

Manipulator automation for Fresh Fruit Bunch (FFB) harvester

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Abstract: The need to mechanize major field operations that are labor intensive in oil palm industry of Malaysia has led to the study on agricultural machine automation. In general, study was on machine automation to reduce the number of workers required for harvesting as well as to provide comfortable ergonomic for the operator of oil palm harvester. The objective of the study was to perform interfacing between the oil palm tree and hardware (harvester) as well as to compare the harvesting efficiency between the mechanical and automated manipulator. Kinematic analysis was calculated based on the D-H configuration for the position and orientation of harvester arm using high resolution webcam and ultrasonic sensor to obtain 3D coordinates required by the D-H notations. PIC Circuit Board (PCB) design and fabrication as well as testing and implementation of concept of camera vision operation system for FFB harvester with fully developing a Graphical User Interface (GUI) was conducted to assist the automation of the harvester manipulator. The automation of 5DOF manipulator harvester operation proves to be faster than the manually operated mechanical harvester with an approximation of 60 percent significant decrease in speed of the manipulator with 70 percent of accuracy.

Keywords: manipulator, automation, interface, FFB

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1 Introduction

The existing mechanized oil palm harvester is claimed to be unsuccessful due to inefficiency in harvesting fresh fruit bunch. Based on the experiment performed before by the MPOB(1990) (Malaysian Palm Oil Board), the operator of the harvester takes around three to five minutes just to adjust the position of the cutter and grabber for one bunch, compared to a labor who manages to harvest a tree within a minute. Not only the operation consumes long time, but also the operator experiences neck aches and body pain after operating each tree. So, the ergonomic of the operator was also a major issue here. As a solution to the

inefficiency of the harvester, automation of the harvester was carried out with much faith. The novelty of this research is to transfer the image of FFB (Fresh Fruit Bunch) to the Denavit & Hartenberg (D-H) model and perform interfacing between the environment with controllers and hardware for the manipulator automation. This study benefits the oil palm industry by increasing the efficiency of the harvesting process by introducing automation of manipulator of the oil palm harvester. The general objective is to reduce the number of workers required for harvesting as well as to provide comfortable ergonomic for the operator of oil palm harvester. The more specified objective was to perform interfacing between the environment and hardware as well as to compare the harvesting efficiency between the mechanical and automated manipulator. The study includes design, PIC Circuit Board (PCB) fabrication, testing and implementation of concept of camera vision operation system for FFB harvester with fully developing a Graphical User Interface (GUI) for outdoor

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agricultural activities.

A robot has human like arm structure, sometimes called anthropomorphic arms^[1]. Basically, manipulator consists of joints and links where each joints may have more than one Degree of Freedom (DOF). In order to obtain a large number of position measurements needed for kinematic calibration, Parker and Gilby^[2] proposed laser interferometry-based sensing and measuring (LISM) technique to perform dynamic measurements of the robot's position. Denavit and Hartenberg^[3] introduced a convention for selecting frames of reference in robotics application where (D-H) representation has become the standard way of representing robots and modeling their motions. Kinematic analysis was calculated based on the D-H configuration for the position and orientation of harvester arm, where position of harvester was calculated instantly when all joint variables were known. Consequently, in order to place the harvester arm in a desired location, the amount of each joint movement was calculated through the inverse kinematic analysis^[4]. This was possible with the information of the position of the harvester arm with the help of high resolution webcam.

A mushroom harvester was automated by Reed et al.^[5] to be capable for location, sizing, selection, picking, trimming conveyance and transfer of mushroom using monochromatic camera vision as well as algorithm based on pixel brightness. Similarly, Lee, Slaughter and Giles^[6] used automation principle for tomato weed control using computer vision system and selective herbicide application for precise cultivation using solenoid valves. Likewise, the high resolution webcam used to feed the desired position 2D coordinates in the form of pixel which was later converted into meters. Font-Llagunes and Battle^[7] used a novel technique to estimate a mobile robot pose using odometry and angular discontinuous measurements by laser localization system, which consists of a rotating laser scanner and a set of catadioptric landmarks. Similarly Zhao and Li^[8] used laser radar imaging to acquire images in their study, where a continuous-beam laser was used to send laser light to the object and collect the returned signals. The phase shift in the return signal was used to measure the

distance. Since a single camera was used, another sensor such as the ultrasonic sensor was used to obtain the third coordinate to complete 3D information required by the D-H notations.

The Px, Py and Pz coordinate information were used for the inverse kinematics calculation to obtain the desired angle for the harvester arm movement^[4]. The image location and calculations were carried out through Matlab with the help of the operator to click on the desired position on the screen^[9]. Once the calculations were completed, signal was sent to manipulator to move and harvest the FFB.

2 Methodology

The 5DOF mechanical harvester currently located at MPOB, Bangi Lama was used for testing with the camera vision (Figure 1). The machine was developed under the 'IRPA' research grant in collaboration between Universiti Putra Malaysia (UPM), Malaysian Palm Oil Board (MPOB) and Universiti Kebangsaan Malaysia (UKM).



Figure 1 Mechanical harvester located at MPOB, Bangi Lama

The manipulator has the rotations and translation in the order of RTRTR as discussed in Helena^[4]. The forward kinematics in Equation (2) developed in the section below using D-H notations on the harvester where the result was based on the basic notation from Equation (1), represents the product of five matrices representing the transformation between five joints:

Thus the result of forward kinematics was^[4]:

$${}^R T_H = (A_1 A_2 A_3 A_4 A_5) = \begin{bmatrix} nx & ox & ax & Px \\ ny & oy & ay & Py \\ nz & oz & az & Pz \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$= \begin{bmatrix} C1C3C4+S1S4 & -C1C3S4+S1C4 & C1S3 & C1[S3d5+C3a2+a1]+S1d2 \\ S1C3C4-C1S4 & -S1C3S4-C1C4 & S1S3 & S1[S3d5+C3a2+a1]+C1d2 \\ S3C4 & -S3S4 & -C3 & -C3d5+S3a2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

Where $C1 = \cos \theta_1$ and $S1 = \sin \theta_1$.

A user friendly Graphical User Interface (GUI) was developed using Matlab for the operator to interact with the semi-automated system. In this GUI, the video streaming of camera that is placed above the operator was viewed in the first image display while the second image display shows the still image captured. The captured image gives the 2 dimensional values of 'x' and 'y' in pixels. At the same time, an ultrasonic sensor was used to measure the distance of the FFB providing the 3rd dimensional value of 'z' to be feed for manipulator computation. The ultrasonic sensor gives its reading in terms of counts which was later converted into centimeters for the inverse kinematics. The operator was required to click on the FFB stalk in the image to obtain the coordinates of the desired point where the cutter is to be placed. Thus to begin with the harvesting process, the operator is required to click tab 'Run' to activate the camera and capture the image as in Figure 2.

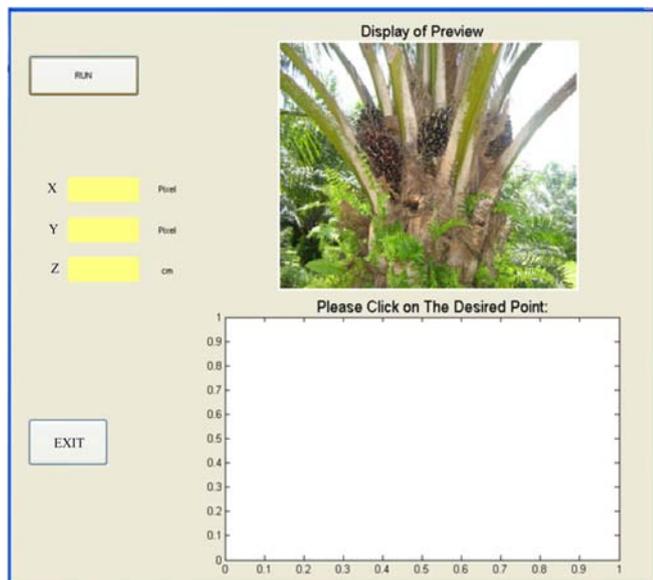


Figure 2 Graphical user interface of oil palm harvester

Then the camera and ultrasonic sensor provides the 3D coordinates of P_x , P_y and P_z and was displayed on the GUI screen for the operator's view^[9]. The 3D coordinates obtained was then passed to the Matlab to compute the inverse kinematics developed especially for the 5DOF mechanical harvester. Thus the result of Inverse kinematics was^[4]:

$$A_2 A_3 A_4 A_5 = \begin{bmatrix} C1nx + S1ny & C1ox + S1oy & C1ax + S1ay & C1Px + S1Py \\ nz & oz & az & Pz \\ S1nx - C1ny & S1ox - C1oy & S1ax - C1ay & S1Px - C1Py \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} C3C4 & -C3S4 & S3 & S3d5 + C3a2 + a1 \\ S3C4 & S3S4 & C3 & -C3d5 + S3a2 \\ S4 & C4 & 0 & d2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\theta_1 = \tan^{-1} [ay/ax]$$

$$\theta_1 = 0^\circ$$

Thus, $C1 = 1$ and $S1 = 0$

$$\theta_3 = \cos^{-1}(-az)$$

$$\theta_3 = 180^\circ$$

Thus, $C3 = -1$ and $S3 = 0$

Then the following is from Equation (9),

$$\theta_4 = \cos^{-1}(S1ox - C1oy)$$

$$\theta_4 = 180^\circ$$

Once the angles θ_1 , θ_3 and θ_4 were found as 0° , 180° and 180° respectively, they were used to move the harvester rotational joints to the desired position. Matlab was then used for the programming part which will result with the time required to move each joint of the arm to achieve the desired location. The information was then transferred to the Programmable Integrated Controller (PIC) to control the harvester arm motion. Thus, the PIC must always be connected to the laptop or pc to enable information transfer or in other words, as an interface between the pc and the controller. Figure 3 shows the Programmable Circuit Board (PCB) used in this project. It consists of 16F877A programmable Integrated Circuit (PIC), 5 pair of relays, Max 232 (serial port connector microprocessor), RS232 connector, crystal, 0.6 metal film resistors of 10k ohm and 330 ohm, ceramic disc capacitors and power supply circuit. The PIC was suffixed on to a Programmable Circuit Board (PCB) with

corresponding relays where two relays were assigned to control one solenoid valve.

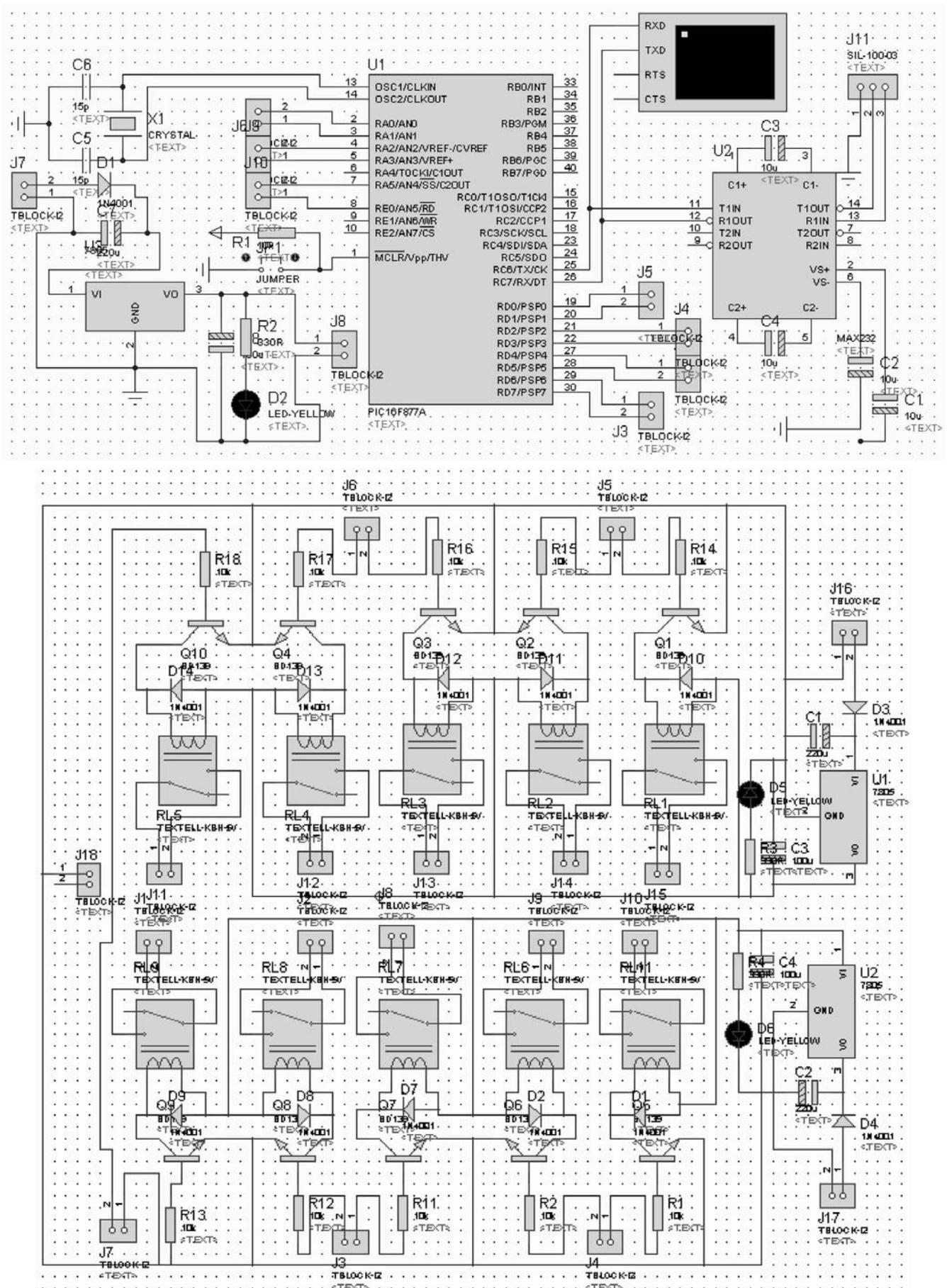


Figure 3 PCB with MINI40 PIC and relay circuit diagram

The PIC acts as a controller for the harvester arm, deciding on which joint has to move accordingly. This was preprogrammed into the PIC using C-language, in such a way that it will receive the time (delay in milliseconds) information from the pc and uses it to signal the harvester arm to move accordingly.

The PIC sends signal to an array of relays, located beside the PIC on a different circuit board, which then sends signal to the respective solenoid valves. Each solenoid valve actuates one double acting cylinder and was controlled by a pair of relays. One relay signals the solenoid valve to extend the cylinder while the other relay signals the solenoid valve to retract the same cylinder. Thus a pair of relays was required for the actuation of every double acting cylinder. The array relay acts as the interface between the electronic and mechanical components.

Thus the time information received from the Matlab was sent to the PIC to actuate the corresponding cylinder to move the respective joint arm. This was done for all the joints to enable the arm's end effectors to move to the desired location. Thus the cylinders move from their home position to the desired position and clamps on the FFB, working in an open loop system as shown in Figure 4.

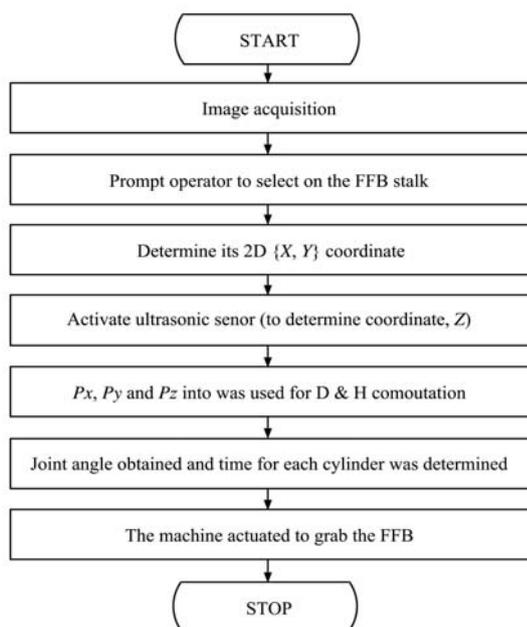


Figure 4 Flow chart of the semi-automated manipulator harvesting process

Then, the operator will cut the FFB manually using the lever since the cutting system was inefficient to be controlled automatically.

3 Results and discussion

As mentioned earlier, experiment was conducted to determine the time taken for the end-effectors to move from the home position to the FFB and was repeated three times to examine its consistency as well. The experiment was conducted using digital stopwatch and time was recorded. The results are as shown in Table 1.

Table 1 Operated speed difference between mechanical and semi-automated harvester

No.	Mechanical harvester/min	Semi-automated harvester/min
1	3.59	1.25
2	3.27	1.54
3	4.12	1.42
Average	3.66	1.41

Table 1 shows that the automated manipulators operation of the mechanical harvester proves to be faster than the manually operated mechanical harvester and was able to move in a rather consistent amount of time. The experiment shows an approximation of 60 percent increase in speed of the manipulator which was significant.

Then, to ensure accuracy of the joint angles provided by the D-H computation the joint angles were examined manually once the movement was completed. Table 2 shows the percentage of error between the D-H computation joint angle and the joint angle obtained manually upon the movement of the harvester arm to the desired location. The accuracy of the harvester arm was obtained manually using angle measurement apparatus and measurement meter tape. It was determined that there was 70% of accuracy of the oil palm harvester arm coordination using the automation system. It may not be satisfactory, but is a stepping stone for further development of more accurate harvester that will one day completely replace the manual methods of harvesting.

Table 2 Difference of percentage error of angle between the actual (manual) and D-H results

No	Cylinders	Experiment 1			Experiment 2			Experiment 3			Ave of error
		Angle (DH) /($^{\circ}$)	Angle (M) /($^{\circ}$)	Error /%	Angle (D-H) /($^{\circ}$)	Angle (M) /($^{\circ}$)	Error /%	Angle (D-H) /($^{\circ}$)	Angle (M) /($^{\circ}$)	Error /%	
1.	C1	182	130	28	176	120	32	170	125	26	28
2.	C2	230 cm	160 cm	20	225 cm	164 cm	27	220 cm	177 cm	19	25
3.	C3	105	70	33	103	70	32	102	77	24	30
4.	C4	35 cm	25 cm	28	33 cm	27 cm	18	30 cm	28 cm	6	16
5.	C5	15	10	33	14	10	28	15	11	26	29

Note: D-H – Denavit & Hartenberg, M – manually obtained angle; C1-Cylinder 1, C2-Cylinder 2, C3-Cylinder 3, C4-Cylinder 4, C5-Cylinder 5.

4 Conclusions

Interface between the environment and the software (pc) was possible through the usage of the high resolution webcam and ultrasonic sensor. Meanwhile interface between the software (pc) to the hardware (harvester machine) was fabricated successfully, known as the PIC Circuit Board (PCB). Hence the PIC receives information from the Matlab program and successfully passed the information to the respective solenoid valves on the harvester. Therefore, the harvester machine was able to move its arm based on instructions from the program, avoiding cramps on the operator's neck to position the manipulator. A successful automation design involving Denavit & Hartenberg (D-H), PCB fabrication, testing and implementation of the concept of camera vision operation system for FFB harvester with a fully develop graphical user interface (GUI) for outdoor agricultural activities was achieved.

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