Design and Development of Eggplant Harvester for Gantry System

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ABSTRACT

This paper describes the design and development of harvesting system for the gantry system to harvest eggplants. For this purpose, the harvesting robot was successfully designed and fabricated for the gantry system to harvest eggplants. The operation of the harvester was controlled by Programmable Logic Controller (PLC). Basically, the limit switches, DC motor, and relay are connected to the PLC. Meanwhile, a PLC ladder diagram was designed and developed to control the operation of the eggplant harvester. A visual basic programme was developed to interface the harvester with a greenhouse gantry control system. A videogrammetry method was employed to calculate the distance between the stems of eggplants and the cutter of robot end effector. The end effector used electric as its power source and it was controlled via Programmable Logic Controller (PLC). Visual Basic Programme was developed to interface the harvester with the gantry control system. The accuracy of the videogrammetry was tested to be 67.2% for X-axis, 88.2% for Y-axis and 84.7% for Z-axis. Meanwhile, the speed of the end effector for harvester is 2.4 km/h and it could lift up to 55 cm. In order to determine detachment force of eggplant, 16 samples of mature eggplants were tested in a greenhouse, and as a result, more than 22.76 N force was needed to detach a mature eggplant inside the gantry system.

Keywords: Design, eggplants, harvester, gantry system

INTRODUCTION

A solution to solve acute shortage of labour in the plantation and agricultural sectors is to mechanize all operations. In particular, mechanization or the use of machines for all the operations will reduce manpower, lighten most burdens, increase productivity, as well as make agricultural work more interesting. The increasing use of modern technologies and production processes to increase productivity can reduce dependency on labour force, which is very important for both the agricultural and industrial sectors. Thus, in order to increase the productivity of agricultural products, engineering technology such as mobile robots, machine vision, artificial intelligence, mechanization, automation and robotic, remote sensing, global information system, and global positioning system must be introduced. In more specific, automation and robotic system should be introduced and developed immediately in the agricultural sector, particularly in solving harvesting, collection and transportation of agricultural products. Nonetheless, this technology is relatively new in the agricultural sector and thus, it still requires a lot of research to be carried out. For example, recent activities in the mechanization of harvesting of agricultural products have brought about significant reliance on the engineering properties of agricultural materials. Sound knowledge of the engineering properties of

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agricultural materials should be of value not only to engineers, but also to food technologists and scientists who may find new uses for these products (Wan Ishak *et al*., 2007).

In some agricultural systems, robots have been used for various operations in static applications under controlled environment such as milking, shearing, harvesting, sorting, grading, micro propagation, as well as in some field operations. In the latter cases, literature offers a fair number of robotic systems which were developed to perform operations such as harvesting fruits and vegetables (oranges, tomatoes, and melons), pruning, etc. Some others which have been mentioned represent the opportunities to be better explored, including weed detection and control, and agrochemical applications (Hirakaw *et al*., 1998). Hayashi *et al*. (2002) developed an intelligent robot that could automatically harvest eggplants. The developed system comprised of a machine vision unit, a manipulator control unit and an end-effector unit, which could automatically perform basic harvesting operations like recognition, approach, and picking tasks. The system showed a successful harvesting rate of 62.5%, although the end-effector cut the peduncle at a slightly higher position from the fruit base. The execution time for harvesting of an eggplant was 64.1 seconds. Kondo *et al*. (1995) developed harvesting robots for tomatoes, petty-tomatoes, cucumbers, and grapes in Japan. These robots consist mainly of manipulators, end effectors, visual sensors, and travelling devices. The robots must work automatically by themselves in greenhouses or fields. Murakami *et al*. (1998) designed and developed a harvesting robot for cabbages. The robot consists of a 4-link hydraulic drive manipulator and a gripper to harvest efficiently without degrading the quality of the products, and a machine vision system which measures the size and locations of cabbages in the field. Meanwhile, Bulanon, Kataoka and Hiroma (2001) developed an algorithm for the automatic recognition of Fuji apples on trees for a robotic harvesting system. This system is used to differentiate the fruit from the other portions of the trees, such as the leaves and the branches, as well as to locate the fruit centre and the abscission layer of the fruit's peduncle. The location of the fruit centre and the abscission layer were determined using a geometrical approach and basic image processing procedures.

The objectives of this project were to design a suitable eggplant harvester for the gantry system and to operate the eggplant harvester using a computer control system. Thus, a Visual Basic programme was developed to interface the harvester with the gantry control system. In the project on the eggplant harvesting system, the gantry movement and robot end effector were controlled vertically, horizontally, and in the forward direction by the PLC. A web cam was mounted on the manipulator as the camera captures the image of eggplants and determines the locations of the vegetable by using the videogrammetry method. Through this particular method, the coordinates of the object targets were calculated using the triangulation principle based on the video scene of two different locations of cameras (Mohd. Hudzari *et al*., 2005). The manipulator will move forward to the eggplants and start the harvesting task. The robot arms will be lifted up to push the eggplants upward until they are detached from the tree. Finally, the fruit was transferred into a plastic bag which was placed beside the manipulator.

HARVESTER DESIGN

The fruit harvesting robotic system consists of four basic components, namely a manipulator, an end effector, a power source, and a controller. The manipulator is the arm of the robot which comprises of a system of mechanical linkages and joints that can move in different directions. The end effector is a device which is connected to the wrist flange of the manipulator's arm. In the fruit harvesting operation, the end effector is very important, since it has to meet different criteria for fruit detachment. The main function is to detach the fruit from the tree. The robot arm consists of an arm and a cutter. The robot arm lifts up and pushes the eggplants upward and the cutter will

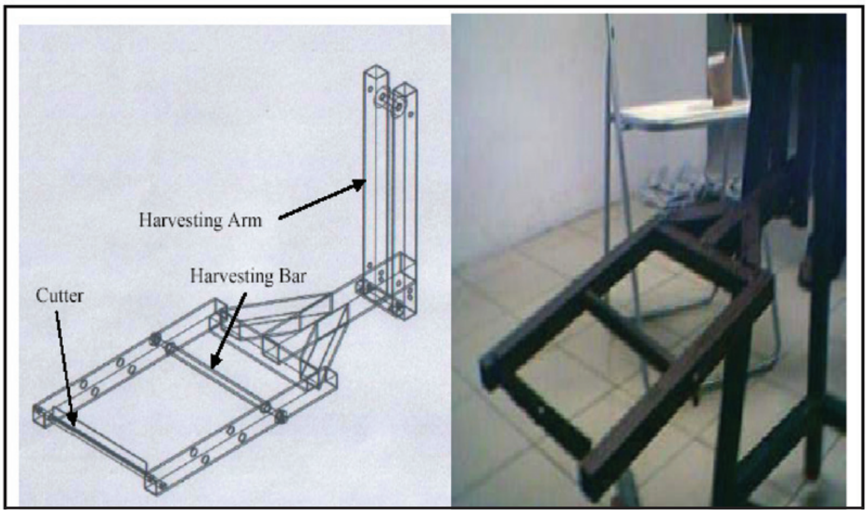


Fig. 1: The structure of end effector

then cut the peduncle of the eggplants during harvesting process. *Fig. 1* shows the design and fabrication of the robot arm harvester end effector. It consists of a cutter, a harvesting bar, and a harvester arm.

The power supply is the unit that supplies power to the controller and the manipulator. The controller is used to control the manipulator movements of the robot, as well as to communicate and control the peripheral components such as machine vision for fruit identification and sensor. Unlike most industrial robots, the fruit harvesting robot will not be stationary. Rather, it will be mounted on a platform, and is able to move in the orchard under various soil and topographic conditions.

Mechanical components such as lead screw, belt, pulley, gears, and chains are used as means of transmitting power from the motor and parts that move on the robot. Lead screw is the more common types of drive mechanisms found in any linear motion machinery. This screw comprises of threaded rods that are fixed with a nut. The basic function of a screw is to convert rotary input motion to linear output motion. The nut is constrained from rotating with the screw, so that when the screw is rotated, the nut travels back and forth along the length of the shaft. Industrial motors are used to convert electrical energy to mechanical energy and they are neither precision speed nor precision positioning devices. For many automated devices and systems, precise positioning is required. Stepper motors are unique because the motion of the rotor is precisely determined by the input signals of the motor. The stepper motor input signals consist of a series of pulses, with the rotor advances one step for each pulse. The motors of the stepper do not require any encoder and servo-control system to achieve the precise positioning required in robotic applications because of the fixed relationship between input signals and rotor motion.

DC servo-driven type robots invariably incorporate feedback loops from the driven components back to the driver. Thus, the control system continuously monitors the positions of the robot components, compares these positions with the positions desired by the controller, and notes any differences or error conditions. The DC current is applied to each motor to correct error conditions until the error goes to zero. In this project, 24 VDC was required for most parts of the equipment. A switching power supply unit was used to convert the AC voltage from the main source to 24 DC voltages. A 12v, 40rpm DC motor was used to connect to the lead screw. The motor rotates clockwise and counter-clockwise to push the robot arm forward and reverse. Meanwhile, a lead screw was used to transmit power from the DC motor to the end effector. Limit switches were used to start, stop, slow down, speed up, or reboot the robot operations. The DC motor was installed to the lead screw to move it forward and backward as well as to push the robot arm for lifting up and down movements.

At the designing stage, the following limitations were considered: (1) working space of the gantry robot were 300m x 600m x 220m; (2) the maximum height of the end effector was 762 mm; (3) the system should be able locate the position of eggplants; (4) the end effector should be able to detach the eggplant from tree; (5) the accuracy of videogrammetry method; and (6) detachment force of eggplants. *Fig. 2* below illustrates the design and development of the Automatic Eggplant Harvesting System.

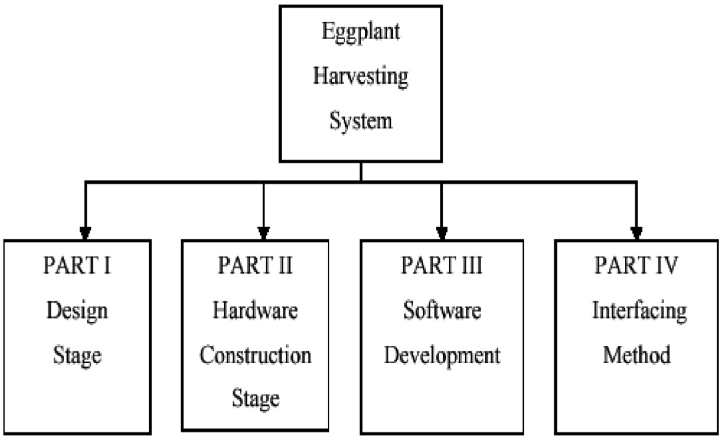


Fig. 2: Four project activities for the development of an automatic eggplant harvesting system

Programmable Logic Controller (PLC)

A programmable logic controller is defined as a digital-operated electronic apparatus that uses a programmable memory for the internal storage of instructions to implement specific functions such as logic, sequencing, timing, counting, and arithmetic, as well as to control various types of machines or processes through digital or analogue input/output modules (Keramas, 1999). The control of the gantry system is operated by a computer and PLC. The PLC consists of the input interface which receives and converts signals from the process into a form that can be understood by the central processing unit. The Central Processing Unit (CPU) interprets the input signals and carries out the control actions according to the programme stored in its memory. It also communicates the decisions as action signals to the output interface. The function memory section is to store the logic control circuit and fundamental operating data for the logic control circuit. It also acts as a scratch pad for the CPU to store external data for future use or immediate actions. The programming language was used to write a logic control programme into the PLC. The logic control programme such as the ladder diagram language represents relay logic control scheme, coils, and contacts. The programming tool provides the connection between the programmer and the PLC. The programmer designs the necessary control circuit and programmes it in a language used by the PLC. The output interface takes signal from the CPU and converts the digital signals into forms that are appropriate to produce control actions. The signals are then fed to external devices such as motors, pumps, valves, and heaters. In this project, NAIS PLC model FP2 was used to control the system. This PLC comes with a power supply, central processing unit (CPU), input modules, output modules, RS232 communication ports, and a special function module to control motor drivers which support a maximum of four axes. It has a maximum of 768 points for both the inputs and outputs.

Machine Vision System

The first major task of a fruit harvesting robot is to identify fruit on the tree and determine its location. While humans can recognize familiar objects from almost any angle, it is difficult to replicate this intricate process by machine vision. Fruit are objects of various shapes, sizes and colours, existing in random positions in trees of various sizes, volumes, and limb structures. The common objective was to develop a computer vision system to obtain a digital image of the fruit in the trees, and develop an image-processing algorithm capable of identifying and determining the locations of fruits in these images (Sarig, 1990). Machine vision is often thought of as having the capability to sense, store, and reconstruct a graphic image that matches the original image as closely as possible. It has specific tasks such as checking for proper orientation, identifying parts, searching for specific defects, or checking alignment for assembly (Asfahl, 1992).

Videogrammetry is *per se* fully three dimensions, and works in a non-contact mode to determine and track even very complex point clouds with a high number of particles, delivers very precise and reliable results, and can be fully automated. Two parallel webcams are used to determine the distance between the object and the camera. A Lifeview FlyCam USB 1.00 camera was used as a machine vision system in this project. The webcam has an image resolution of 352x 288 pixels.

Software Development

Robot programming language is a set of words and rules governing their use, employed in constructing a programme. The programme provides the control instruction required for the robot to perform its tasks. The robotic programme instructs a robot how to execute some motions. In other words, this programme supplies the intelligence that enables the robot to receive, understand, and carry out any given tasks.

The PLC programme development software was used to create, edit, store, and monitor PLC user programmes. The environment of FP WIN GR was developed by Matsushita Electric Works LTD. FP WIN GR provides 3 programming styles, namely Ladder Symbol Mode, Boolean Ladder Mode, and Boolean Non-Ladder Mode. In this project, the ladder symbol mode was used to create the PLC programming Ladder diagram. The PLC performs its task after a user programme is loaded into the CPU internal memory. This programme was developed by a personal computer, Visual Basic, and PLC programming software. The programme was downloaded to the PLC via a communication cable through the RS232 port. The software used in this project is known as the FPWIN GR. The first step in the software development is to do a sequence of the processes involved in the whole system. A flowchart should be developed in such a way that it can represent the total programme logic. A programme called ‘Eggplant Harvester’ was developed to control the end effector operations and videogrammetry. Using this particular programme, an operator can use it to give instructions to the gantry and harvester so as to perform the tasks. *Fig. 3* shows the flowchart of the software development for this project.

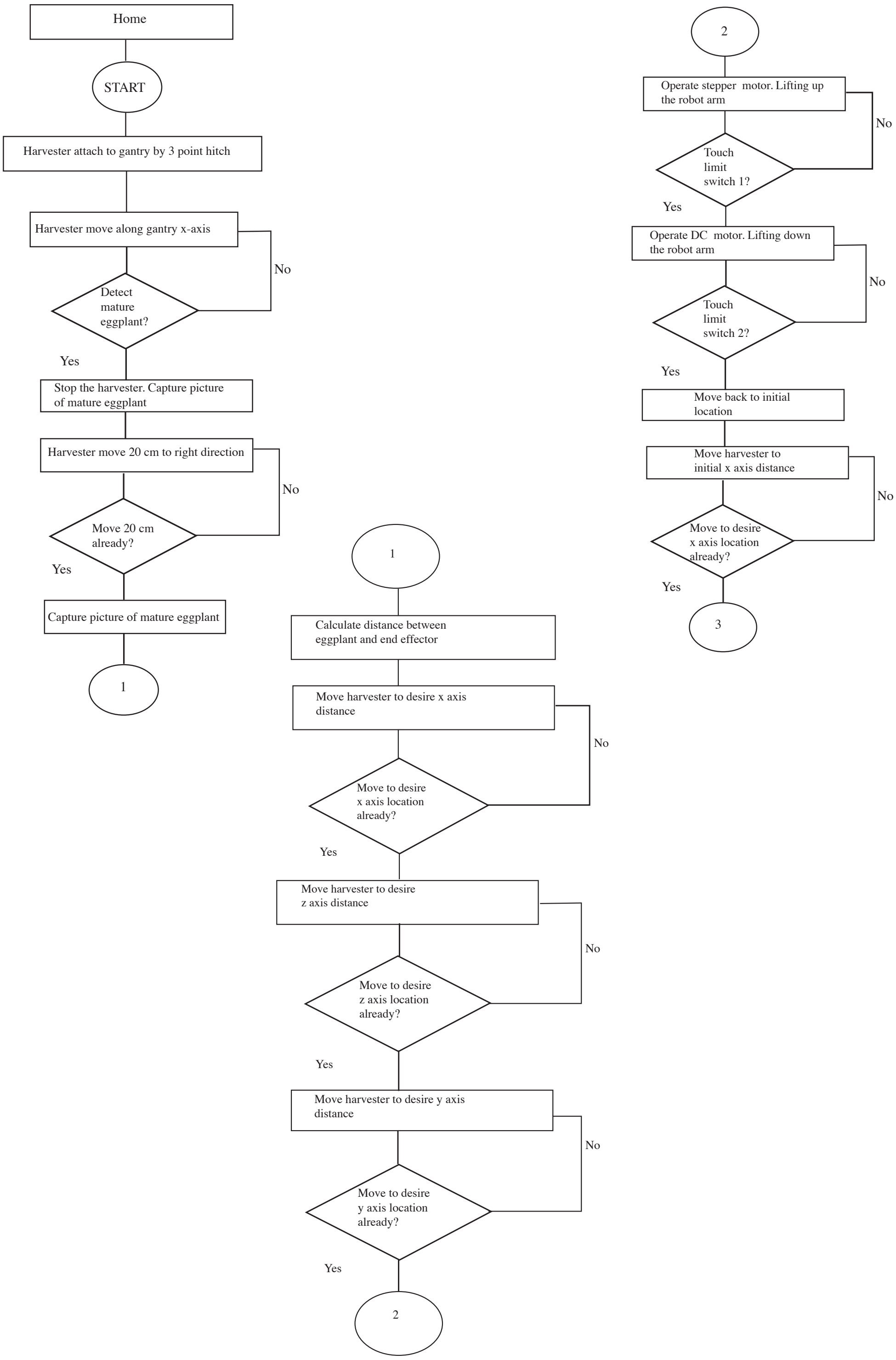


Fig. 3: Flowcharts of the programme

Harvester Operations

Initially the harvester was in home position. The harvester was then attached to the three-point hitch of the gantry. The gantry and the harvester moved along the X axis, while the operator monitor the eggplant tree used a webcam which was attached to the harvester. If the operator detects any mature eggplants in tree, he would stop the movement of the gantry by clicking the stop button and automatically capture the picture of mature eggplant by clicking the capture button. The harvester would automatically move to the right, i.e. about 20 cm in distance, and the operator would then recapture the picture of the same egg plant. When the picture appears on the screen, the operator has to click on the peduncle of the mature eggplant in the same location. After that, the programme will automatically calculate the distance between the peduncle eggplant and the robot end effector cutter. After the location of the mature eggplant is determined, the harvester will move to the desired X axis, Z axis, and Y axis distance. Then, the DC motor will operate in the counter-clockwise direction and the robot arm will be lifted up to cut the peduncle of the eggplant. The motion of the robot arm is stopped when it touches the limit switch 2. The relay changes the polarity of the motor when the limit switch 2 is activated. The motor will then turn in a clockwise direction and the robot arm will move down until it touches the limit switch 1. If the limit switch 1 is activated, the DC motor will be stopped. After the eggplant has been detached from tree, the harvester will move back to the initial position. The harvester will move to another row to perform another harvesting process.

1. The harvester is attached to the gantry robot by the three-point hitch.
2. The harvester moves along the gantry x-axis and the operator monitors the eggplant tree through a video which is captured by a camera.
3. If any mature eggplant is detected, the operator will stop the harvester manually.
4. The operator captures a picture of the mature eggplant, and the harvester will then move 20 cm to the right of the tree and recapture the eggplant picture.
5. The operator clicks the peduncle of the mature eggplant on both pictures to make sure that the same object is pictured.
6. The distance between the peduncle mature eggplant and the end effector is then calculated.
7. The gantry will move the harvester to the desired location.
8. The DC motor will operate and push the robot arm upward as its lifting operation. The cutter at the end effector will then cut the peduncle of eggplant during the process.
9. Mature eggplant is then detached from tree and dropped into a plastic bag.
10. The gantry will move the harvester to its initial place and repeat step 2.

RESULTS AND DISCUSSION

The average detachment force for a mature eggplant inside the gantry system was determined to be 22.76N. *Fig. 4* shows the output data for this particular project.

Sample No	Diameter of eggplant (cm)	Length of eggplant (cm)	Weight of eggplant (g)	Pulling strength		Angle of pulling
				(kg)	(N)	
1	4	13	160	2.5	24.53	0º
2	3	19	70	2	19.62	0º
3	3	15	60	2.3	22.56	0º
4	3	10	80	3	29.43	0º
5	3	27	100	5	49.05	0º
6	2.5	15	40	1	9.81	0º
7	2	14	40	3	29.43	0º
8	2.5	18	60	2.5	24.53	0º
9	2.5	18	80	2	19.62	0º
10	2.5	15	50	2.5	24.53	0º
11	2.3	18	60	2.5	24.53	0º
12	2	10	30	1.5	14.72	0º
13	2	11	30	2.3	22.56	0º
14	2	12	40	2.5	24.53	0º
15	2	12	40	1	9.81	0º
16	2	11	30	1.5	14.72	0º

Fig. 4: The output data to determine the pulling strength of peduncle eggplant

Based on the data presented in *Fig. 4*, the average detachment force is calculated as:
= (2.5+2+2.3+3+5+1+3+2.5+2+2.5+2.5+1.5+2.3+2.5+1+1.5) kg / 16
= 2.32 kg
= 22.76 N

For the videogrammetry accuracy test, the average relative error in the X axis, Y axis, and Z axis was found to be 32.8%, 11.8% and 15.3%, respectively. The accuracy of the videogrammetry varies significantly due to several reasons such as the resolution and quality of the camera, size of the object measured, the number of video used, and the location of the camera.

The End Effector Test

In this study, the end effector was successfully tested in the laboratory. During the operation of the DC motor, the lead screw pushes the robot arm to move in either forward or backward direction. The maximum height of the lift was found to be 55 cm from the initial position. The average time for the robot arm to be lifted up and pulled down for the harvesting operation was 42 seconds. Visual Basic Programme and ladder diagram were also tested. The 'Eggplant Harvester' software was developed to capture images and to monitor the harvesting system.

Fig. 5: User interface of eggplant harvester programme

The Software Test

The operator started the Gantry Control programme and the main form of the window was then displayed. The operator pushed or pressed the "Monitoring" click button to proceed to the next page programme. In this window, the operator selected the crop followed by the harvesting operation. If the operator clicked on "Exit" button, this programme would then be terminated.

Firstly, the operator has to connect this programme to the webcam. Then, he has to click on the button "CAMERA" to load the webcam software and video. If a mature eggplant is detected and shown in the video, the operator has to capture the image using the webcam software. He will then click on the button "second camera" for the camera to capture the image to be used by the second camera which is situated 20 cm away from the first camera. The operator clicks on the button "LOAD PICTURE" to load both images on the picture box. The "CALCULATE" button is then selected count the distance between the end effector to the mature eggplant. *Fig. 5* and *6* show the developed graphical user interface for this project.

A programmable logic controller programme was developed to control the sequence of movements and operations of the harvester. For this purpose, the programme was downloaded to the PLC through a communication cable between the PLC and the computer. *Fig. 6* shows a sample of the output data from the computer programme for this project.

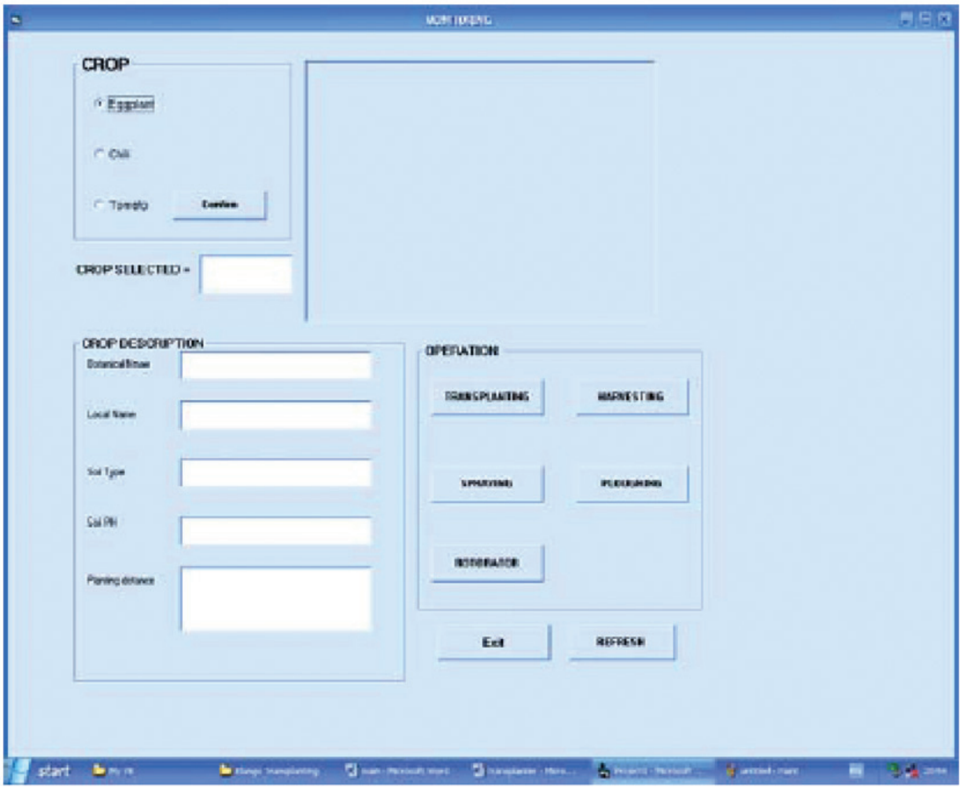
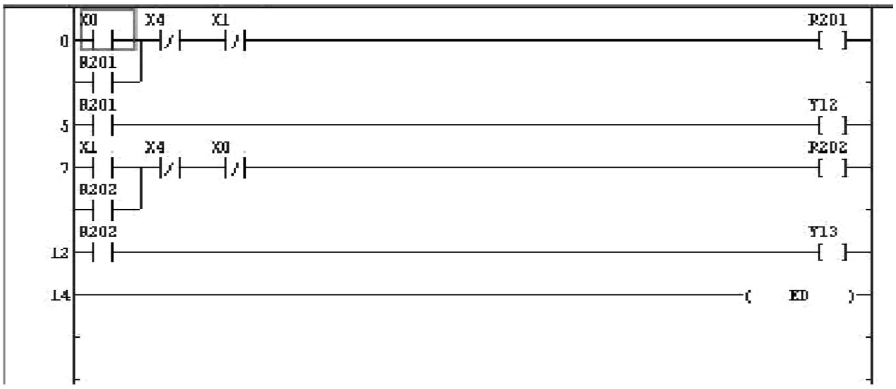


Fig. 6: Selection form of the programme



Input and output mapping of the FP2 PLC

Input Port	Device	Output Port	Device
X0	Start Button	Y12	Motor turn clockwise
X1	Backward sensor	Y13	Motor turn in conterclockwise
X4	Forward sensor		
R201	Relay		
R202	Relay		

Fig. 7: The sample output of ladder diagram

CONCLUSIONS

The eggplant harvester for the gantry system of the green house was successfully designed, fabricated, and tested. The operation of the harvester is controlled by PLC. Basically, the limit switches, DC motor and relay are connected to the PLC. A PLC ladder diagram was then designed and developed to control the operation of the eggplant harvester. The speed of the end effector was 2.4 km/h and it could lift up to 55 cm.

A machine vision system programme was developed using Microsoft visual basic. The function of this programme is to determine the three dimension axis location of eggplants. The videogrammetry method was employed to calculate the distance between the stem of eggplants and the cutter of the robot end effector. The accuracy of the videogrammetry was tested to be 67.2% for the X axis, 88.2% for the Y axis, and 84.7% for the Z axis. Thus, the maximum absolute error measured in the three dimensional locations was 42.3 mm (X axis), 93.79 mm (Y axis), and 20 mm (Z axis). The minimum absolute errors for X axis, Y axis, and Z axis were 15 mm, 18 mm, and 14 mm, respectively.

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