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Multi-functional Automated Cultivation for House Melon
- Development of Tele-robotic System -

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Abstract

In this paper, a prototype tele-operative system with a mobile base was developed in order to automate cultivation of house melon. A man-machine interactive hybrid decision-making system via tele-operative task interface was proposed to overcome limitations of computer image recognition. Identifying house melon including position data from the field image was critical to automate cultivation. And it was not simple especially when melon is covered partly by leaves and stems. The developed system was composed of 5 major modules: (a) main remote monitoring and task control module, (b) wireless remote image acquisition and data transmission module, (c) three-wheel mobile base mounted with a 4 dof articulated type robot manipulator (d) exchangeable modular type end tools, and (e) melon storage module. The system was operated through the graphic user interface using touch screen monitor and wireless data communication among operator, computer, and machine. Once task was selected from the task control and monitoring module, the analog signal of the color image of the field was captured and transmitted to the host computer using R.F. module by wireless. A sequence of algorithms to identify location and size of a melon was performed based on the local image processing. Laboratory experiment showed the developed prototype system showed the practical feasibility of automating various cultivating tasks of house melon.

Keywords : Tele-operation, Man-machine interface, House melon, Wireless operation

1. INTRODUCTION

There have been many research and development activities toward greenhouse automation. So far, most automation was focused on the environment control in a greenhouse such as moisture, temperature, CO_2, and nutrients. In addition, automatic pesticide application system was widely used though it is not site-specific. However, most tasks which require delicate handlings such as pruning and thinning out superfluous flowers and fruits, harvesting, stem induction etc. still remain to be automated. Harvesting robots have been developed to automate harvest task but only showed the feasibility of application through limited experiments. They were not successful and practical in the real field operation (Arima and Kondo, 1994; Kondo et al., 1996; Umeda et al., 1997; Kondo and Ting, 1998).

Major bottlenecks of implementing a task specific robotic system are lack of real time processing in task identification,

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too much complex system for farmers to handle, and difficulties in adapting the system to variable and unstructured task environment. Furthermore, the required system cost is too high and on the other hand, machine or system operating time for an individual task is too short compared to the overall growth period of each plant. Computer vision is one of the most essential technologies in automating house melon cultivation. However, it has limitations of computing time, adaptability, and robustness in recognition of an object under the volatile and unstructured environment. In general, the sensitiveness of the image processing results caused by the varying environment state was a key barrier in robotizing field operations of bio-production.

There have been many research efforts to improve object recognition via various artificial intelligence technologies. Though it has demonstrated successful results in various applications, the current status of technology is still far behind the human's capability typically for the unstructured and time varying complex task environment (Shirai et al., 1998).

In house melon cultivation, the plant density is high and a precise control of plant growth environment such as atmosphere and nutrition is usually being exercised. And it is known to be desirable to maintain the greenhouse as a closed space separated from outside to prevent bad insects and diseases from migration. And the optimum atmosphere to plants is usually not good for human health because of pesticide and the other harmful gases. Tele-operation could offer the comfortable and safe workspace and solve the deficiencies of the usual automation approach of greenhouse cultivation.

A tele-operative robotic system, which is a new concept of automation for bio-production, has been proposed to solve most of the obstacles mentioned above while maximizing system operation time and reducing total system investment (Hwang and Kim, 2003; Kim and Hwang, 2003; Kim and Hwang, 2004). In this paper, similar concept was adopted to develop the multifunctional automated cultivation system for a musk melon via tele-operated robotic system.

2. MATERIALS AND METHODS

Musk melon was chosen as a representative fruit bearing vegetable in this research. Musk rmelon is high value added vegetable, and it is somewhat difficult to handle because of its weight. The developed system was designed to fit the greenhouse located at Seji-myun, Naju-si, Chonlanam-do where is the major melon production area in Korea. Average weight and diameter of a musk melon was around 34 N and 18 cm respectively. Melon was cultivated at the 120 cm height from the ground and fastened with an induced string as shown in figure 1. Each plant has one melon and was grown at a distance interval of 30 cm.

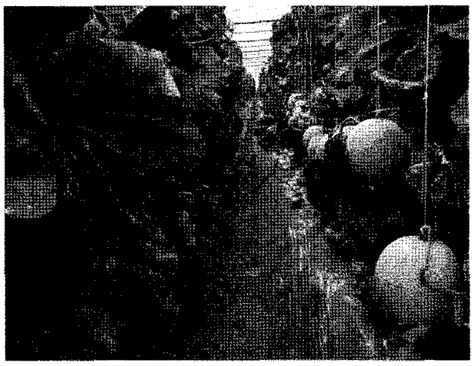


Fig. 1 Site of the house melon cultivation.

Table 1 shows required labor of each cultivation process for melon production. As shown in Table 1, it took 160 hrs for harvest and packaging, 100 hrs for irrigation, 80 hrs for pruning and soil preparation. Though most tasks were conducted in the greenhouse, overall mechanization rate was merely 12% because of the limited workspace and limitation of machine availability. Tasks required to be mechanized mostly were those related to delicate operations which are difficult to be automated such as weeding, planting, pruning, fruit thinning, bud trimming, harvesting, etc. Moreover, differently from 1970s and 1980s, the issue of environment preservation have been emphasized these days. R&D on organic farming and environment friendly cultivation have widely spread out and actively performed.

Among tasks of the cultivation, pruning, watering, fertilizing, pesticide application, and harvest with loading were selected according to the required labor intensiveness and functional similarities. Physical data of melon were collected

Table 1 Labor requirement of each task of cultivation and harvest

Task Description	Time (hr/330 m^2)	
	Human labor	Machine
House installation	22	
House management	18	
Seed disinfection and seeding	20	-
Pot preparation	20	-
Seedbed management	12	-
Chemical spraying	4	-
Irrigation and ventilation	20	-
Plowing and harrowing	-	4
Mulching	40	-
Bed preparation	80	-
Set up pole and net	20	-
Planting	20	-
Branch inducement	60	-
Lower leaf elimination	20	-
Bud picking and trimming	80	-
Mating	60	-
Fruit thinning and hang up	20	-
Weeding	20	-
Top dressing fertilizer	10	-
Pest control	20	-
Irrigation	100	100
Ventilation	50	-
Harvesting and shipping	160	-
Total	876	104

(Source : standard farming textbook-66 fruit and vegetables)

based on the large and medium size fruit bearing varieties to properly design the system.

Considering adaptability of machinery to multi-tasks, maximizing machine operation time, economical efficiency, and feasibility of commercialization, following functional specifications were set up prior to developing a system:

1) System was to be developed to perform various tasks by introducing modular type exchangeable end tools resulting into the improvement of machine operation time and reduction of the total system cost.
2) System was to be secure enough to handle a heavy melon.
3) System should have functions of high speed and precise operation in performing tasks, while keeping the robustness for the volatile tasks under the uncontrolled greenhouse environment.
4) System was to be capable of performing environment friendly operation, while optimizing consumption of the pesticide and fertilizer via introducing site-specific precision application.
5) System adopted tele-operative concept through developing wireless remote control of the system, data and signal communication, and operator friendly man-machine control with graphic user interface, while keeping farmer off the cultivation site.
6) System should be able to provide practical solutions for the labor shortage, while allowing the inexperienced farmer to grow plants via supporting of easy access of knowledge base.
7) System should allow a farmer to the flexibility of labor (day and night labor) and real time monitoring and control of operations in greenhouse.
8) System should provide a farmer with safe and comfortable working environment and also prevent plants from migrating disease and pesticide from outside.
9) System is to be capable of constructing spatio-temporal quantitative database for plant growth and harvest states by collecting information on major environment factors through equipped sensors and remote image processing.

Based on the above functional criteria, a prototype multi-functional modular tele-robotic system to automate tasks of cultivation, harvest, sorting, and loading of a musk melon was developed at the laboratory. The developed system was composed of 5 major modules: (a) main remote monitoring and task control module, (b) wireless remote image acquisition and data transmission module, (c) three-wheel mobile base mounted with a 4 dof articulated type robot manipulator (d) exchangeable modular type end tools, and (e) melon storage module.

A man-machine interactive hybrid decision-making system was proposed to overcome limitations of the current computer's own image processing and cognitive capability. Task sharing was performed based on the functional characteristics of human and computer. And the proposed hybrid decision-making system was composed of three modules such as wireless image monitoring, task specification and control, and man-machine friendly interface modules. Real time and robust image processing algorithms were developed to extract features of a melon at the cultivation site such as size and shape including position. Those features are crucial to the subsequent tele-robotic operation and development of the cultivation database.

3. RESULTS AND DISCUSSION

A. Wireless Remote Image Processing System

As shown in figure 2, image was acquired using a progressive scan color CCD camera (TMC-7, Plunix) and an interlaced scan monochromatic stereo CCD camera (STH-V3, Videre Design). A color camera was used for image acquistion and processing for object identification and a stereo camera was for range detection. Image data of cultivation site of house melon acquired from the color CCD camera was transmitted by wireless to IBM PC compatible host computer through R/F transmitter and receiver modules. Received image data was input to the color frame grabber and was displayed through the monitor. Then operator touches the point of interest onto the touch screen of the monitor with finger. The touch-screen (AccuTouch, ELO touch system, USA) was mounted onto the 15 inch TFT LCD Monitor (Artistage, NewComm, Japan). Touch screen adopted 5 line resistive overlay and communicated with a computer through RS232 via mouse emulation.

Part of the image touched by finger was clipped with the pre-assigned area (local window). Specifying local processing window using finger touch allowed robust processing results with real time extraction of features of interest. Pointing the object of interest by the operator gave basic primary information such as the existence of object and the approximate center point of the object. With the specified local window of interest, a sequence of algorithms to identify the location and size of the melon was developed. A local window was specified as a default rectangular size of 200 by 200 pixels and was size adjustable. Once object of interest was extracted, range information was obtained easily using a stereo CCD camera with given position information. Table 2 shows the specification of the system elements of the remote image processing system.

Table 2 Specification of wireless image acquisition system

Item	Model and Specification
Color Camera Stereo Monochromatic Camera	1/2" CMOS Progressive scan TMC-7 Series, Plunix Interlaced scan STH-V3, Videre Design
R/F Image Transmitter Receiver	RF-Korea RTS-112 (2.4 GHz) 4 CH RRS-212 (2.4 GHz) 4 CH
Frame Grabber	Matrox Meteor 2/4 with Mill Lite 7.2
Computer	Pentium III 800 Mhz O/S : Windows 2000
Data Transmitter Receiver	RM-447, HOW Co., Korea Power: 10 mW Trans. Speed: 19200 bps Freq.: 447 Mhz, 4 CH Range: 150 m RS-232C

B. Camera Conveying System

In a case of prop type melon cultivation, fruit was located at around 120 cm height from the and stem grew up maximum 180 cm. Camera conveying system was designed and built to move a camera from 43 cm to 150 cm from the ground in order to acquire the image of a plant sequentially following the induced string vertically. As shown in figure 2, a color CCD camera and a stereo camera was mounted on the 20 mm diameter TM screw. And camrea could rotate 180 degree along the vertical axis to capture the left and right side images. DC motor and with two 16 mm diameter guide rods were used for up and down motion of a camera.

C. Automatic Guided Vehicle

Automatic guided vehicle was built as a box structure and had a size of 1,060 mm × 480 mm × 650 mm (length × width × height). Power supply, robot arm and vehicle controller, and camera conveying system and controller were mounted inside the box frame. Two 12 V, 100 AH automotive batteries were connected in series to supply enough power for the system. Maximum 800 W of the required power to activate the whole system components. Two batteries could allow 3 hrs of operation.

On the top of the vehicle, base bracket for a 3 dof (degree of freedom) robot arm were built and was moved by the LM guide and ball screw. This device made robot arm to move along the driving direction of a vehicle with a stroke of 640

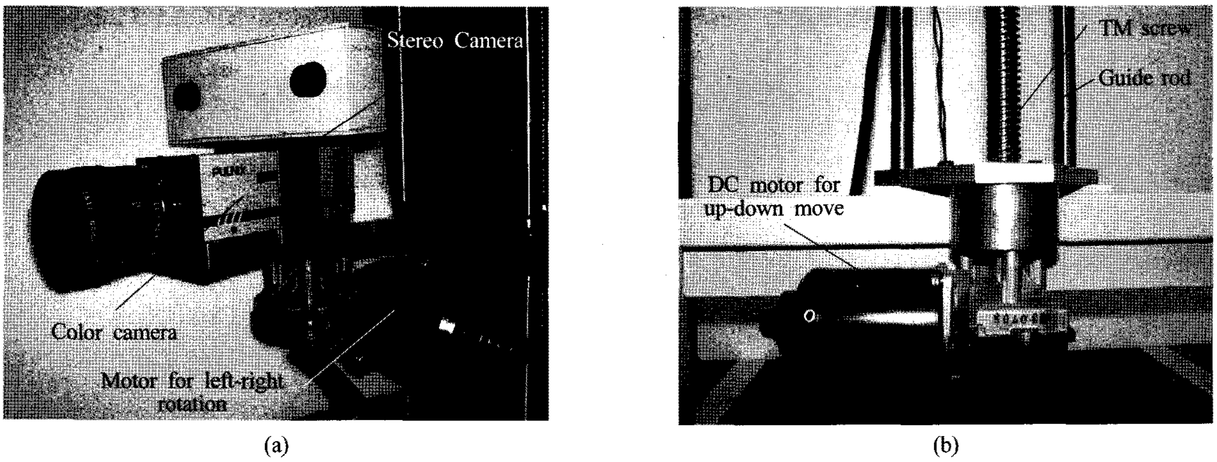


Fig. 2 Camera conveying device: (a) left-right rotation of color and stereo cameras (b) up-down device.

mm. Sliding base bracket of a robot arm was for the precise locating of a robot arm. Once object of an interest was identified, base bracket was moved to locate robot arm precisely to align with the object.

Vehicle was driven as real wheel drive using DC servo motor (24 Volt 100 W, Tamagawa) with 60:1 gear reduction. Rubber tires (300 mm external diameter with 85 mm width) maintained 1,087 N under 36 psi air pressure. Rotational speed and direction of left and right wheels were controlled independently using PWM. Maximum speed of a vehicle was set to be 0.5 m/sec.

As shown in figure 3, a vehicle was driven along the guide rail which was put onto the ground to maintain constant the distance between the vehicle and plant. 50 mm × 50 mm size 'ㄱ' type steel beam was used as a guide rail. V A guide roller with V type groove were attached at the bottom of the front and rear of the vehicle. Front side roller was fixed straight along the vehicle driving direction and rear side roller was mounted as free. In the greenhouse, though driving path along the planting area was straight, a turning was required to move to te next plant row after driving a straight section. For a turning path, a color tape or a thin color plastic strip was lain onto the ground. 11 light reflective type photo sensors (GP2A22, Sharp) which could identify the existence of the object were mounted at the front bottom of the vehicle to trace the plastic strip. And a steel plate was put in the middle of the induced string of a melon in order to stop the vehicle precisely. Proximity sensor (PS50-30DN, Autonics) was mounted at the side of bottom plate of a vehicle to detect the steel plate. Once steel plate was detected, vehicle was

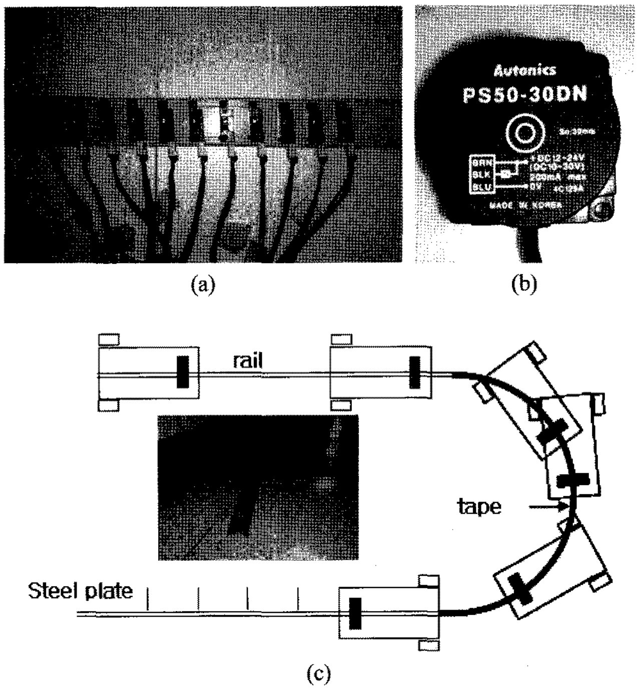


Fig. 3 Schematic of path tracking of AGV: (a) GP2A22 photo interrupter (b) PS50-30DN proximity sensor (c) guide rail and path tracking of AGV.

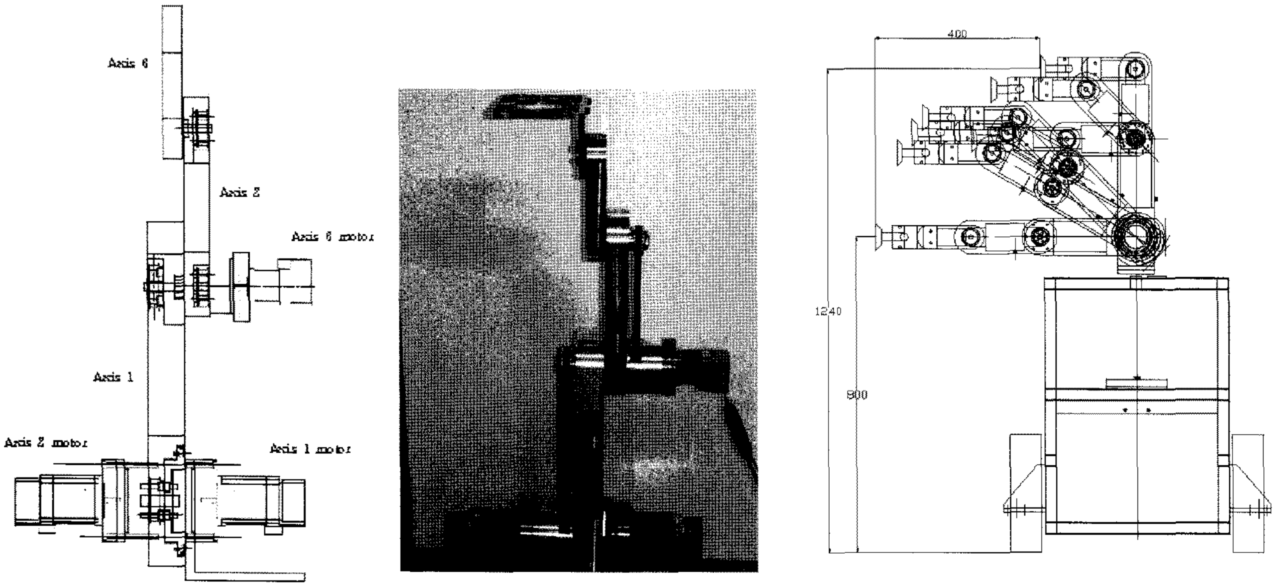
stopped and after finishing the required task a vehicle was moved according to the move command.

D. Robot Arm

End-effector of a robot was specified to work from 400 mm to 800 mm from the plant. Since the workspace was limited inside the greenhouse, articulated type robot arm which allowed the maximum workspace and motion flexibility was selected. Lengths of shoulder (axis No. 1), elbow (axis No. 2), and wrist (axis No. 3) links were set to be 250

Table 3 Specification of robot arm

Index	Length (mm)	speed (rpm)	Torque (N-m)	Motor (rpm)	Trans ratio	Harmonic drive Max. Torque
Arm 1	250	5	71.7	500	100:1	105.8 N-m
Arm 2	180	5	44.2	500	100:1	105.8 N-m
Arm 3	180	5	15.0	500	100:1	38.2 N-m



(a) (b)

Fig. 4 Three dof robot arm and its workspace (unit: mm).

mm, 180 mm, and 180 mm respectively. Loading capacity was determined as 78.4 N considering weight of a melon as 34 N and weight of an end-effector. As shown in figure 4, joint motor for wrist was installed on the elbow axis and motor for elbow was placed on the shoulder axis and timing belt was used for power transmission to reduce the required torque for each joint motion. Cool Muscle AC step servo motor with harmonic drive of 100:1 gear ratio was installed for each joint. Each revolute joint had a range of 300 degree. And total weight of a robotic arm was 147 N. Table 3 shows the specification of robot arm.

Since wrist link was always kept parallel to the ground, height of the workspace was from 800 mm to 1240 mm. From the sliding joint using LM guide robot base could slide 400 mm stroke. Considering base sliding joint, robotic arm mounted on the automatic guide vehicle was 4 dof robot arm. Figure 4 (b) shows the projected workspace. Figure 5 shows the mobile platform and robotic arm mounted onto the vehicle.

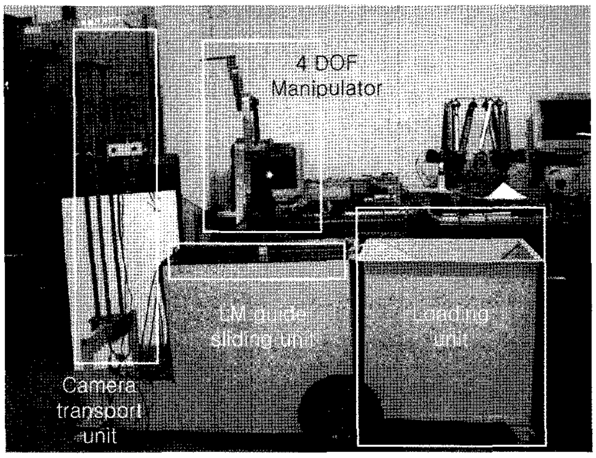
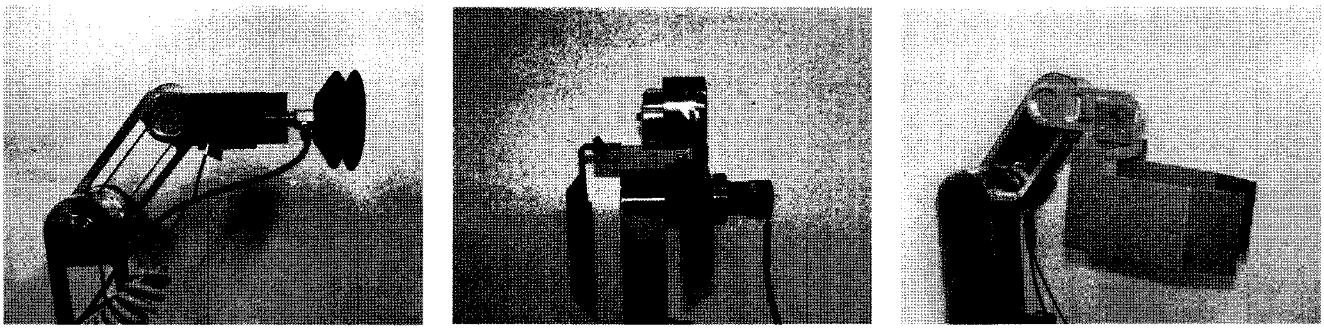


Fig. 5 Mobile platform and 4 dof manipulator.

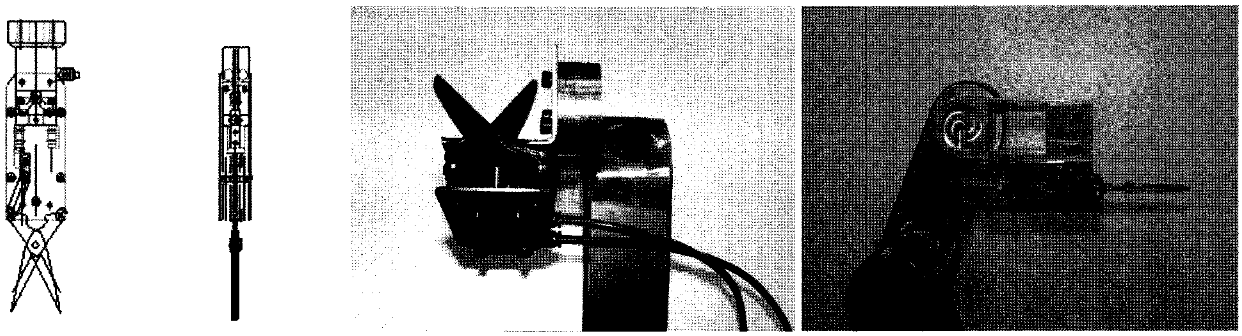
E. Modular End Tools

End-tools were developed to be modular type in order to handle various tasks by simple exchange. End-tool was designed to be lightweight, small size, and simple structure. End-tools such as pruning scissors, compliant vacuum pad for rmelon harvest, nozzle device for watering and pesticide application, and harvest gripper with stem cutting device



(a) (b) (c)

Fig. 6 Gripper for harvest: (a) vacuum pad type gripper (b) pneumatic gripper.



(a) (b) (c)

Fig. 7 Drawing of cutting knife for pruning and developed pruning tool.

were developed.

Compliant vacuum pad was developed using ball joint and spring. Figure 6 (a) shows the picture of the suction pad. Vacuum pad was designed and vacuum power was set up to handle 78N. Diameter of pad was 110 mm and stroke of rubber bellows was 33 mm. However, since the surface of musk melon had a rough web pattern surface, vacuum generator should be operated continuously to maintain the required vacuum pressure during the gripping process.

To avoid this problem, pneumatically activated gripper was developed as shown in figure 6 (b). Inside the gripper, soft sponge was attached to prevent from the damage.

Stem pruning is performed consecutively throughout the period of cultivation. Pruning scissors was designed considering stem thickness of 4 mm to 8 mm. Electro-pneumatic cylinder with 10 mm stroke was used to activate the scissor linkage resulting into 50 mm stroke at the end of scissor. Fixture of scissor blade was designed to exchange easily and proximity sensor was used to monitor the motion of scissor. Figure 7 shows the developed pruning end-tool.

Operator indicates a series of pruning spots by touching area of interest in the wireless transmitted monitor image. According to the operator's indication, a local window is specified and then image processing is performed with the local image to extract the precise pruning position. A sequence of pruning position data is accumulated until operator stops data acquisition. When operator commands manipulator to execute the task, stored position data for pruning are extracted and manipulator follows the sequence of motion command.

Spray nozzle for watering and or pesticide application was developed as shown in figure 8. Spraying location was specified through touch screen interface. Spray was performed based on spot (100 diameter circle) or area (200×200 pixel

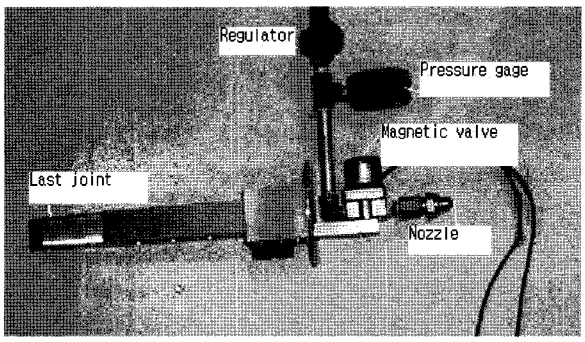


Fig. 8 Spraying tool.

size). Flow rate was controlled by pressure control and moving speed of end-effector.

F. Tele-operative System

Identifying house melon was performed using wireless image transmittance and localized computer image processing. A tele-operative hybrid decision-making was utilized to overcome limitations in recognizing the object with the aid of computer alone. Job environment related to melons raised in the greenhouse was selected to realize the proposed concept. Identifying melon from the wireless transmitted camera image of the cultivation area is very difficult because of the ambiguity among stems, leaves, shades, and a fruit, especially when melons are covered partly with leaves or stems.

Remote local image processing system was built as shown in figure 9. The image was transmitted from the task site to the console for image processing using transmitter and receiver. Then the color image of the melon was captured remotely and processed via local assignment of the interest area by touching screen. And then the image was clipped to the pre-assigned area. Command data from the operator console was transmitted to the manipulating system including camera transport device installed at the greenhouse through wireless data modem. System controller drove a corresponding mechanism according to the motion control data received. And results of motion control were transmitted back to the task command console by wireless.

G. Communication Protocol

Wireless remote control is sensitive to the characteristics of the transmission environment. Response function to command signal was added between host and local controllers. And to reduce the possible transmission error, communication protocol as shown in figure 10 was developed.

Header indicates data start and transmitted data. Command transmission was denoted by '#' and normal and abnormal responses were denoted as '$'and '!' respectively. Normal response represented no structural error in data. Abnormal response indicated error in command data format. Carriage return was used as a data terminator, which indicated the end of data and it allowed transmitting long data. Check Sum was defined as lower 1 bit of the summed result of Header,

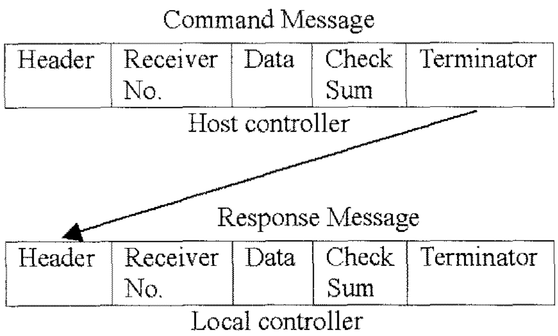


Fig. 10 Communication protocol.

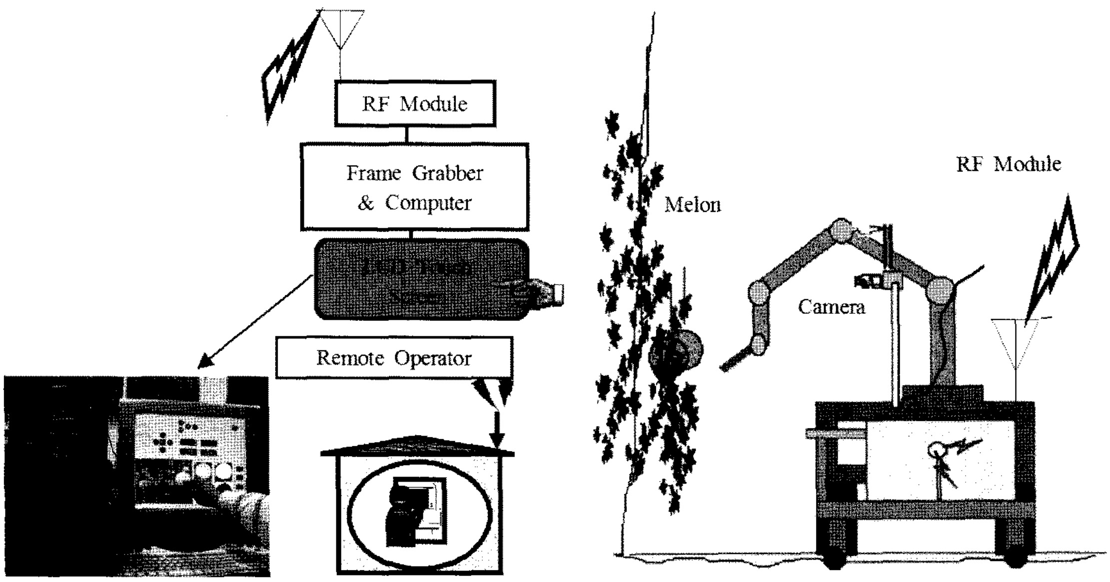


Fig. 9 Schematic diagram of tele-operative task and environment interface system.

Receiver Number, and Data to check the communication error. Data for digital I/O control, motor control, state monitor, and communication line monitor were used to remotely control the manipulating system completely.

H. User Interface

Figure 11 shows the task control and monitoring software module with touch screen interface. Task control and monitoring module was divided into four windows such as task selection window, camera control window, window for mobile platform and manipulator control, and image acquisition and processing window. Since system was activated through RS232 serial communication, activation of the box buttons on the touch screen was controlled to prevent repeated commands from being generated during the operator's touch command. Simultaneous multi-unit control and single unit control functions were separated to ensure the communication stability.

Software module was developed using MS Visual Basic 6.0. Major functions of the system software were manual system control, harvest, pruning, watering, and spraying. Using a manual system control, each unit of the system could be controlled independently. And system diagnosis allowed the communication test and system initialization including change of system initial values. Each module had wireless remote communication through RF data modem (PM417, RF Korea) via 19,200 bps. Remote task control system transmits the operator's command to the control unit of the machinery and also receives the signal state of the task execution of machine. Task command was done by touch screen. User interface was developed as user friendly graphic interface. Considering human operator's response time, keyboard response time was set around 0.3 sec and set to be controlled by operator. Time duration to display results of image processing for most tasks was also assigned around 0.2 sec.

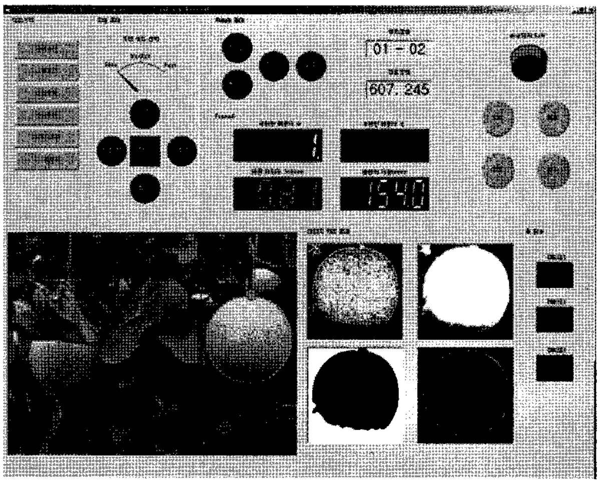


Fig. 11 Main user interface module.

4. CONCLUSIONS

A man-machine hybrid automation via tele-operation is characterized into the efficient task sharing between operator and computer controlled machine such as a robot and the efficient interface between operator and robot. As an interface system between operator and robot, a touch screen mounted on the monitor and remotely captured imaging system were used. Object indication was done by the operator's finger touch to the captured image onto the monitor. And image processing was performed onto the specified local area to extract desired features of the target object.

In this paper, a prototype multi-functional tele-operative robotic system for musk melon cultivation and harvest was developed. Modular type exchangeable end tools were developed to meet the various cultivation tasks and it would improve the increase of machine operation time and reduction of the total system cost. The developed system could perform an environment friendly operation via introducing site-specific precision application while optimizing consumption of the pesticide and fertilizer. Tele-operative robotic system could perform high speed and precise operation in performing tasks, while keeping the robustness for the volatile tasks under the uncontrolled greenhouse environment through hybrid decision making.

The prototype tele-operative system through wireless remote control of the system, data and signal communication, and operator friendly man-machine control with graphic user interface kept farmer off the cultivation site. A farmer could have safe and comfortable working environment through tele-operation and also prevent plants from migrating disease and pesticide from outside. Moreover, the prototype system could provide practical solutions for the labor shortage, while allowing the inexperienced farmer to grow plants via supporting of easy access of knowledge base. The developed prototype could allow a farmer to the flexibility of labor (day and night labor) and real time monitoring and control of operations in greenhouse.

MS Windows based interface software was developed using Visual C++6.0 and Visual Basic 6.0. User friendly GUI interface software was developed such as task assignment, manual machine control, system diagnosis, and task execution modules.

Thouh the prototype multi-functional modular type tele-operative robotic system was not implemented in site it showed the practical and feasible way of automation for the volatile bio-production process. From the test results of sample tasks, it was concluded that the developed system could realize the real time machine operation, robust and precise object identification, and adaptability of various jobs and environments.

For further research, it is required to have more field tests in order to verify the system stability and is required to develop diverse end-tools to expand its tasks. The proposed scheme can be adopted easily to automate other greenhouse plant cultivation. Researches related to plant science such as growth modeling, establishing spatio-temporal database of plant growth, and quantitative monitoring of plant growth state are highly recommended utilizing the developed system.

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