBOT performance in transferring large seedings produced trays which were more than 98% survived one week after transfer. In general, the system generated much better than expected.

Key Word : Agricultural Robot, Gripper, Computer Vision, Spectroscopy, Infrared Sensor, Transplanting Seedling, Tobacco

INTRODUCTION

It seems apparent that robotic systems for agriculture will have to be "tailored" for specific applications in order for them to be economically feasible. Research is proceeding along three lines : [1] The development of an economical agricultural robot, [2] development of agricultural grippers, and [3] integration of computer vision and other sensors.

The first applications of agricultural robots will probably be in those areas where there is some semblance of order, e. g. products flowing on a belt and products in an organized tray system. A Cartesian (X-Y-Z) robot appears to be an optimum configuration since it lends itself to handling agricultural products arranged on a plane, flowing on a belt, in trays, etc. Furthermore, it is quite flexible and can be constructed more economically than other configurations.

Computer vision will play an important role in the application of robotics to agriculture. By implementing imaging spectroscopy the system can take advantage of the absorption characteristics of the product in order to enhance the desired image while, at the same time, reducing the background noise.

Cell-grown seedling technology would be much more attractive if there was a way to assure that each cell contained a viable plant. Since 100% germination is almost impossible, an alternative approach seems desirable. Manual insertion of plants into cells containing no plant, or a bad plant, is time consuming, tedious and costly. Therefore, mechanization of this operation is essential if cell grown seedlings are to become an attractive alternative in plant production.

Robotic systems, incorporating computer vision, appear to be an attractive alternative with a high potential for success. Such a system would have two trays, an "acceptor" tray and a "donor" tray. A robot incorporating computer vision could identify "empty" cells in the acceptor tray and take appropriate action to fill those cells with viable plants from the donor tray.

There are four purposes of this research : (1) to implement a X-Y-Z robot to move tobacco seedlings from a donor tray to an acceptor tray, (2) to design a gripper to pick up and release plugs, (3) to enhance the image of the tobacco seedlings by using computer vision to detect the presence and quality of plants in each cell and (4) to develop software for integrating the above three robotic components for making transfers of cell-grown tobacco seedlings.

MATERIALS AND METHODS

1. Hardware design

The robotic system designed and constructed for this project (called AGBOT) was composed of a Cartesian manipulator, a gripper (or hand), a digital-matrix camera (or eye) with a narrow-band interference filter wheel and an IBM/XT computer (or head). A block diagram od AGBOT is shown in Figure 1.

(1) The Vision System

The camera power supply was mounted on the horizontal bar near the camera. Image information from the camera was transferred the power supply box to the IBM PC/AT computer over coaxial cables. An image capture board (Model DT2851) coordinated the transfer of images from the camera to the computer. The real-time images of two trays sitting side by side could be displayed on a Panasonic Video Monitor (Model MW-5410). The light source for ordinary black\white image detection was overhead fluorescent lamps already monted on the ceiling of the laboratory. Tungston lamps with a color temperature of approximatetely 3,000 Kelvin were used to illuminate the trays for performing imaging spectroscopy.

The Data Translation DT2851 frame grabber board can digitize, display and process multiple images with spatial resolution of 512 x 512 pixels with 0 (black) to 255 (white) intensity levels. However, the Parosonic monitor screen had a spatial resolution of 512 x 480 pixels. All image processing functions were performed on the whole image, even though the monitor could not display all of the resulting information.

The WV-CD50 camera had a 512 x 512 matrix array sensor and operates like an ordinary camera. the focal length of the lens was 12.5 mm with an aperture which could be adjusted from maximum value of f/1.3 to minimum value of f/16. The camera viewed an area of 91 cm by 76 cm at a distance of 140 cm from the working surface.

(2) AGBOT: The agricultural robot

AGBOT, a Cartesian robotic manipulator, was built in the Research Shop of the Department of Biological and Agricultural Engineering at North Carolina State University.

AGBOT is Cartesian coordinate robotic manipulator. It has three perpendicular axes (X, Y and Z) making it capable of picking up and transferring objects within a working volume measuring 75 cm x 75 cm x 35 cm high. The gripper platform can be moved horizontally over a square working surface using the X-Y axes.

Stepper motors are used to drive the X, Y, Z and W axes. Linear motion is created through the use of the timing belts which are coupled to the motor pulleys and attached to the twin ball bushing carrying the axes. The W axis (end effector actuator) stepping motor drives a lead screw which activates the end effactor.

The actuator system consists of an American Micro System (AMS) smart motor controller card containing four, independent, motor controller circuits, four translator modules and power supplies and four stepping motors to move the AGBOT manipulator within the its work space and to activate the gripper.

(3) Gripper

AGBOT was designed with a general purpose platform which made it easy to attach grippers of various designs. Three grippers were designed, one with four spades, an end effactor consisting of four needles which could provide gripping if necessary and a single-needle accessory with no gripping action. Only the spade end effectors was tested during this project. The needle end effectors were not tested.

The spade gripper (refer to Figure 2) was designed to pick up a plug, consisting up of a soil-type medium, requiring support from four sides in order to avoid disturbing the seedling root system. Each spade was trapezoidal in shape (measuring 2.8 cm at the top, 1.4 cm at the bottom and 4.1 cm in height) to fit the traperzoidal shape of the cells in the plastic trays. The spades were made of spring steel to provide some flesibility on insertion into the growing media and to flex when gripping the plug.

Pickup and release of the plugs was accomplished by activating the W axis motor. Turning the motor CCW caused the screw block to descend, pushing out on the spade link. This action caused the top of the spade handle to move outward, closing the spades. Turning the motor CW caused to screw block to ascend, pulling in on the spade link. This action cause the top of the spade handle to move inward, opening the spades. The distance between the tips of the spades in the fully opened position was 3.81 cm: fully closed, 1.27 cm.

2. Software Design

The AGBOT program was a menu driven program written in Microsoft c within a PC/AT environment. It implemented both control of the robot and griphics on an EGA monitor. The Main Menu (see Figure 3) was divided into three major sections: GENERAL-WORK, IMAGE PROCESSING and HELP. Each section was designed with three subsections.

The GENERAL-WORK section contained three subroutines called ROBOT ONLY (for actuating to robot by itself), SPADE WORK (for the tansfer of seedling under camera control) and NEEDLE WORK (for the transfer of black/white styrofoam chips), the latter was used only for demonstration purposed. the IMAGE PROCESSING section included the HISTOGRAM, fILTERING and LINE subroutines. The third, or HELP , section included the subroutines EXIT, DOCUMENT and IMAGE DATA. Each sbroutine listed above (except only the EXIT subroutine) had than one menu.

The MAIN menu (see Figure 3) is easily implemented by pressing a keypad key (KPK) on the keyboard. By pressing the cursor keys, the user can any of the three major subroutines. Continued manipulation of the KPK will enable the user to reach any of the major subroutines in each of the three subsections. After a user views a subsections, the user can run a subroutine by positioning the highlighting and pressing the ENTER key.

In order to develop the software for our research, we used the DT2851 image capture board(card) and the PCMC motor control board(card). Using the two cards in the computer, we developed two basic programs. The first program was the grabber program to capture the image data by using the DT card. The second program was the movement program for the robot movement using the PCMC card.

3. Ferformance Tests

(1) Plant Detection

The Max-Average algorithm was based on subjective comparisons with the Average filter and Roberts 2 x 2 operator using the ALGORITHM subroutine (refer to "Lee (1990)"). Three image processing techniques were used to enhance computer vision detection of tobacco seedling in the two trays: (1) Labeling by thresholding of the original black/white image, (2) Max-Average filtering of the original black/white image and (3) Imaging Spectroscopy.

Performance data were collected from 48 trays of plants, each tray containing 162 cells. Dicisions by the computer were compared with operator decisions. There were two possible decisions by computer, a seedling was present or a seedling was not present in the cell. The operator had the option of the same two decisions. Hence, there were four possible classificationss of success/errors: (1) the computer "said yes" a seedling was present and the operator "said yes" a seedling was present (CYOY), (2) the computer "said yes" a seedling was present but the operator "said no" a seedling was not present (CYON), (3) the computer said a seedling was not present but the operator said a seedling was present (CNOY) and (4) the computer said no seedling was present and the operator said no seedling was present (CNON). All 8064 decisions were organized in Table 1 for discussion.

The procedure followed is essentially the same as that followed using the labeling method. In this case the MAX_AVERAGE algorithm was applied after labeling. Peformance data were acquired and tabulated in the same manner as employed with the labeling method.

Imaging spectroscopy data required intense illumination during the time images were being acquired. Two 250 watt incandescent lamps running at 3600 K provided illumination. Two opical interference filters, one at 670 nm and one a 800 nm. Note that the 670 nm filter produces a blank seedling image against the background of the growth medium and plastic cell ridge while the 800nm filter produced a whiter seedling image against the same background. The darker image produced by the 670 nm filter is caused by the absorption of chlorophyll at 670 nm : the lighter image of the seedling produced by the 800 nm filter was indicative of the fact that there is very little chlorophlyll absorption at that wavelength. Since the bandpass or transmittance of the filters were not the same it was necessary to normalize the two images. A gray zone or area outside the trays was selected for calculating the normalization factor. This factor was defined as the ratio of the average intensity of the gray zone at 800 nm to the intensity of the same gray zone at 670 nm. Normalization was achieved by multiplying the image taken at 670 nm by the ratio factor.

(2) AGBOT Performance

The performance of AGBOT was evaluated using imaging spectroscopy as the image processing tool for detecting plants. Note that AGBOT had five functions to perform. First, it had to remove a NS plug from the acceptor tray leaving an empty cell. Second, it had to deposit the NS (No Seedling) plug in the garbage can. Third, a CS, which Contains a Seedling, plug was deposited in the empty cell of acceptor tray. Finally, after every three transfers, AGBOT would dip the gripper in water for cleaning. Not performing any of these functions during a single donor/acceptor arrangement were conducted. Success/failure data were recorded and tabulated for discussion. Replacement of an NS plug with a CS plug was considered as two success decisions. Missing or "overlooking" an NS or CS plug was considered a failure. Data were tabulated for discussion.

The functions AGBOT followed in picking up a seedling. The first step in picking up a plug was to position the tips of the spade gripper just below the rim of the cell. Next the gripper tips were opened until they just touched the edges of the cell. Closure of gripper was synchronized with the downward movement of the gripper until at the bottom of the cell the gripper was fully closed. The same procedure was followed when picking up plugs.

AGBOT to release a plug into a cell required two functions. First, the plug in the closed gripper was lowered until the tips of the spades were down to one half the depth of the cell. Second, the spades were opened to 2/3 maximum opening. Third, the spade tips were raised to 2 mm above the rim of the cell. The gripper was fully opened and forced to chatter by driving the gripperr against a stop. This chattering assisted in the release of the plug.

RESULTS AND DISCUSSION

(1) Plant Detection

The three methods used to detect tobacco seedling in the tray cells were: (1) Labeling, (2) Max-Average and (3) imaging spectroscopy. Table 1 gives data for comparing these three methods.

Data are presented for three plant sizes: small, medium and large. The average spread (or maximum dimension) of the 10 biggest seedling for each size were 1.92cm, 2.30cm and 2.95cm respectively. The results are reported in terms of the computer decisions and the individual (operator) decisions concerning the presence or absence of seedlings. There were two possible decisions by the computer, a seedling was present or a seedling was not present in the cell. The individual operator had the option of the same two decision. Hence, there were four possible classifications of success/errors: (1) The computer " said yes " a plant was present and the operator said yes a plan was present (CYOY), (2) the compter said yes a plant was present but the operator said no plant was present (CYON), (3) the computer said a plant was not present but the operator said a plant was present (CNOY) and (4) the computer said no plant was present and the operator said no plant was present (CNON). All 8064 decisions were organized in Table 1 as percintages. Failures of the computer vision system are those given the classifications of CYON and CNOY. On the other hand, successes are those given the classifications of CYOY and CNON. The sum of CYOY, CYON, CNOY and CNON is 100%.

Figure 4 shows a graphical representation of the data in Table 1 for the three seedling sizes, small, medium and large. For small size seedlings (refer to Figure 4 [A]), imaging spectroscopy was the best seedling detection method with an error rate of only 1.31%, while errors for Labeling and Max-Average were 20.91% and 13.35% respectively. For medium size seedlings (see Figure 4 [B]), imaging spectroscopy had an error rate of 1.00% while the error rate for Labeling and Max-Average were 10.80% and 9.10% respectively. For the large seedlings, the error rates for the imaging spectroscopy, Labeling and Max-Average algorithms were 2.08%, 9.91% and 7.33% respectively. Imaging spectroscopy performed best of the three methods and the Max-Average method performed better than the Labeling method. It appears that the increased error rate of 2.08% for the imaging spectroscopy method was probably due to overlay of the leaves of large seedlings into cells which had no plants.

(2) AGBOT Performance

Performance tests of AGBOT, the fully integrated system, were conducted using the spade gripper and the imaging spectroscopy method to determine the presence of absence of seedlings in the cells. Five replications of the donor/acceptor arrangement were completed.

The AGBOT performed the work in two steps. The first step moved the bad seedling plug in the acceptor tray to the garbage can. The next step was to transfer a good plug from the donor tray to the acceptor tray. The average time for each performance was 26.5 seconds.

Table 2 gives the number of errors involved in the transfer of seedlings to acceptor trays. The experiment was replicated five times. The five acceptor trays required the transfer of 168 seedlings to make sure that every cell in all five acceptor trays contained seedling. Average time to finish transplanting completely for one acceptor tray was about 19 minutes.

Error were classified as follows : (1) VEN, a computer vision error which occurred as a result of identifying a cell as having a plant when no plant was actually present, (2) REN, an AGBOT error caused by failure of the manipulator to make a successful transfer (i.e. the seedling was dropped, damaged, etc.), (3) SEN, a survival error indicating the number of dead transferred plants one week after transfer.

Of a total of 168 plants transferred, one plant did not reach the transfer site (REN, a manipulator error) and 7 seedlings did not survive (SEN) after one week of continued observation. The vision system identified eight of the cells in the acceptor trays as having plants (VEN), and, therefore, the system took no action with respect to these cells. A total of 8 trasfer errors out of 168 gave a system transfer success rate of 95.2%.

Keep in mind, however, that the objective of the system is to assure that the acceptor trays have a plant in every cell. In this regard, the success rate was better than 98% (or, { 1.0- (16 / (162 x 5) } x100). Since the VEN errors were due to overlap of the large seedlings into cells with no seedlings, the success rate of the system would improve from 98% to better than 99% (note it indicated that detection error for small and medium seedlings were zero) for trays containing only small and medium seedling.

CONCLUSIONS

AGBOT proved to be a reliable system for transplanting tobacco seedling plugs from a donor tray to the acceptor tray. Its development involved the integration of a Cartesian manipulator, grippers and a vision system along with an IBM/AT computer. Software, written in C, combined the functions of image capture, image processing, and control into one program. Two separate programs, one for the spade gripper and one for the needle gripper, were written. Separate subroutines for control of the robot only and for image analysis were included in the software.

Based on the results of this research the following conclusions were made:

1) AGBOT transplanted large seedlings with a success rate of more than 98%.
2) If small and medium seedlings were transplanted the success rate would be better than 99%.
3) The success rate of seedling transfer was 95.2%.
4) A four finger gripper, designed and constructed for this project, was adequate for transfering plugs consisting of a soil-type growth medium.
5) Imaging spectroscopy was the best image processing method tested, performing better than the Labeling and Max-Average method.
6) Imaging spectroscopy, used in conjunction with medium and small seedlings, was error free. Errors encountered when transferring large seedling were caused by overlap of seedling leaves into cells which had no seedling.

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Table 1 Comparison of the three plant detection algorithms.

unit; %

Size	Terms	Labeling	Max-Average	Spectroscopy
Small	CYOY	64.20	71.37	80.79
	CYON	2.62	2.62	0.00
	CNOY	18.29	10.73	1.31
	CNON	14.89	15.28	17.90
Medium	CYOY	73.53	74.15	80.48
	CYON	2.85	1.77	0.00
	CNOY	7.95	7.33	1.00
	CNON	15.66	16.74	18.52
Large	CYOY	74.61	75.93	79.71
	CYON	2.24	1.77	0.54
	CNOY	6.87	5.56	1.54
	CNON	16.28	16.74	18.21

Table 2 AGBOT Performance; Total errors in making seedling transfers.

NO.	VEN	REN	SEN	Total
1	1	1	3	5
2	1	0	1	2
3	2	0	2	4
4	2	0	1	3
5	2	0	0	2
Total	8	1	7	16

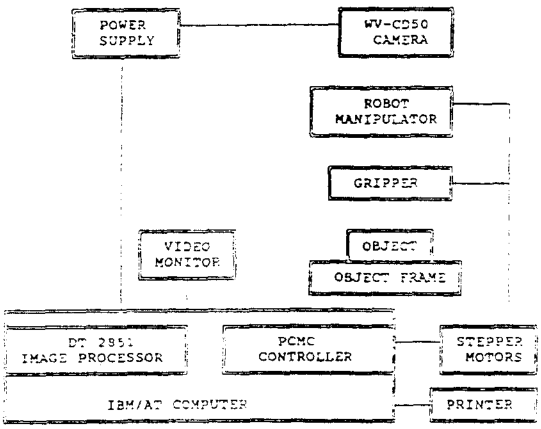

Fig. 1 A block diagram of the agricultural robot, AGBOT.

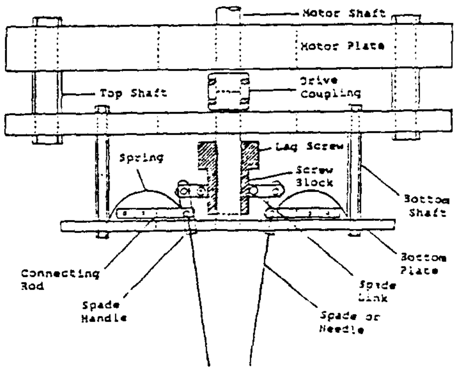

Fig. 2 Spade-type gripper for transferring plugs.

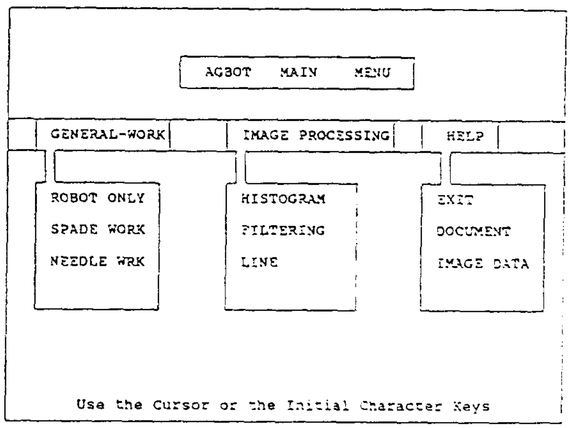

Fig. 3 The main of the AGBOT program. The keypad cursor keys (KPK) may be used to select the appropriate subroutine.

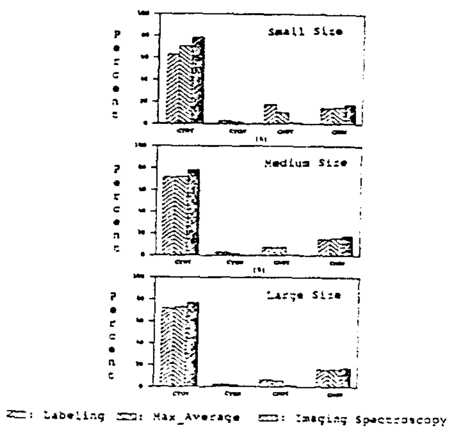

Fig. 4 Comparison of the three plant detection methods for three seedling sizes: [A] small size, [B] medium size and [C] large size.