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Development of an automatic cutting system for harvesting oil palm fresh fruit bunch (FFB)

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The purpose of this project was to design, fabricate and test a harvesting mechanism for oil palm fresh fruit bunches (FFB). A carrier machine was designed and fabricated which can move around the tree trunk smoothly while carrying the cutting system. A mechanize motor system also was designed and assembled on the carrier machine for moving the cutting machine forward and backward along the tree trunk radius. For a successful and smooth cutting process, two direct current (DC) motors were used for carrier machine. Cutting machine consists of a mechanism for cutting and a cutting blade. A reciprocating mechanism was used in this project because of the added advantages of this method as compared to others. Design of the blade tooth for doing a fast and clean cut was an important parameter in this project. An HM-TR Transparent Wireless Data Link Module and an ATmega8 microcontroller were used to control the cutting system. This system was tested successfully in both laboratory and field condition.

Key words: Cutter blade, fruit harvesting, oil palm, reciprocating cutting, remote controller.

INTRODUCTION

The goal of agricultural robotics does not only apply to robotics technologies in the field of agriculture, it also applies to using agricultural challenges to develop new techniques and systems (Ito, 1990). An agricultural robot must deal with an unstructured, unknown, uncertain and varying environment. Fruits are randomly located on trees and are difficult to detect and reach (Jimenez et al. 1999). In recent years, harvester robots have been among the noteworthy topics studied by researchers. Until now, different robots have been designed for harvesting fruits, such as apples and oranges (Baeten et al., 2008; Sanders, 2005).

The production of palm oil and palm kernel oil in 2005 reached 36 million tons, and palm derived oil has become the most abundant and consistently supplied oil among vegetable oils of the world (Kanoh et al., 2008). The oil palm is a tree without branches but with many wide leaves at its top. The fruits are compactly packed in bunches which are hidden in leaf axils in crowns that may be over 12 m above the ground. In traditional harvesting methods, the short oil palm trees within arm-reach are harvested using the chisel to cut the fruit bunches and fronds. The tall trees above 9 m in height are harvested using a curved knife with the sharp edge which is attached to the end of a bamboo pole. The worker stands on the ground while the pole and knife are raised to the tree crown in order to harvest bunches (Adetan et al., 2007).

Timeliness of harvesting is very crucial to the quality and quantity of oil palm fresh fruit bunches (FFB). The design and fabrication of the harvester robot for oil palm bunches are subjects that have stimulated the interest of many researchers to work on better method (Muhamad,

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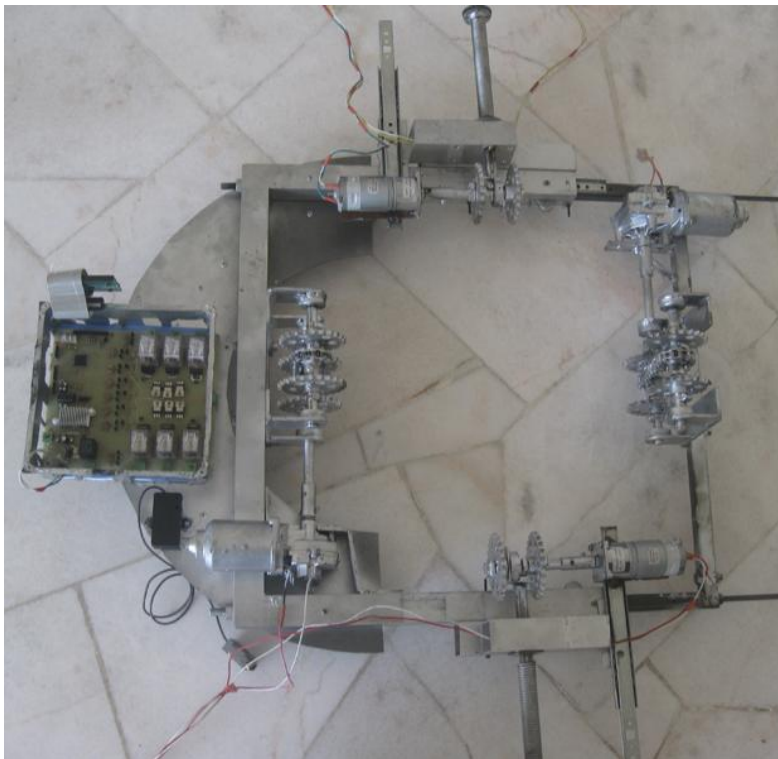*Corresponding author. E-mail: hamedshokripour@gmail.com. Tel: 0060-173724849.

Figure 1. Oil palm climbing robot.

2008). The proposed cutting system consists of two main parts: (1) a system for cutting the leaves, bunches and fronds and (2) a system for carrying the cutter blade near to the fruit bunches.

This project was carried out to design and fabricate a light and powerful cutting system that can be carried by a four wheeled tree climbing robot (Shokripour et al., 2010). The climbing robot used in this project can carry the weight of a cutting system with a maximum of 7 kg while keeping its balance. Previous oil palm harvesting machines use a hydraulic power source; hence, these machines are powerful, big and heavy. An electric power source and electrical components were used to make it a light and powerful cutting system. After considering and testing different mechanisms of cutting the oil palm leaves and bunches, the reciprocating motion of a rectangular blade was found to be the best option. An alternative current (AC) motor was used as the driver of cutting machine. An inverter device was used to convert the direct current (DC) from the battery to an appropriate AC current for the motor of the cutting machine.

MATERIALS AND METHODS

The cutting system comprises of three main parts: cutting machine, carrier machine and the electronic control system. The function of the cutting machine is to cut the fronds and the stem of the fruit bunches. The cutting process is carried out by fast and continual reciprocating motions of a rectangular saw blade. The cutting

machine was installed on the carrier machine. Carrier machine can generate a circular motion for cutting machine to go around the tree trunk and also a forward and backward motion on the tree trunk circumference. This system makes the cutting machine able to cut the leaves and bunches on any point of the tree trunk. The control system of the robot analyses the received commands from the operator's remote controller to send an appropriate command to each electric motors.

The whole components of the cutting system are assembled on a four wheels tree climbing robot. Designing the cutting system with minimum weight was one of the most important parameter in this project, because the climbing robot can carry a load with a maximum weight of 7 kg. The climbing robot carries the cutting system to and near the leaves and fruit bunches. Figure 1 shows the climbing robot. The mechanism and operations of the climbing robot can be obtained from (Shokripour et al., 2010).

Cutting machine

Two essential parameters for designing a cutting machine for any material are the cutting mechanism and the cutter blade design. Common types of cutting machines include reciprocating saws, horizontal endless band saws, universal tilt frame band saws, abrasive saws, and cold saws (Ko and Kim, 1999).

Rotary saw cutting is a cutting method which is versatile and effective for a variety of industrial applications. The advantages of using the rotary saw method are: faster cutting times, closer tolerances, better finishes, less kerf, easier tool changes, better tool life, and an overall wider range of applicability (Varvatsoulakis, 2009).

The reciprocating saw mimics the back and forth motion of a common hacksaw. The gearing system inside the reciprocating saw will cause the saw blade to move back and forth across the material
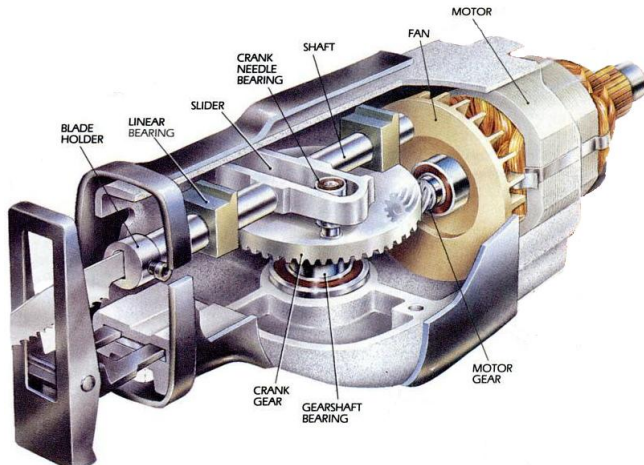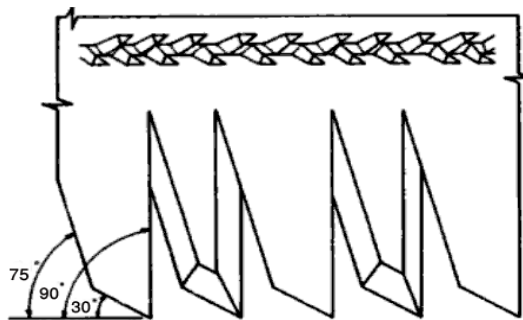
Figure 2. Reciprocating mechanism.

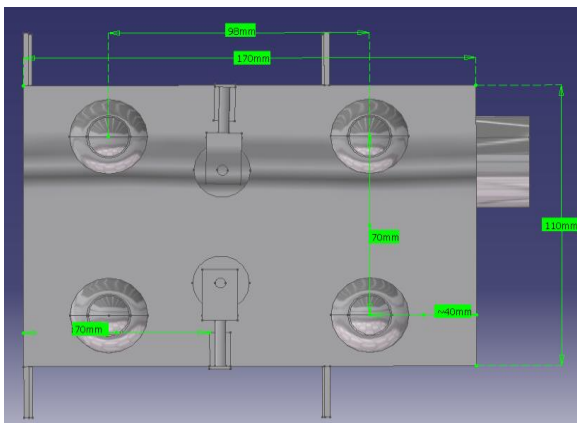**Figure 3.** The alternate set of style and its angles.

Figure 4. Top view of the carrier machine.

that needs to be cut. This saw is usually used to cut wood, plaster, plastic or some other soft material (Brumbach and Clade, 2003). The wire saw can successfully cut the leaves; however, finding an appropriate wire, assembling the wire, repairing or changing the cut wire are some problems that operators encounter in the field. Round saw blade for cutting the fruit bunches was tested, and it failed. The diameter of the round saw blade for cutting the leaves

needs to be more than 26 cm, which is twice the diameter of the leaves. It causes strong vibrations during the cutting process. Furthermore, after cutting the oil palm leaves, the leaf fibers stuck around the blade shaft and cause the motor to stop. Cleaning these fibers is a difficult and time consuming process for operators.

After testing and comparing different cutting methods, the reciprocating method was used in this project for cutting the leaves and bunches. Reciprocating motion is produced in various ways. The helical pinion gear that powers a flat drive gear at right angles was used to transfer the rotary motion of the motor in to a reciprocating linear motion. The drive gear has an offset roller bearing that acts as a crank. In conjunction with a channel mounted on the reciprocating shaft, also known as a slider, the circular motion is converted to reciprocating motion. Figure 2 shows the components of the reciprocating machine used in this project.

A 350 W AC motor was used to drive this system. DC motors that can generate the same speed and power are found to be big and heavy but were not recommended. Since the power source was used for climber robot and other components are a direct current battery, we used an inverter device to convert the 12 V DC to 220 V and 500 W AC for this motor. The speed of the motor, and accordingly, the number of strokes can be adjusted within the range of 200 to 3000 min^{-1} for the saw blade.

The important parameters to be considered when choosing a blade for cutting are the type of metal, width, blade set, thickness, tooth form and length of the blade. Most saws are designed to create a kerf that is wider than the saw blade. This difference is called the side clearance which is the most important parameter for doing a curve cut (Duginske, 1989).

The teeth of the blade used in this project were bent alternately in opposite directions to create a kerf wider than the body. The amount of bending is usually proportionate to the thickness of the blade body and is usually 25% of the blade thickness. The angle at which the points of the saw tooth make contact with the material is an important factor of the effective cutting performance of a saw blade. Figure 3 shows the design of the alternate tooth style and teeth angles of the blade used in this project for cutting the oil palm leaves.

The radial lengths of the circles that can be cut by a blade depend on the ratio of the width of the blade to the width of the saw kerf. Since the diameter of the tree trunk is not constant, the blade was designed based on the minimum size of the oil palm tree trunk which is 32 cm. The appropriate size of the blade width is calculated using:

$$\frac{W^2}{2} = (R + K)^2 - (R + T)^2$$

Where W is the blade width, R is the radius of the tree trunk, K is the size of the kerf width and T is the thickness of the blade.

Carrier machine

One of the most important objectives of this project was to design a mechanism that can move around the tree to place the blade of the cutting machine at any point around the tree and at any distance from the surface of the tree trunk. A special rail was designed for the carrier robot to guide the cutting machine on a fixed circular path around the tree. The carrier machine comprises of one DC motor, four ball transfers, three ball bearings and one sprocket. Figure 4 shows the top view of the transporter robot.

The ball transfers were used as the wheels of the machine. Using the ball transfers as the wheel enable the carrier machine to smoothly navigate itself around the tree trunk, because it generates only a small amount of friction and have three degree of freedoms.
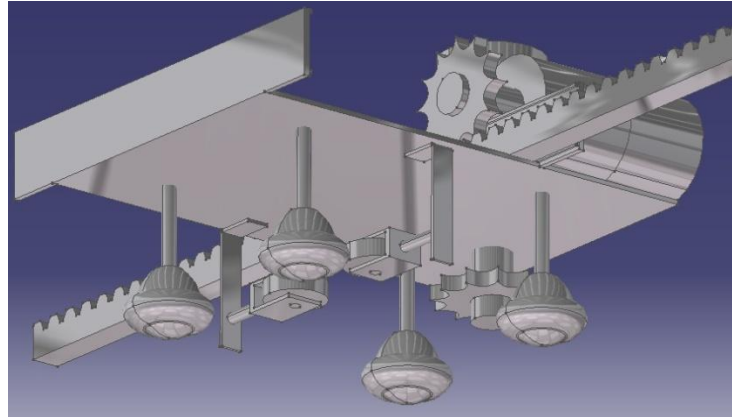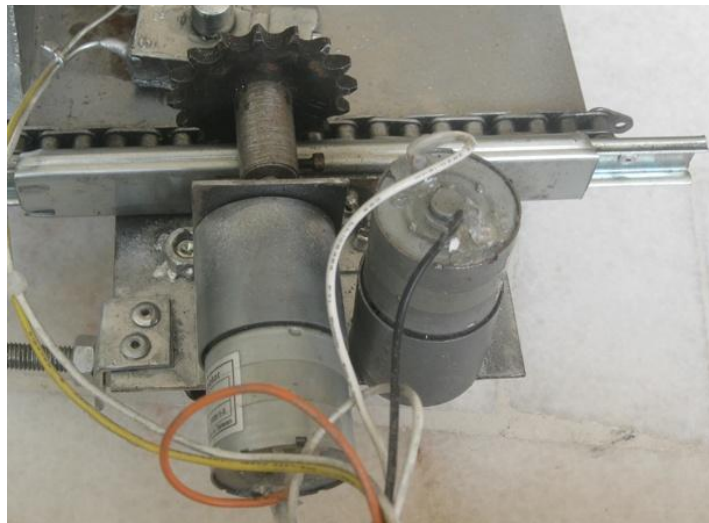
Figure 5. Carrier machine.

Figure 6. DC motor, plate, sprocket and chain.

The power required to drive the robot is generated by a DC micro gear motor. A gearbox was installed on this motor to reduce its speed from 2500 to 5 rpm. The slow motion of the cutting system causes smooth and accurate cutting. Furthermore, decreasing the motor speed causes an increase in the power and torque of the motor which lead to more force to push the cutting blade into the branch. The power of the motor is transferred to a 4 cm diameter sprocket. The speed of the carrier machine moving around the tree is calculated as:

$$V = 5 \text{ rpm} \times (4 \times 3.14) = 51.52 \text{ cm. min}^{-1}$$

The motor rotation direction is controlled by the operator via a remote controller.

To do an accurate cutting, a gear system was added on carrier machine to move the cutting machine forward and backward along the tree trunk circumference. It comprised of a DC motor with a sprocket, a set of two ball bearing drawer slides and two limit switches. Figures 5 and 6 show the schematic and fabricated system after they have been installed on the carrier machine.

The DC motor was installed in such position so that the teeth of its sprocket were placed inside the chain. The rotation of the DC motor causes the sheet metal to move forward and backward. One limit switch was installed at the head of the cutting machine. When the cutting machine moves forward, the limit switch touches the tree surface and stops the motor. Controlling of the DC motors is done by the operator using the remote controller.

REMOTE CONTROLLER

A remote controller system comprises of hardware and software designed and fabricated for operator to control the cutting system. The remote controller and the cutting system each have one HM-RF transmitter receiver device and an ATmega32 microcontroller as the main hardware components. A specific program was written for each microcontroller to receive the data, analyze them and finally generate and send the appropriate commands to other components, such as DC motors and HM-RF devices.

A HM-TR Transparent Wireless Data Link Module consists of two parts, both of which can send and receive data wirelessly. The first part is used by the remote controller to send the operator's commands and the second part is installed on the cutting system to receive the commands from the remote controller. The data

Table 1. Program for controlling the cutting system functions.

R1 = Udr
If Flag1 = 0 Then
If R1 = 10 Then
Cs1 = 10
Flag1 = 1
Count1 = 1
End If
Else
Sdata1(count1) = R1
If Count1 = 2 Then
If Cs2 = Sdata1(2) Then
Setpoint1 = Sdata1(1)
Count1 = 0
Flag1 = 0
End If
End If
Incr Count1
Cs2 = Cs1 + R1
End

Figure 7. Carrier system and cutting machine.

transferred between these parts uses a radio frequency that ranges between 310.24 and 929.27 MHz. This paper focuses more on the processes needed to transfer the data from the HM-TR Module to the microcontroller, and the analysis of them.

The HM-TR Transparent Wireless Data Link Module uses RS232 logic level for transferring data to the microcontroller. The RS232 physical specification produces a logic 1 at receiver input as -3 to -25 V and logic 0 as +3 to +25 V. Since the ATmega64 microcontroller can receive and analyze the data on the transistor-transistor logic (TTL) logic level, a MAX232 integrated circuit (IC) is used for converting the data of the HM-TR Module to TTL logic level. It can generate the necessary RS-232 voltage levels of approximately -10 and +10 V internally from a single +5 V power supply. It can reduce RS-232 inputs which may be as high as ±25 V to standard TTL levels 5 V.

Software

When the operator pushes a button of the remote controller, the remote controller sends three numerical codes to the receiver of the robot. The first number informs the microcontroller that a new command is being sent by remote controller and it readies the microcontroller to receive the next two numbers. The second number is the code of the command that is allocated to a button of the remote controller. By analyzing this number, the microcontroller understands what the operator wants the robot to do. The third number is a summation of the first and the second numbers and is called the check sum number. The microcontroller also adds up the first and the second received numbers and compares the result with the check sum. If these numbers are the same, the microcontroller understands that it has received the data from the remote controller completely and correctly. Table 1 shows the main part of the remote control program that was written for controlling the functions of cutting system.

In the next program, the microcontroller sends the appropriate command to each DC motor based on the value of the second number. To change the motors rotation directions, a miniature intermediate power relay was used for each motor. The operator can start and stop the DC motors for moving the cutting system around the tree trunk and also move it forward and backward. Furthermore, turning the AC motor of the cutting machine on and off is controlled by the remote controller.

Since the power supply of this robot is a 12 V DC, an inverter device is used to convert the 12 V DC to 220 V and 500 W AC. To decrease the weight of the system, the inverter device is placed on the ground.

RESULTS AND DISCUSSION

Different parts of this cutting system were tested in laboratory condition. The cutting machine was tested by cutting the oil palm leaves. The blade cut the leaves successfully and created a suitable kerf but it was suggested to design and fabricate a new type of blade with round shaft like round fine with larger and sharper teeth for developing this system. Figure 7 shows this machine after assembling the cutting system on carrier machine.

The center of the oil palm leaves is made of very hard wood. During the cutting process this part caused intense vibrations to be generated in the carrier robot. This problem was solved by adjusting the carrier robot to make it more stable during the cutting process. The speed of moving the blade through the leaves was slow enough to carry out an accurate and successful cutting.

Fabricating and adjusting the carrier machine was a difficult part of this project because of having large number of components. For developing this system can redesign some parts of the carrier system to make it more stable against the vibrations.

The maximum size of the oil palm leaves and bunches were 14 cm in this tests and the speed of the cutting system is 51.52 cm/min. The time required for cutting a leaves is 14 × 60/51.52 = 16.3 s. Figure 8 shows the cutting system after assembling on the climbing robot.

The weight of the cutting system was 6.3 kg, so the climbing robot can carry it successfully to and near the
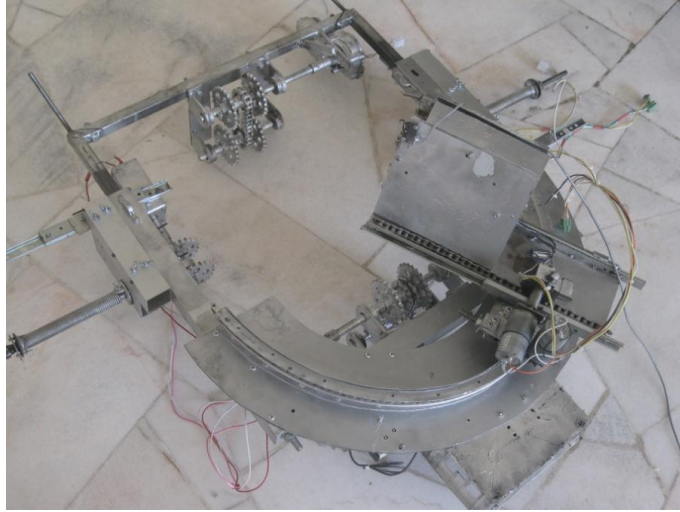
Figure 8. Cutting system after assembling on climbing robot.

leaves and bunches. The total weight of climbing robot and cutting system is 18.5 kg, so the operator can move it easily from tree to tree in the farm. The power supply of the climbing and cutting system is 12 V DC which can be generated by automobile battery. Different functions of the remote control of the system were tested successfully. Since it was designed to be user friendly, the operator can control the robot easily after short training.

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