JARQ 30, 227–232 (1996)

Development of Multipurpose Robot for Vegetable Production

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Abstract

The objective of these studies was to develop a multipurpose intelligent robot for vegetable production. Many of the vegetable-producing operations are presently performed by human labor, because they need to be carried out selectively. In this study, the robot which consisted mainly of a rectangular manipulator, a traveling device and computer (80286 CPU) was constructed on an experimental basis. The outline of the robot and its application to transplanting, weed control and harvesting for several leafy vegetables in the hill space are reported. Two types of transplanting and harvesting hands were tested. Weed location was determined by processing color images, and the weeds were removed with a blade constructed experimentally. As a result, it was shown that 1) cabbage and spinach seedlings could be transplanted with a hand constructed on an experimental basis, 2) weeds could be accurately determined and 3) leafy vegetables like spinach could be harvested with the hand with reciprocating knives.

Discipline: Agricultural machinery
Additional key words: transplanting, weeding, harvesting, machine vision, manipulator, hand

Introduction

Many of the vegetable-producing operations are presently performed by human labor. However, in Japan agricultural labor consists mainly of elderly people with few successors. Therefore, the development of a vegetable-producing system aimed at saving labor is required to secure a sufficient quantity of vegetables. For the mechanization of these operations, environmental conditions related to the object and location of crops or targets must be recognized by the robot[3,4] (machine that has a sensory system and can be used for operations).

Besides, farm operations which vary according to the seasons cover a shorter period than factory work. Accordingly, vegetable production cost using mono-functional machines or robots is very high. However, robots which are characterized by a high flexibility can be used based on the same construction processes for a large number of field and greenhouse operations[2,6]. As a result, the transplanting process, weed control in the hill space and harvesting of leafy vegetables were studied experimentally.

Fundamental construction of the robot

The robot can be employed for a variety of crops and tasks with emphasis placed on leafy vegetables. Operations for the production of leafy vegetables are mostly traveling performed in the range from 15 to 50 cm in height, above the ridge, in Japan.

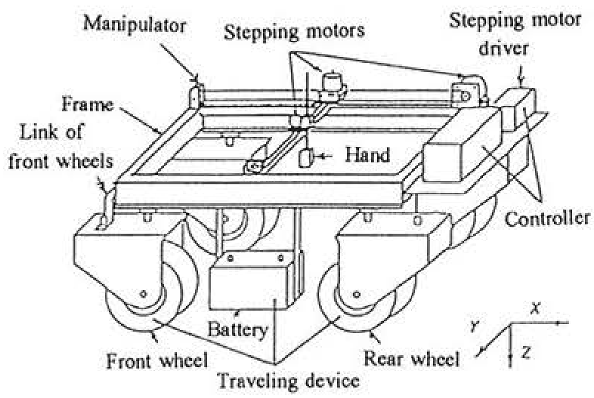

Fig. 1. Outline of robot

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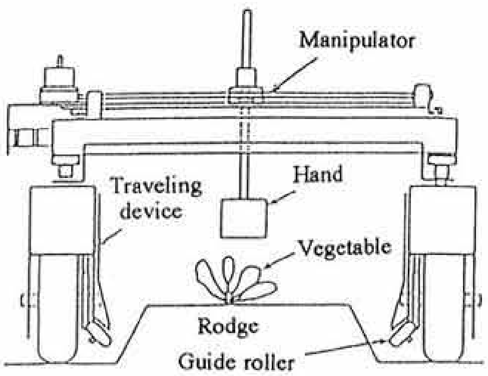

Fig. 2. Robot in field

Therefore, the robot shown in Figs. 1 and 2 was designed. A manipulator is located across a ridge and the traveling device can be passed through the furrows which are opened on both sides of a ridge.

The robot consisted mainly of a rectangular manipulator, a traveling device, a control unit and a sensory system which is composed selectively of a photoelectric sensor including an optical fiber sensor, a Toshiba IK-M32 CCD color TV camera with NTSC output and 7.5 mm lens as the vision system for image processing, or a sensor of the active range finder type to detect the 3-dimensional shape, depending on the operations.

1) Manipulator

The rectangular manipulator which has a wide working space (Fig. 3) can be controlled only to input the 3 dimensional objective point. The 3 axes of the manipulator are driven by stepping motors which are controlled by a 16-bit microcomputer by the motor controller and driver. Each axis is controlled at 0.183 mm per pulse, because the rotation angle of the stepping motor was 0.36° per pulse. However, in this study, it was controlled with a 1 mm accuracy. The mobile range of the X-axis which represents the direction of the progression of the robot was 740 mm, the mobile range of the Y-axis crossed with the X-axis was 520 mm and that of the Z-axis which moves up and down was 375 mm. The initial position of each axis was determined by the limit switches attached at each axis. The manipulator control program was developed using C compiler.

The average of the moving speed of each axis was about 0.6 $m \cdot s^{-1}$ (X-axis), 0.5 $m \cdot s^{-1}$ (Y-axis) and 0.2 $m \cdot s^{-1}$ (Z-axis), respectively.

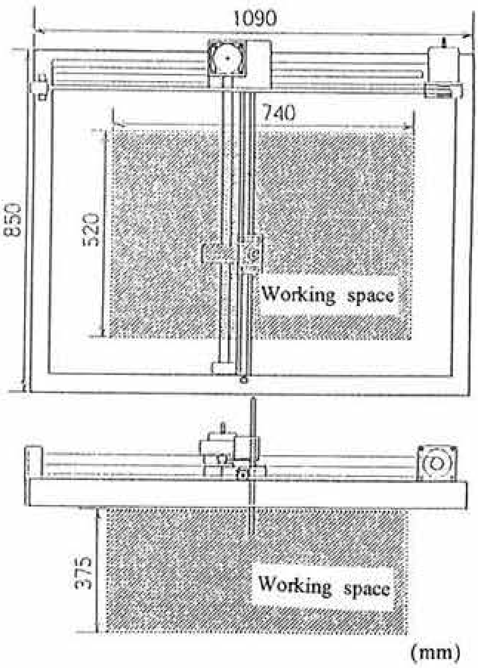

Fig. 3. Rectangular manipulator and working space

2) Controller

The controller consisted mainly of a 80286 CPU, 512 KB RAM and 256 KB ROM which were included for the main parts in the board computer. Otherwise, it consisted of 2 stepping motor controllers, an image processing unit and a digital input-output unit which was used to control the DC motors of the traveling device and the hand through relays and to input the signal of the on-off control action sensors.

3) Traveling device

The 4-wheel drive traveling device utilized a battery car available in the market. Each wheel was coupled to a 24 V DC motor attached to the reduction gear. The robot could be moved at 0.9 $m \cdot s^{-1}$ in the higher and 0.4 $m \cdot s^{-1}$ in the lower speed modes, respectively. Both sides of the front wheels were linked to obtain the same steering degree. The guide roller was installed at the front wheel cover to control the direction of progression.

Transplanting of leafy vegetables

Several vegetable transplanters developed in Japan consisted mainly of 1-row transplanting type with limited spacing in the row, and generally, they could not be used for many kinds of vegetables. However,

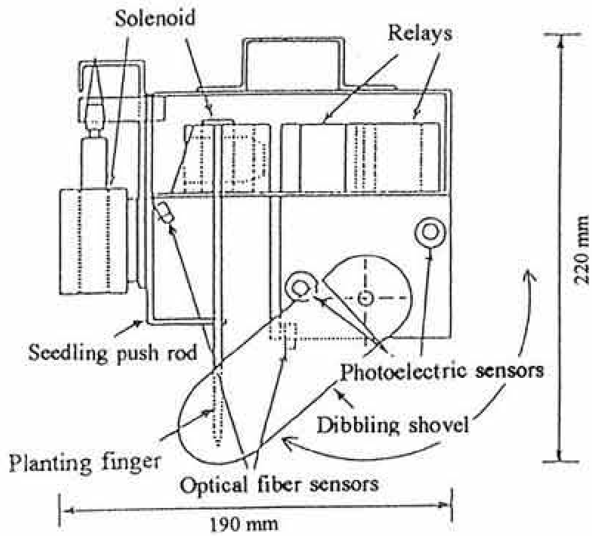

Fig. 4. Transplanting hand

it was considered that the planting density could be changed easily by the robotic transplanting system. Therefore, for many leafy vegetables like cabbage, lettuce and spinach, a transplanting hand was constructed on an experimental basis, as shown in Fig. 4. This hand was supported to utilize the seedlings in the cell plug tray[7]. It consisted of transplanting fingers, a shovel for digging holes for the seedlings, a DC motor, a solenoid and photoelectric sensors which are connected with the optical fiber to the detector. Two parallel fingers which were processed from steel sticks 4 mm in diameter were 90 mm long and opened and closed at a distance of about 20 mm by the solenoid. The seedling push rod was attached above the fingers. In front of these parts, a shovel which could rotate by the DC motor was set up. When a seedling was picked up, it was brought down into the soil and the hand advanced by about 40 mm to dig a hole.

For the sensory system to detect the seedlings and for the position control of a shovel and the height control from the ridge, the Omron photoelectric sensor and the Sunx FX-7 optical fiber sensor were tested. Infrared light beams were emitted from these light emitting diodes (LEDs) and the reflected light from the seedlings or soil surface returned to a photo detector. These sensors were on-off controlled by the luminosity of the reflected light.

Fig. 5 shows the detection distance from the sensor to the cabbage and the bed soil. It was measured by 4 kinds of optical axis degrees (crossing degree between the optical axis and horizontal plane). As a result, it was easy to distinguish the seedlings

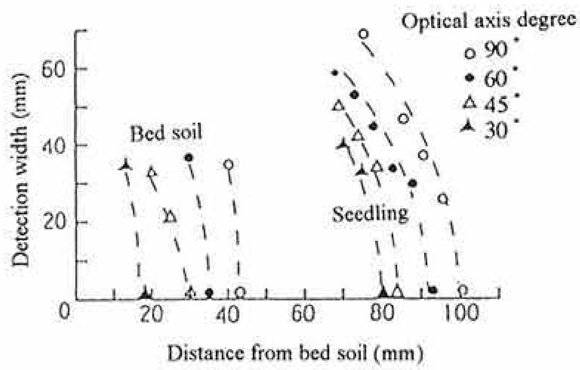

Fig. 5. Detection distance of optical fiber sensor

from the bed soil, and the presence of the seedlings was detected by the optical fiber sensor. When the value exceeded 60°, transplanting error could be prevented accurately. The height of the hand from the ridge was also detected by another optical fiber sensor to obtain the accurate planting depth. Seedlings of cabbage and spinach in a 128-cell plug tray could be transplanted fairly well with the hand and program. However, in a clay field, soil covering was not sufficient, because soil crumbling occurred when the hand was lifted upward.

Weed control

Two types of weed control hands were constructed on an experimental basis and were attached to the manipulator. The color image of the weed was fed to the computer from a color TV camera and the 3-dimensional location of the weed was calculated using a stereo-camera method. A range finder[1] which could be scanned and was able to measure the 3-dimensional shape of objects was also tested to detect the weed location.

Figs. 6 and 7 show the hands experimentally constructed for weed control. One was attached to a weed knife with a spiral shape and a diameter of 4 cm. The other was attached to 3 weed knives. When weeding was performed for each weed detected by the color image processing in the hill space, a weed knife type hand was used. For weeding in all the hill space, the other type was used.

The weed detection system consisted of the abovementioned unit. The frame store provided 256 horizontally × 242 vertically, 8-bit images for storage. The image processing board was digitized from analog color signals including NTSC formats to RGB value. An image processing program was designed by MASM Assembler. When the TV camera was

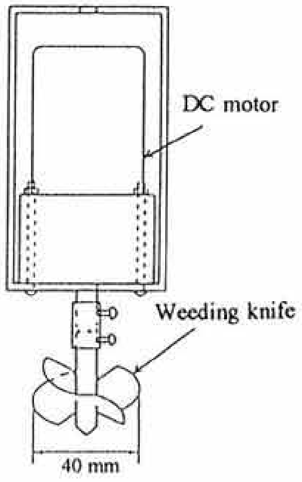

Fig. 6. Weeding hand (1 knife)

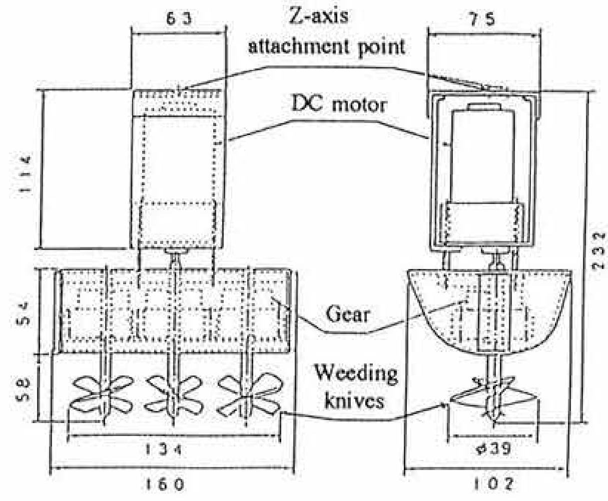

Fig. 7. Weeding hand (3 knives)

set up at a 460 mm height above the ridge, the visual field of the TV camera was 325 mm × 244 mm (*X*-axis direction × *Y*-axis direction).

In order to detect the weeds based on the color characteristics, the spectral reflection of 2 kinds of soils, of lettuce and 2 kinds of weeds was measured. As a result, although it was easy to discriminate a plant from soil[5], the discrimination of a weed from a crop was very difficult, because each spectral characteristic was similar. In a cropping system with transplanting, since many weeds germinate about 1 week after transplanting, the weed width or length will be smaller than that of the crop. Therefore, until the hill space is covered by the crop leaves, the weeds can discriminated by the following algorithm or processes:

1) By obtaining the color image on the ridge and digitizing analog color signals.
2) By obtaining the binary image, picking up the pixel with a G value (digitized green tone) larger than the average of R value (digitized red tone) and B value (digitized blue tone).
   To discriminate a plant from soil, the following procedures can be adopted.
3) Following the border of the binary image.
4) Selecting the binary image.

If the binary image is shorter than 8 pixels or longer than 80 pixels in horizontal or vertical length, it can be eliminated as a noise or crop. Other binary images are stocked in RAM as weed information including the horizontal and vertical central positions and the width of the binary images.

The 3-dimensional location of the weed was determined by using a stereo-camera method with the following algorithm. One of the stereo-images was obtained at the primary image inputting point, and the second image at the point located at 50 mm in the *X*-axis direction from the primary point. As a result, the stereo-images were obtained by one TV camera.

The 3-dimensional location of an annual weed, fleabane (*Erigeron annus* (L.) Pers) which was 45 mm × 32 mm in size was tested. Fig. 8 shows the relation between the actual distance from the TV camera to the object and the results obtained. The measuring accuracy was good within a distance of about 80 cm and image processing was executed quickly (about 0.5 s per image).

The weeding hand constructed on an experimental basis was attached to the spiral weeding knife

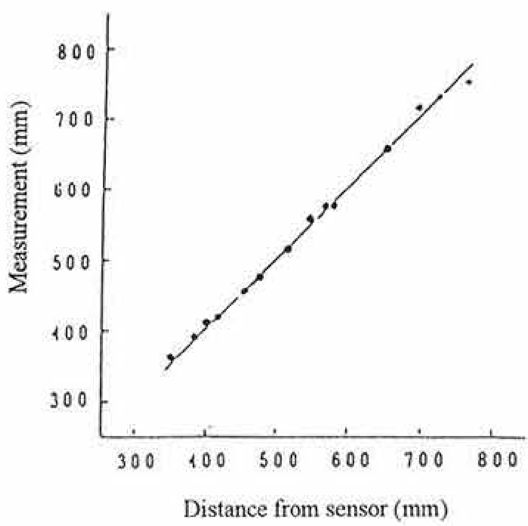

Fig. 8. Measurement of distance
(Image processing)

Table 1. Effect of weeding

Population of weed	Robot	Human	No-weeding
Fresh weight ($g \cdot m^{-2}$)	24.2	4.1	201.2
Dry weight ($g \cdot m^{-2}$)	3.2	0.6	22.8

10 days after weeding.

which was rotated by 100 rpm to dig up the weed with a 10 VA DC motor. The weeding experiment was conducted to stop the traveling device. When the rotating weeding knife aimed at the target and was inserted from 20 to 30 mm in depth under the ground within 2 s, the weed could be dug up easily.

In the field test, it took 53 s to dig up scattered 10 weeds in the working space of the manipulator. Table 1 shows the results of the experiment with robot weeding compared with manual weeding in a lettuce field. The weeding was performed 14 days after transplanting, and weed emergence was examined 10 days after weeding. There was hardly any weed emergence in the field with manual weeding. In the field weeded with the robot, emergence was 5 times higher and one seventh in the field without weeding. Weed damage in the robot-weeded field was almost equal to that of the field with manual weeding.

Harvesting of leafy vegetables

Potherb ('nanjyaku-yasai' in Japanese) is one group of leafy vegetables included in Chinese vegetables ('chingensai' in Japanese). The planting density is high, and since harvesting is always performed manually, it accounts for 60% of the time required for the total production. Therefore, a labor-saving production system should be developed.

Fig. 9 shows the harvesting hand with fixed knives which consisted mainly of the harvesting parts and crop holding parts. Four knives made of stainless steel were attached to the harvesting frame. Crop holding was executed by 2 steel sticks, 3 mm in diameter and about 100 mm in length. Each part was rotated by a 15 VA DC motor. Harvest was performed by digging up the target without cutting roots, because in western Japan, the root of the vegetable should not be cut to indicate the freshness.

The location of the vegetable and the height of the hand from the ridge were detected by optical fiber sensors, in the same way as the transplanting hand. The potherb was fairly well harvested by the hand experimentally constructed. However, when the soil hardness was high, harvesting could often not be performed, because the DC motor power was not sufficient. Therefore, the harvesting hand should be improved.

Conclusion

The objective of these studies was to develop a multipurpose robot for vegetable production. Most of the vegetable-producing operations must be performed selectively. For such operations, a robot should be constructed with a sensory system to recognize the crop and environmental conditions. Therefore, a multipurpose robot which consisted mainly of a rectangular manipulator, several sensors including a TV camera, controller and a traveling device was constructed experimentally. The application of the robot to 3 kinds of operations for vegetable production was tested, including transplanting of

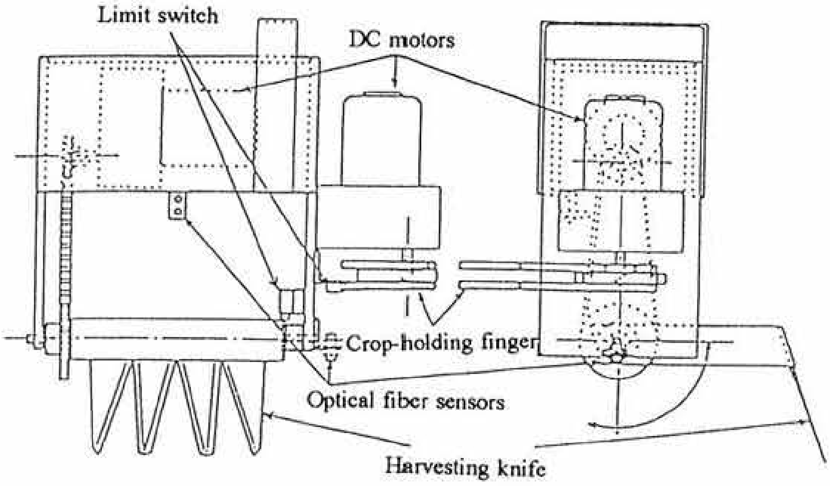

Fig. 9. Harvesting hand for potherb

vegetable seedlings, weeding in the hill space on a ridge, harvesting of potherb. Each operation could be performed by using the hand constructed experimentally as well as the sensory systems and programs.

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(Received for publication, November 10, 1995)