DEVELOPMENT OF A 3-DOF ROBOT FOR HARVESTING LETTUCE USING MACHINE VISION AND FUZZY LOGIC CONTROL

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ABSTRACT

In Korea, researches on year-round leaf vegetables production system are in progress, most of them focused on environmental control. Therefore, automation technologies for harvesting, transporting, and grading are in great demand. A robot system for harvesting lettuces, composed of a 3-DOF (degree of freedom) manipulator, an end-effector, a lettuce feeding conveyor, an air blower, a machine vision system, six photoelectric sensors, and a fuzzy logic controller, was developed. A fuzzy logic control was applied to determine appropriate grip force on lettuce. Leaf area index and height were used as input variables and voltage as an output variable for the fuzzy logic controller. Success rate of the lettuce harvesting was 94.12%, and average harvesting time was approximately 5 seconds per lettuce.

Keywords: Machine vision, Fuzzy logic control, Lettuce, Robot, Harvesting end-effector

INTRODUCTION

Greenhouse cultivation in Korea increased from 1.9% in 1990 to 4.8% in 1997. Moreover, glass houses to which new technologies could be applied greatly spread. However, only few new technologies including automatic seeder, compositive environment control, and automatic nutrient-solution management system have been automatized. Most tasks such as transplanting, sorting, and harvesting were still dependant on manual labors (Yun, 1996).

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Researchers in Rural Development Administration investigated input labors per hour of greenhouse lettuce in each stage of tasks and reported that 47% of total working hours was applied to harvest. Therefore, shortage of labors could be settled with automation of harvesting work.

Recently, research on design of an end-effector, a core technology of agricultural robot system, is actively in progress in agricultural engineering area. Kondo *et al.* (1996) developed a cherry tomato harvesting system, which includes a stereo machine vision device and an articulated robot with approximately 70% accuracy. Harvesting robot system composed of machine vision system, Cartesian robot, and an end-effector with suction cup was also constructed by Reed *et al.* (1994), showing 67% success rate. A lettuce harvesting system was developed in 1994 by Uchida *et al.* for plant factory to harvest 1800 heads per hour. However, as the port used in the system was of disposable type and was cut off along with the lettuce roots, another process to remove it was necessary. Moreover, the remainders in the port became an issue in that they could cause environmental pollution. Weber *et al.* (1991) and Simonton *et al.* (1991) applied agricultural harvesting robot systems to melon and geranium, respectively. However, most systems were not cost-effective since they were developed using industrial robots. To overcome the problem, Tillet *et al.* (1995) fabricated 2-DOF robot with pneumatic device and developed a tomato packing robot system competitive in terms of accuracy and cost.

This study was conducted to develop a competitively low price system for automatic harvesting.

MATERIALS AND METHODS

2.1 Construction of Lettuce Harvesting Robot System

A lettuce harvesting robot system was constructed. The system included a machine vision system for taking the image of lettuce, photoelectric sensors for measuring height of lettuce, a lettuce feeding device for feeding lettuce into harvesting position, a 3-DOF manipulator and an end-effector for harvesting lettuce, an air blower for lifting drooping leaves when an end-effector approached the lettuce, and a controller for controlling these processes. The schematic diagram of a lettuce harvesting robot system is given in fig. 1.

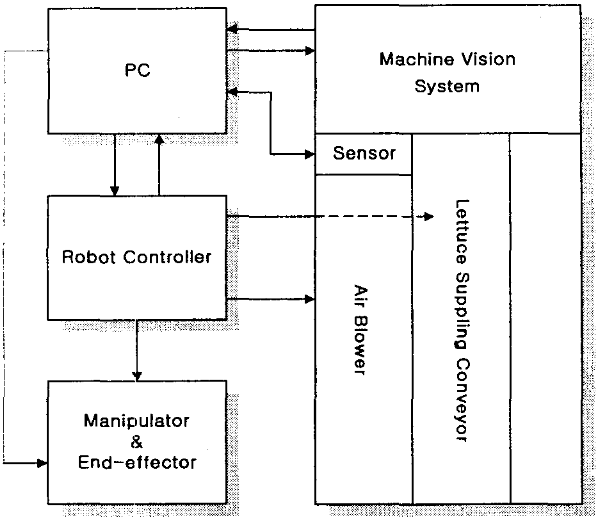


Fig 1. Schematic diagram of a robot system for harvesting lettuce

2.2 Algorithm for Harvesting Lettuce

Algorithm for harvesting lettuce was as follows (fig. 2):

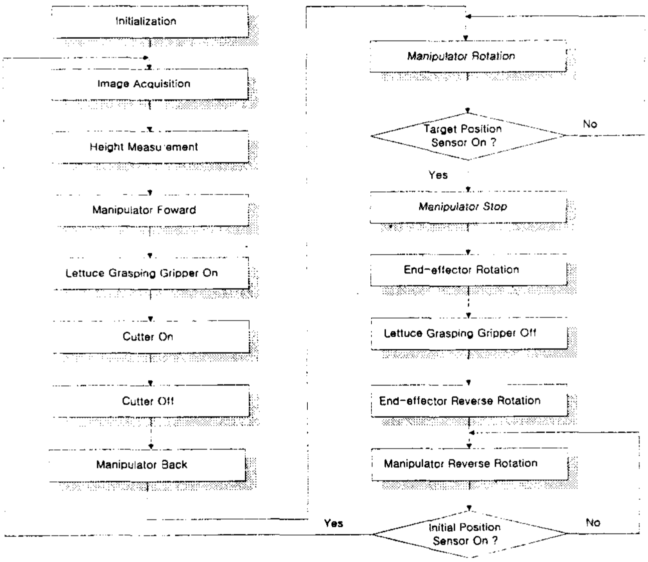


Fig 2. Algorithm for harvesting lettuce.

① Machine vision device took the image of the lettuce, and photoelectric sensors detected the height.

② Lettuce feeding device fed lettuces into appropriate position one by one.

③ Air blower in the lettuce lifting device lifted drooping leaves when the end-effector approached the lettuce.

④ The lettuce was cut by a cutting blade after a gripper, whose grip force was controlled by fuzzy control, grasped it.

⑤ The cut lettuce was sent on a packing conveyor through rotation of the manipulator.

⑥ Aforementioned steps ①-⑤ were repeated after manipulator returned to the initial position.

2.3 Manipulator

3-DOF manipulator based on cylindrical coordinate system was fabricated. Manipulator was rotated about z axis using AC servomotor, and its position was controlled with photoelectric sensors. Manipulator was linearly moved using pneumatic cylinder and rotated with a stepping motor about y axis.

The following must be considered when pneumatic cylinder moves back and forth.

① As the leaves of grown lettuce droop, a proper stroke clearance of cylinder must be kept to prevent damage on the drooping leaves when manipulator approaches.

② Deflection of cylinder resulting from the weight of the end-effector must be considered when the end-effector is attached to the end of the pneumatic cylinder (use of cylinder with guide).

2.4 Control Device

The manipulator was controlled with PB-1S, a one-chip microcomputer, which was an improved version of PIC16C73. It was composed of 14 input/output ports and 2 other output ports for generating frequency. The pneumatic cylinder was controlled by a double-acting solenoid valve, which was driven by relay.

2.5 End-effector

End-effector was composed of cutting blade and lettuce grasping gripper. Cutting blade was designed to cut lettuce while grasping a port with open type air chuck. End-effector was driven by solenoid valve and relay, and controlled with PB-1S. Lettuce gripper must grip the base of lettuce with proper force to prevent damage on the lettuce. In order to determine appropriate grip force, informations on the minimum grip force for maintaining 'stable grasp' and the maximum grip force without damaging the lettuce were necessary. The maximum and minimum gripper sizes for grasping, the rigidity of grip surface, and the weight, size and geometrical shape of lettuce were necessary for the gripper to grasp a lettuce properly. The gripper utilized air chuck with an opening and closing interval of 0-180°, and MC (monomer cast) nylon was used for finger of the gripper. Sponge attached to inner part of MC nylon reduced impact force during grasping. Manipulator to which the end-effector was attached, and the driving controller are shown in figs 3 and 4, respectively.

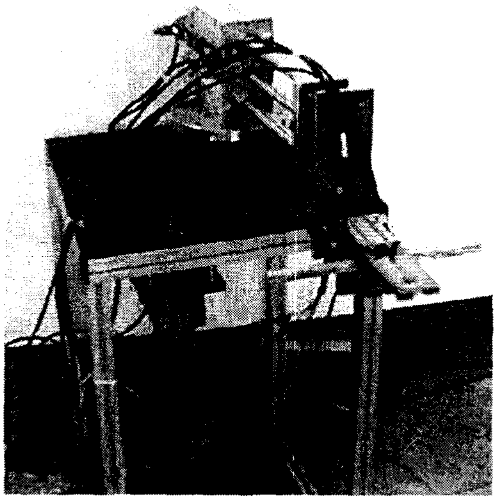


Fig 3. Manipulator and end-effector

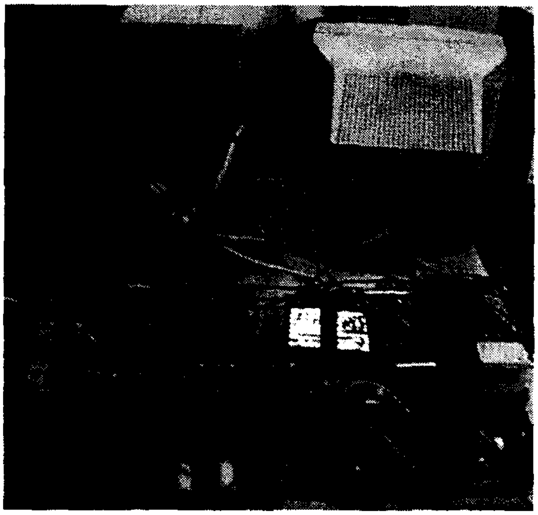


Fig 4. Controller

2.6 Machine Vision System

A machine vision system was used to take the image of a lettuce and obtain such informations as the leaf area of a lettuce and geometrical shape. The system was composed of a color CCD camera (PULLiX) and a frame grabber (Matrox corona-LC/8). Luminous intensity was kept between 2.3 and 3.0 klux on the entire field of view. A chain code method was used on the acquired image to detect its outline, and leaf area was calculated. Information on detected leaf area was used as an input variable of fuzzy controller to control lettuce gripper.

2.7 Photoelectric Sensors

Six photoelectric sensors attached to a bar at 3 cm intervals detected height of the geometrical shapes of lettuce. Photoelectric sensor was a direct reflection type, and its control output was an NPN open-collector.

2.8 Leaf Lifting and Lettuce Feeding Devices

Leaf lifting device was fabricated to prevent damage on the lettuce by lifting drooping leaves when the end-effector approached a lettuce. It was driven by solenoid valve and relay, and was controlled by control signal from the PB-1S, a one-chip microcomputer. Lettuce feeding device was fabricated to feed lettuces into proper place one by one and was driven by an AC motor, MC34C87 (line driver), and relay.

2. 9 Construction of Fuzzy Controller

Fuzzy controller was used to control grip force of lettuce gripper. As shown in fig. 5, leaf area and height detected with the machine vision system and photoelectric sensors, respectively, were used as input variables of the fuzzy controller, and the driving voltage of the air chuck as an output variable.

Fuzzy variables of leaf area, height and voltage were determined using all 25 fuzzy rules.

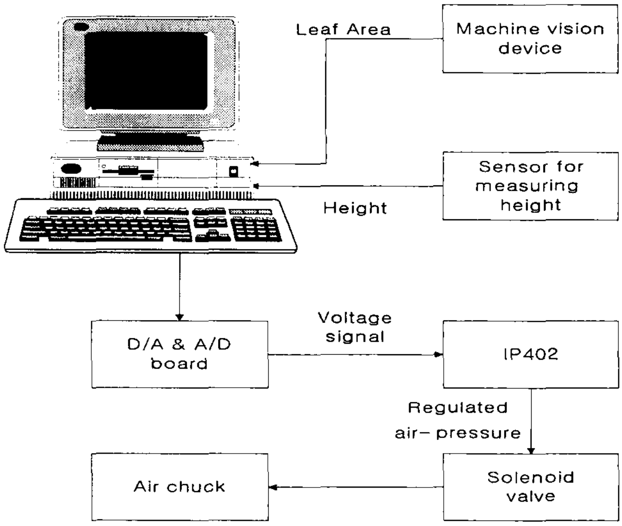


Fig 5. Components of the fuzzy logic controller

RESULTS AND DISCUSSIONS

3.1 Controller of Manipulator

Rotational motion of the manipulator was regulated by controlling AC servomotor. Modeling of AC servomotor with a PI controller is given in fig. 6. Closed loop transfer function, eq.1, was derived from fig. 6.

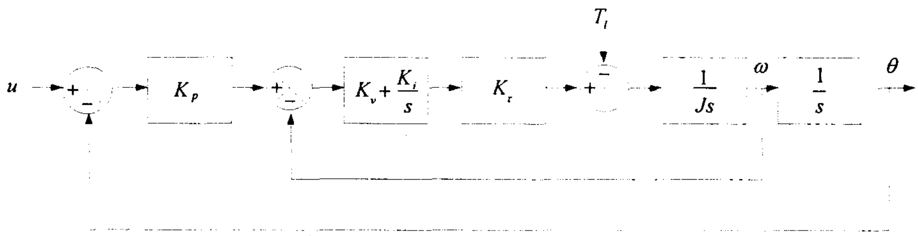


Fig 6. Modeling of AC servomotor with the PI controller.

$$\frac{\theta}{u}=\frac{K_pK_vK_\tau S+K_pK_iK_\tau}{JS^3+K_vK_\tau S^2+(K_iK_\tau+K_\tau K_pK_v)S+K_pK_iK_\tau} \qquad \text{Eq.(1)}$$

Where, K_p = position constant

K_v = velocity constant

K_I = integral gain

K_τ = motor constant

J = moment of inertia of the motor

Parameters such as position constant, velocity constant, and integral gain were determined using eq. 1 and MATLAB. Selected position constant, velocity constant, and integral gain were 500, 500, and 5, respectively.

3. 2 Harvesting Performance Evaluation

In order to evaluate harvesting performance, leaf lettuces(*Lactuca sativa var. crispa*) appropriate for greenhouse cultivation and commonly found in Korea were selected and cultivated. The result of fuzzy controller-controlled grip force of the lettuce gripper is given in fig. 7. As leaf area and height increased, grip force was also increased, maintaining stable grasp so as not to damage the lettuce. Harvesting test on 85 heads of lettuce was conducted (fig. 8). The test results showed that end-effector damaged leaves of five heads with an average harvesting time of 5 seconds per lettuce (table 5). The damaged lettuces still had commercial value as only the very bottom leaves were partly torn.

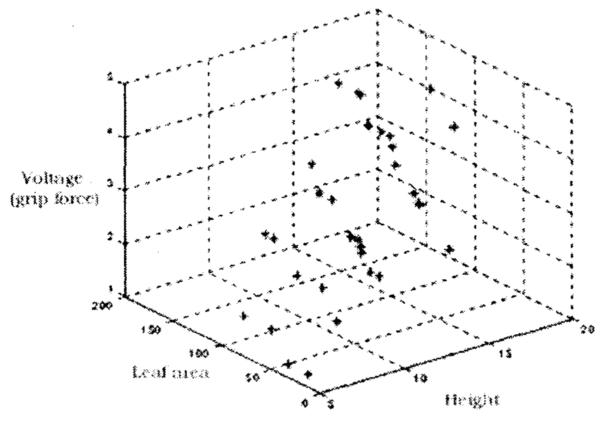
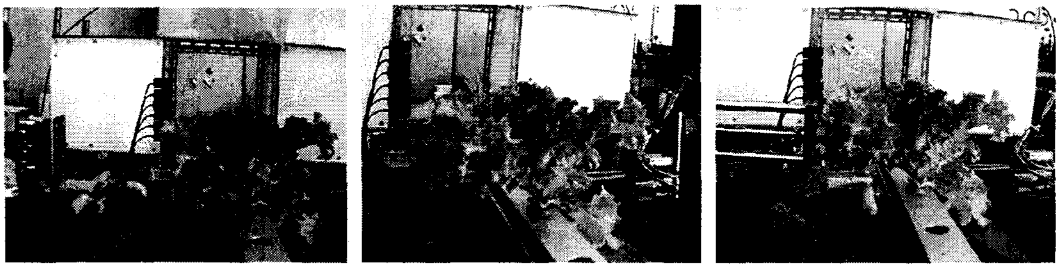


Fig 7. Result of fuzzy logic control.



a. Feeding a lettuce. b. Blowing a lettuce by air. c. Manipulator forward.

d. Grasping & cutter on. e. Cutter off & gripper on. f. Manipulator rotation.

g. Stepping motor rotation. h. Stepping motor reverse rotation.

Fig 8. Steps for the robotic lettuce harvesting.

Table 5. Performance of the robotic lettuce harvest

Result analysis	No. of lettuces	Percentage (%)
Successfully harvested	80	94.12
Harvested with little damage	5	5.88
Total	85	100.00

CONCLUSIONS

This study was conducted to develop a lettuce harvesting robot to automate factories, which produce green vegetables on a large scale.

The important results were as follows:

(1) Lettuce harvesting robot system composed of a 3-DOF manipulator, an end-effector, a lettuce feeding device, leaf lifting device, machine vision system for taking the image, photoelectric sensors for detecting height, and a fuzzy controller, was developed.

(2) Twenty five rules of fuzzy controller was used to determine appropriate grip force of the gripper. Informations on leaf area and height were used as input variables of the fuzzy controller and driving voltage of air chuck was used as an output variable.

(3) Success rate of the harvesting was 94.12%, and average harvesting time was about 5 seconds per lettuce.

(4) Test results showed that the developed lettuce harvesting robot system could be applied to the automation of plant factory.

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