Development of Multi-functional Tele-operative Modular Robotic System For Watermelon Cultivation in Greenhouse

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요 약

생물생산에 요구되는 다양한 작업들을 생력화하기 위한 연구 개발 노력이 전세계적으로 활발히 추진되어 왔다. 이러한 연구 개발은 주로 노동집약적인 작업, 고부가가치 농산물을 생산하기 위한 작업 그리고 작업자에 유해한 또는 가혹한 환경하의 작업 등에 주안점을 두고 추진되고 있다. 하지만, 생물생산분야의 생력화를 추진하는데 있어서 다양한 작업성과 강건성이라는 작업성능 측면에서의 기술적인 문제와 고가의 시스템 및 설비 비용에 따른 경제성 문제가 항상 걸림돌이 되어 왔다. 본 연구에서는 언급한 문제점들 외에 기계가동률, 유지보수 등 생물생산분야의 생력화에 있어 내재되고 있는 문제점들을 효율적으로 해결하기 위하여 무선 원격로봇 시스템에 의거한 새로운 생력화 개념을 제안하였다. 새로운 개념의 생력화는 주어진 작업을 성공적으로 수행하기 위하여 작업자(농민), 컴퓨터 그리고 로봇을 위시한 자동화 작업설비를 대상으로 상대적으로 수월성을 갖는 기능을 중심으로 역할을 분담하는 것이다. 또한 시설재배에 요구되는 전정, 관수, 방제, 제초, 수확, 운반 등과 같은 다양한 작업들을 노동 투하정도와 기능적 유사성 측면을 고려하여 일관적으로 작업을 생력화하는 방안을 제시하였고 제안한 개념을 구현할 수 있는 시스템을 개발하였다. 대상 작목으로는 중량으로 인하여 비교적 취급이 어려운 수박을 선택하였다. 개발 시스템은 크게 무선원격 모니터링 및 작업제어 모듈, 무선원격 영상 획득 및 데이터 송수신 모듈, 4자유도 직교좌표형 로봇 암을 장착한 갠트리 장치부, 교체가 가능한 모듈형 선단 작업장치, 수박 운반 적재모듈의 5개 하드웨어 모듈로 구성하였다. 개발한 시스템은 그래픽 사용자 인터페이스를 통하여 터치 스크린 모니터를 이용하여 작업자와 컴퓨터간의 인터페이스를 구현하였으며 무선 원격데이터 송수신과 분산 제어기를 이용하여 작업자와 컴퓨터 그리고 로봇 작업기 간의 인터페이스와 시스템 제어를 구현하였다. 개발 시스템의 성능을 시험하여 결과를 제시하였으며 본 논문에서 제안한 새로운 개념의 생력화 시스템은 생물생산분야의 생력화 방향을 새롭게 제시하는 실질적이고 실현 가능한 시스템이라는 것을 보여주었다.

주요용어 : 원격작업, 모듈형로봇, 무선작업, 수확, 전정, 방제, 온실, 수박.

1. INTRODUCTION

There have been many research and development activities to automate tasks required to operate greenhouse efficiently. So far, various schemes and types of automatic control system have been developed and implemented to maintain the proper environment to the plants in a greenhouse such as moisture, temperature, CO_2, and nutrients. In addition, automatic pesticide application system(it is not site specific, though) and automatic sorting of post-harvest products have been developed worldwide(Hwang and Lee, 1996). However, most tasks that require delicate handlings such as pruning and thinning out superfluous flowers and fruits,

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harvesting, stem induction etc. still remain to be auto-
mated. Some efforts have been made to automate har-
vest operation but only showed the feasibility of appli-
cation through limited experiments. They were not suc-
cessful and practical in the real field operation(Umeda
1997, Kondo 1996, Arima 1994, Kondo 1998).

Major bottlenecks of implementing task specific ro-
botic system in greenhouse are lack of real time proc-
essing in task identification, too much complex system
for farmers to handle, technical difficulties in adapting
the system to variable and unstructured task environ-
ment, lack of the robustness of the system, and com-
plexity of the system maintenance. Furthermore, the
required system cost is too high and on the other
hand, machine or system operating time for an indi-
vidual task is too short compared to the overall growth
period of each plant. Overcoming above deficiencies in
usual approach toward greenhouse automation was main
motivation of this research.

In Korea, in cultivating greenhouse watermelon,
harvesting requires 58.9 hours of labor per 10a. And it
requires 26.4 hours of labor for sorting and packaging, 43
hours for pruning, 45.7 hours for seedbed administration,
46.1 hours for transplanting, and 26 hours for weeding.
Considering labor requirements of individual task during the
plant growth, harvesting, pruning, and weeding are most
time consuming. These days, differently from 1970s and
1980s, the issue of environment preservation spreads over
the nation. Researches and developments on organic
farming, environment friendly cultivation, and precision
farming have widely spread out and actively performed.

Since greenhouse cultivation often requires high cost
of facility investment, the density of planting is high
and a precise control of plant growth environment such
as atmosphere and nutrition is usually being exercised.
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. Besides, the
optimum atmosphere to plants is usually not good for
human health because of the excessive CO_2. And it is
highly required to minimize the application of chemical
pesticide and fertilizer. The proposed multi-functional
robotic system should cope with not only above prob-
lems efficiently but also quality maximization and im-
provement of overall production rate.

In reality, automating greenhouse cultivation often

requires real time information processing such as job
environment recognition including object identification,
adaptive decision-making, etc. There have been many
research efforts to substitute those human functions and
to change mode of plant cultivation. So far, however,
it is still far from the success especially for tasks
under unstructured environment. Moreover, producing
agricultural products such as fruits, vegetables, and
crops requires many diverse processes, which require
various kinds of machines to automate each process.
Compared with humans' versatility, those machines
have been developed for the individual process with
specialized function. These may help to automate each
process successfully to some degree but resulted into
the increase of the total production cost and decrease
of the machine operation time.

In this paper, a tele-operative robotic system, which
is a new concept of automation for bio-production, is
proposed to solve most of the obstacles mentioned
above while maximizing system operation time and
reducing total system investment. As a representative
plant of weighted fruit bearing vegetables, watermelon
was chosen to implement and realize the proposed system.

2. MATERIALS AND METHODS

Watermelon was chosen as a representative fruit bear-
ing vegetable in this research. Watermelon is high value
added vegetable, but is difficult to handle because of
its heavy weight. The proposed system was designed to
fit arch shape greenhouse as shown in Fig. 1a, which
is a standard size for watermelon cultivation in Korea.
It had center height of 4.8 m, edge height of 3.0 m,
width of 7.0 m, and length of 100 m. Fig. 1b shows
the inside of greenhouse and distance between ridges
was from 2.7 m to 3.0 m and width of the center
furrow was from 0.45 m to 0.55 m.

Major selected tasks of watermelon cultivation to be
automated using the proposed system were pruning,
watermelon turning, harvest, watering, and pesticide
application. Physical data of watermelon were collected
to properly design the system based on the large and
medium size fruit bearing varieties. Weight of
watermelon ranged from 3 kgf to 8 kgf, diameters
ranged from 200 mm to 300 mm, and stem diameters
ranged from 4 mm to 8 mm.
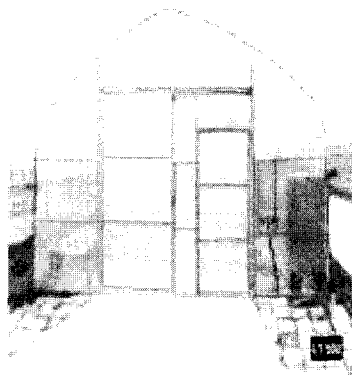
(a) outside
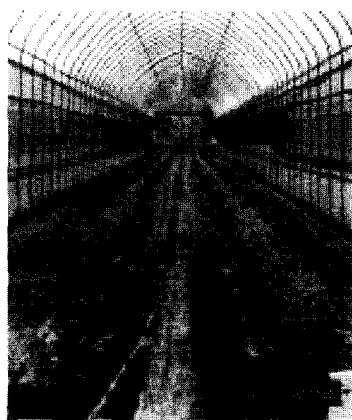
(b) inside

Fig. 1 Arch shape greenhouse for watermelon cultivation.

Considering adaptability of machinery to multi-tasks, machine operating time, economic efficiency, and feasibility of commercialization, following functional specifications were set up for the proposed system:

1. System is 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 is to be secure enough to handle heavy weight watermelon utilizing the gantry structure and Cartesian type manipulator.

3. System is to be environment friendly, while keeping farmer off the cultivation site and introducing site-specific precision application of pesticide or fertilizer including water.

4. System adopts tele-operative concept through developing wireless remote control of the system, data and signal communication, and operator friendly man-machine control and graphic user interface.

5. 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, modular type multi-functional tele-operative robot system for watermelon cultivation, harvesting, sorting, and loading was developed and tested at the laboratory. The developed system was composed of 5 major hardware modules such as a remote monitoring and task control module, wireless remote image acquisition and data transmission module, gantry system equipped with a rectangular type robot arm, and exchangeable modular type end tools, and watermelon loading and storage module.

3. RESULTS AND DISCUSSION

3.1 Gantry frame

Fig. 2 shows the developed gantry type mobile unit driven on the guided rail. Major power source was 1kW 3-phase A.C. electric motor with inverter and position of the gantry unit were controlled with optical sensor and disc type slot. Four degree of freedom Cartesian type robot manipulator was attached to the front part of gantry to ensure the proper workspace. Wrist of the manipulator was built to easily mount various end-tools. Watermelon transfer unit to loading area was attached inside the gantry frame. Wireless image and data transmission unit, system controller, and power unit were also installed in the frame. Overall size of the gantry frame was 3,300 mm width, 1,600 mm height, and 1,600 mm length.

3.2 Modular type end tool

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. Four different kinds of end-tools such as cutting tool for branch and fruit/flower

pruning, compliant vacuum pad for watermelon turning, nozzle device for watering and pesticide application, and compliant harvest vacuum pad with stem cutting device and load cell were developed.
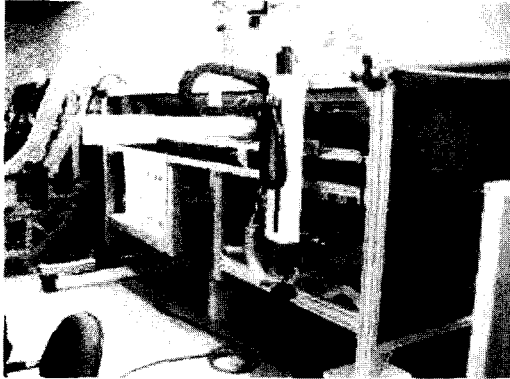

Fig. 2 Gantry type frame.

(1) Pruning head

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. Fig. 3 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.

(2) Turning gripper

Turning watermelon from time to time allows uniform coloring of the watermelon surface. Watermelon turning is rotating watermelon around 40 degree to 60 degree with respect to the stem direction. Compliant vacuum pad was developed using ball joint and spring.

Fig. 4 shows the picture of the suction pad and Fig. 5 shows the schematic drawing of the job sequence.

Suction pad approaches 50 mm to 100 mm offset point along the minor axis(normal to stem axis) of watermelon from the center. Watermelon was rotated by self-weight when lifting vacuum pad. Then vacuum gripper moved to the center point and released the watermelon. This sequence was repeated three times to complete the turning task. Vacuum pad was designed and vacuum power was set up to handle 3 kgf to 8 kgf weight. Diameter of pad was 110 mm and stroke of rubber bellows was 33 mm.
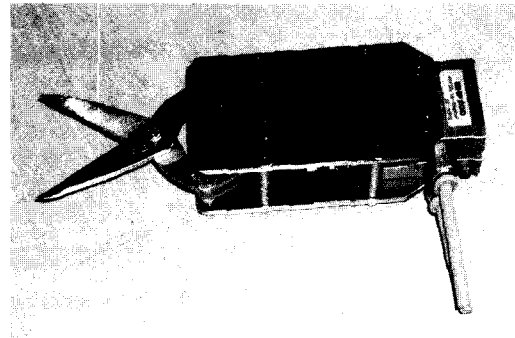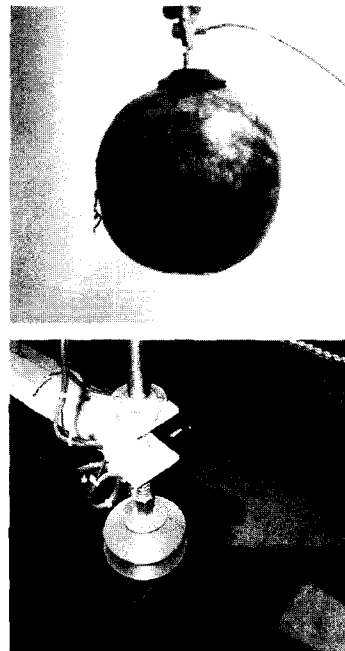

Fig. 3 Pruning scissor.

Fig. 4 Compliant vacuum pad for turning.

Harvesting watermelon requires identifying watermelon position and stem cutting. Since position of stem is not uniform, operator's approximate indication of stem location was utilized to trace longitudinal portion of watermelon surface. Using the surface roller, trajectory of cutter plate was guided through pivot. And cutting was performed repeatedly until vacuum gripper pad
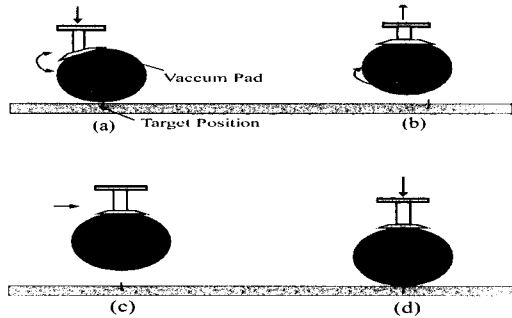

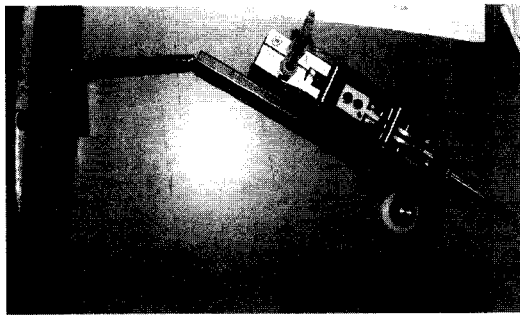Fig. 5 Sequence of watermelon turning operation.

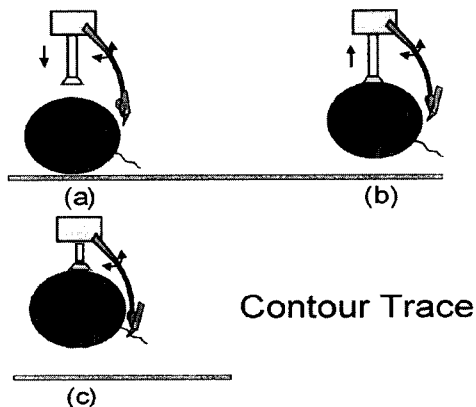Fig, 6 Stem cutting scissor for harvest.

Fig. 7 Schematic diagram of harvest sequence.

reached certain limit. Fig. 6 shows the stem-cutting scissor for harvest. And it was composed of pruning scissor and vacuum pad for watermelon turning. Fig. 7 shows the schematic sequence of harvest sequence. Guide plate could be manually adjusted using slot according to the various diameters of watermelon. Watermelon of 350 mm diameter was used as a standard.

3.3 Robot manipulator and transfer unit

(1) Robot manipulator

CCD color camera and four d.o.f. Cartesian robot manipulator were attached to the front part of gantry to ensure the proper workspace. Three A.C. servo-motors and drivers(x axis: CSM-10BB2ANT-3 with CSDJ-10BX2 driver, y axis: CSM-04BB2ANT-3 with CSDJ-04BX2 driver, z axis: CSM-02BB1ABT-3 with CSDJ-02BX2 driver, Samsung, Korea) were used. And stepper motor with 18:1 speed reduction gear(PK264A1, Oriental motor, Japan) was used for roll axis. Range of motion toward crossway direction was set to be 2600 mm and range of the forward/backward movement was set as 750 mm. And it had a 600 mm of up/down linear stroke and 350 degree roll rotation.

Wrist of the manipulator was built to easily mount various end-tools using wire clip. Each servomotor had accuracy of 2,048 steps per revolution and 0.1 mm/step accuracy. Accuracy of roll joint was 0.1 degree/step. Fig. 8 shows the robot manipulator.

(2)Watermelon transfer unit

Since place of loading watermelon was to be set up inside the gantry frame, intermediate transfer device as shown in Fig. 9 was developed. Once manipulator discharged watermelon to the transfer unit, transfer unit
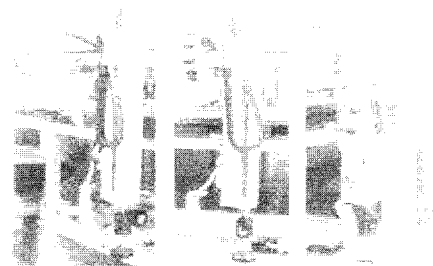

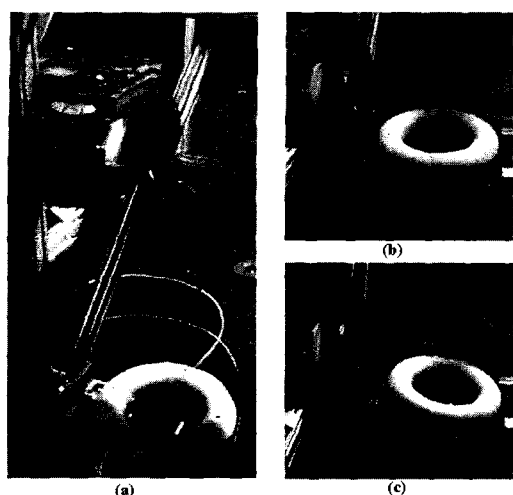Fig. 8 Four d.o.f. robot manipulator.

Fig. 9 Watermelon transfer unit and sequence of movement.

was activated to load watermelon to the storage box. Two electro pneumatic cylinders were used for lifting watermelon supporter and discharging it from the supporter.

3.4 Wireless remote image processing system

Remote local image processing system was built as shown in Fig. 10. Image data of watermelon from the CCD camera was transmitted wireless to IBM PC compatible host computer(Pentium III, 800MHz), by 2.4GHz R/F module(RTX-112, RF Korea) with analog types. Received image data by R/F module(RRX-212, RF Korea) was input to the color frame grabber(Meteor 2/4, Metrox Co., USA), and it was displayed through the monitor. The operator touches the point of the interest onto the monitor with finger. Touch pad screen (IntelliTouch, AccuTouch system, USA) was mounted to the TFT LCD screen (Artistage, NewComm, Korea).

And then the field image of the scene captured remotely was processed via local assignment of the interest area. Local area assignment was done by touching point of interest of the image onto touch screen. Assigning local image window(200 × 200 pixels) has an advantage over the conventional processing of entire image area. Specifying local processing area using touch pad screen allowed to extract features of the interest in

real time and to utilize the complex algorithm because of the small processing area. Moreover, since the existence of the desired object was guaranteed, some AI or rule based processing techniques could be easily adopted. The pointing the object of the interest by the operator gives basic primary information such as the existence of object and the approximate center point of object.

Usual image processing technology has some problems such as heavy processing time, lack of robustness of processing results, and error of finding objects. However, specification of the localized area of the interest and feature information (shape, color, texture, size, etc.) of the objects (weed, watermelon, stem, etc.) could be used efficiently to make a robust decision making.
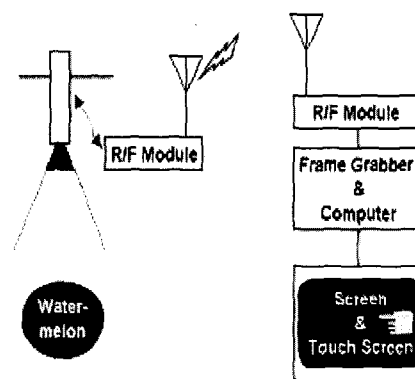

Fig. 10 Remote local image processing system.

3.5 Control system

As shown in Fig. 11, the control system was composed of PLC(AFP22111, Nais, Japan) with digital I/O(32 input and 32 output) and 4 position control modules. 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 divided into task assignment, manual machine control, system diagnosis, and task execution and developed as user friendly graphic interface.
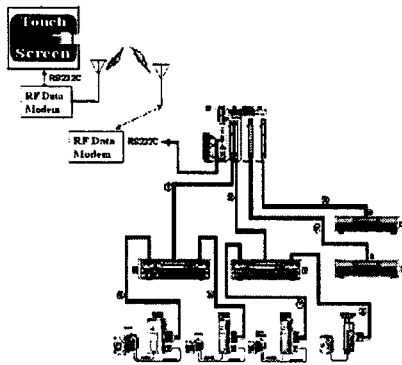
Fig. 11 Schematic diagram of control system.

3.6 Performance of system

Considering human operator's response time, key-board 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 0.3 sec. According to the results of laboratory test, at the stage of task execution without human intervention the developed system showed average 15 seconds to harvest and load each water-melon and average 10 seconds for 3 repetitive turning operations. And it took around 4 seconds for pruning and pesticide application. The developed system worked very successfully for proposed tasks.

4. CONCLUSIONS

A man-machine hybrid automation via tele-operation is classified into two major parts. One is the efficient task sharing between operator and CCM(computer controlled machine). The other is the efficient interface between operator and CCM. As an interface system between operator and CCM, 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.

MS Windows based interface software was developed using Visual C++6.0 and Visual Basic 6.0. Four modules of user friendly GUI interface software was developed such as task assignment, manual machine control,

system diagnosis, and task execution modules. The proposed multi-functional modular type tele-operative robotic system 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.

5. SUMMARY

There have been worldwide research and development efforts to automate various processes of bio-production and those efforts will be expanded with priority given to tasks which require high intensive labor or produce high value-added product and tasks under hostile environment. In the field of bio-production, capabilities of the versatility and robustness of automated system have been major bottlenecks along with economical efficiency. This paper introduces a new concept of automation based on tele-operation, which can provide solutions to overcome inherent difficulties in automating bio-production processes. Operator(farmer), computer, and automatic machinery share their roles utilizing their maximum merits to accomplish given tasks successfully. Among processes of greenhouse watermelon cultivation, tasks such as pruning, watering, pesticide application, and harvest with loading were chosen based on the required labor intensiveness and functional similarities to realize the proposed concept. The developed system was composed of 5 major hardware modules such as wireless remote monitoring and task control module, wireless remote image acquisition and data transmission module, gantry system equipped with 4 d.o.f. Cartesian type robotic manipulator, exchangeable modular type end-effectors, and guided

watermelon loading and storage module. The system was operated through the graphic user interface using touch screen monitor and wireless data communication among operator, computer, and machine. The proposed system showed practical and feasible way of automation in the field of volatile bio-production process.

Keywords : Tele-operation, Modular robot, Wireless operation, Harvest, Pruning, Pesticide, Greenhouse, Watermelon.

5. ACKNOWLEDGMENTS

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