



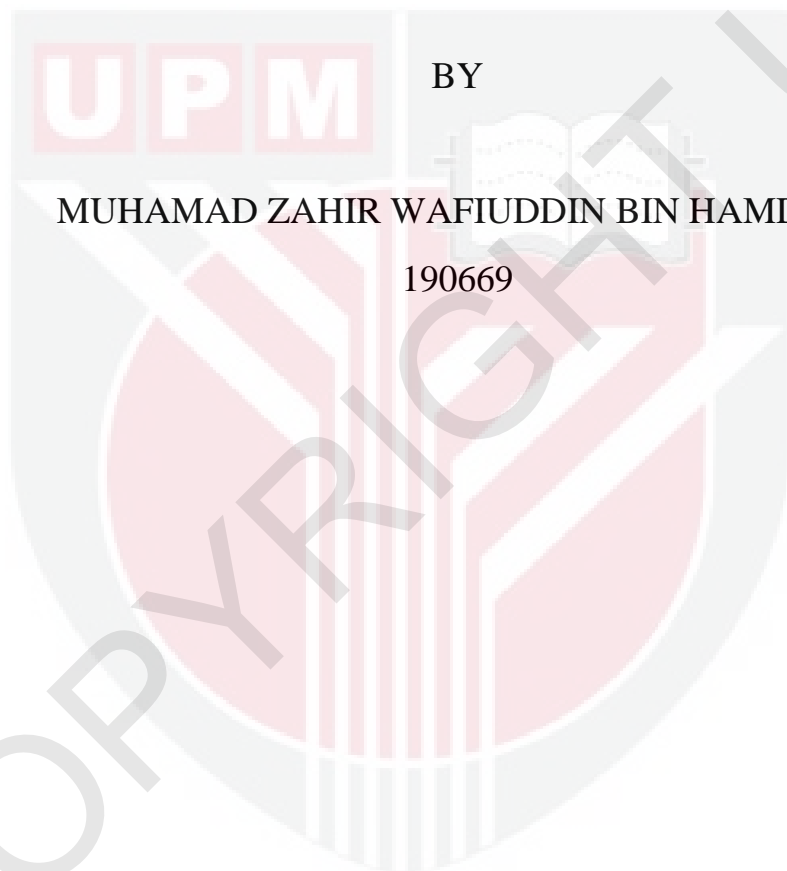
UNIVERSITI PUTRA MALAYSIA

***DEVELOPMENT OF CONCEPTUAL DESIGN OF TEST RIG FOR
ROBOTIC OIL PALM LOOSE FRUIT COLLECTOR***

MUHAMAD ZAHIR WAFIUDDIN BIN HAMDAN

**Ip
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ROBOTIC OIL PALM LOOSE FRUIT COLLECTOR**



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PROJECT APPROVAL LETTER

This project report attached here, entitle “**DEVELOPMENT OF CONCEPTUAL DESIGN OF TEST RIG FOR ROBOTIC OIL PALM LOOSE FRUIT COLLECTOR**” prepared and submitted by **MUHAMAD ZAHIR WAFIUDDIN BIN HAMDAN** in partial fulfilment of the requirement for Bachelor of Agricultural and Biosystems Engineering with Honours is hereby accepted.

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ABSTRACT

The aim of this study was to design a test rig for the development of conceptual design of test rig for robotic oil palm loose fruit collector. The test rig was designed to study the behaviour of loose fruit when collected by roller picker. The development of the robotic system was designed to reduce the time required to gather loose fruit and overcome labour shortages, as well as increase productivity in the field. In the world, demand for palm oil is increasing in proportion to the world population. With the approach of Revolution Industrial 4.0 in Malaysia, the use of robotic systems in the oil palm industry is underway. The field of oil palm also plays a key role, as it is one of the factors that need to be considered in developing a robotic system for oil palm loose fruit. The surface area of the oil palm field will be observed and the vegetation under the oil palm canopy will be recorded as a result of the process of collecting oil palm loose fruit. The properties of oil palm loose fruit from varieties, dura and tenera are being studied in order to know the shape as it will affect the development of robotic systems. The shape will be determined by calculating the sphericity of loose fruit oil palm. The pixel colour trend for each variety is also determined as the data are being collected. The test rig to know how the roller picker collects oil pal loose fruit is also designed. The surface of the track will simulate the condition of the field as a monitoring of how the roller picker reacts to the surface. The formula on the speed and acceleration of the contact area of the roller picker and the simulated surface is also being studied.

ABSTRAK

Tujuan kajian ini adalah untuk mereka rig ujian untuk penghasilan rekabentuk konseptual untuk rig ujian bagi pemungut buah lerai kelapa sawit robotik. Rig ujian direka untuk mengkaji tingkah laku buah lerai ketika dikumpulkan oleh kutip. Penghasilan sistem robotik direka untuk mengurangkan masa yang diperlukan untuk mengumpulkan buah lerai dan mengatasi kekurangan tenaga kerja, serta meningkatkan produktiviti di ladang. Di dunia, permintaan minyak sawit meningkat sebanding dengan populasi dunia. Dengan pendekatan Revolusi Industri 4.0 di Malaysia, penghasilan sistem robot dalam industri minyak sawit sedang dijalankan. Ladang kelapa sawit juga memainkan peranan penting, kerana ladang merupakan salah satu faktor yang perlu dipertimbangkan dalam menghasilkan sistem robotik untuk mengutip buah lerai kelapa sawit. Permukaan ladang kelapa sawit akan diperhatikan dan tumbuh-tumbuhan di bawah kanopi kelapa sawit akan dicatat oleh sebab proses mengutip buah lerai kelapa sawit boleh terganggu. Sifat fizikal buah lerai kelapa sawit dari dua variasi berlainan, dura dan tenera sedang dikaji untuk mengetahui bentuknya kerana ia akan mempengaruhi perhasilan sistem robotik. Bentuknya akan ditentukan dengan mengira bentuk sfera buah lerai kelapa sawit. Tren warna piksel untuk setiap variasi juga direkodkan ketika data dikumpulkan. Rig ujian untuk mengetahui bagaimana kutip mengumpul buah lerai kelapa sawit juga direka. Permukaan trek akan mensimulasikan keadaan ladang sawit bagi melihat bagaimana reaksi kutip terhadap permukaan. Rumus mengenai kelajuan dan pecutan titik sentuh kutip dan permukaan simulasi juga dikaji.

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Chapter 1

Introduction

1.1 Background

Malaysia was introduced to oil palm for the first time as an ornamental plant in 1870. The planted area had rapidly increased since 1960. In 1985, 1.5 million hectares were planted with palm trees, and it had increased to 4.3 million hectares in 2007. Oil palm has become one of the most important commodity crops in Malaysia. In 2019, The total size of the planted area was 5.9 million hectares.

In Malaysia, the palm oil production has increase over the years, from 4.1 million tonnes in 1985 to 6.1 million in 1990 and to 16.9 million tonnes in 2010 as show in figure 1 (MPOB, 2017). The demand kept increasing as in 2019 the production reached to 18.4 million tonnes. The Malaysia palm oil industry easily meets the local oils and fats demand and the excess of the production had been exported. The production of palm kernel oil in 1999 was 1.3 million tonnes and has reached 2.3 million tonnes in 2019. Most of the palm kernel oil that have been produced was exported.

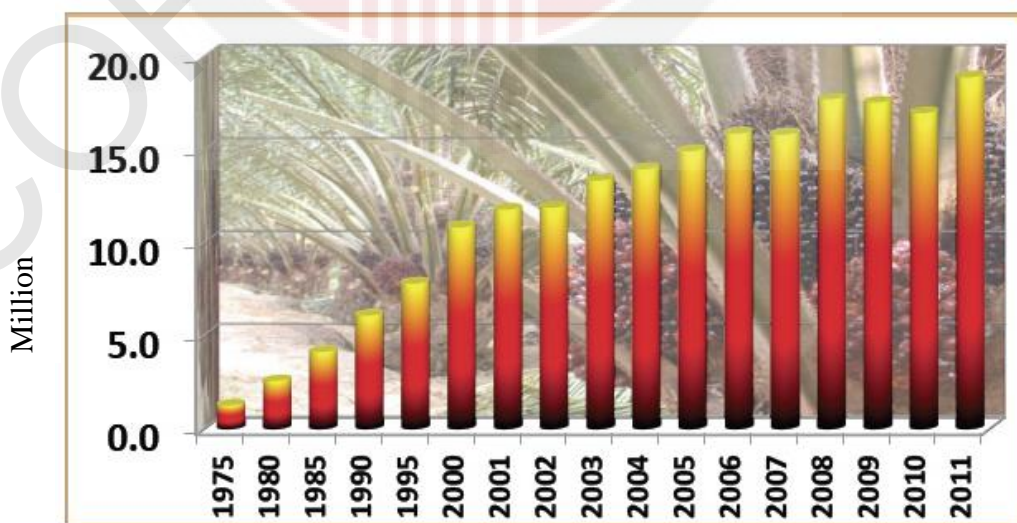


Figure 1. Production of Palm Oil in Malaysia-Million tons

Malaysia is the second-largest producer of palm oil in the world, after being overtaken by Indonesia in 2006. After 1985, palm oil, after soya oil, was the second most consumed commodity in the world. Malaysia accounted for 51% of world production in 1999, which decreased to 25.87% in 2019.

“Harvesting in oil palms begins when they reach maturity which is approximately three years after being planted in the fields” (Muhamad & Aziz, 2018). As oil palms mature, their yield increases, and their production is generally at its peak between the 7th and 18th years of growth. Oil palm yields are expected to decline slowly after the 18th year. The purpose of the harvest is to be able to cut and harvest all the fruit bunches in the field so that fresh fruit bunches can be harvested without damaging the fruit and the palm. Finally, it is possible to obtain fresh fruit bundles of excellent oil content and quality and to achieve best practice.

The entire harvest cycle includes a variety of processes, including cutting fresh fruit bunches and subdued fronds, stacking fronds, collecting fresh fruit bunches, collecting loose fruits and transferring them to the farm, as shown in Figure 2 which shows the process of harvesting oil palms (Yusoff, Zamri, Kadir, Hassan, & Azis, 2019). During practice the harvester team is assigned for several different tasks to a planting field.



Figure 2 The harvesting process of oil palm

The time taken to collect loose fruit is about 30% of the total fruit harvesting and transporting time (Yusoff et al., 2019). To collect the loose fruit, conventional or traditional methods still been practice in the plantation. Loose fruit normally picked up by hand and been put together into bucket, plastic bag, and gunny. There were also different options like using rake, and scoop. Employees must bend their body to collect fruit on the land and need to move from one tree to another tree.

Dirt and debris cause problem to oil processing process in oil palm mill. Almost 20% debris and dirt were estimated being transport to oil palm mill. Various ways and techniques have been experimented until now for collecting loose fruit. Challenges in these collecting loose fruit are being identified and new method to solve the challenges are being considered.

In this project, we are going to propose a test rig design to collect meta-data to develop a robotic system for oil palm loose fruit collector. The meta-data includes the physical properties of oil palm loose fruit and the condition of the oil palm plantation. The meta-data will be used for the robotic system to ensure it functions in the plantation field.

1.2 Problem Statement

The demand of palm oil increase for local and global market. As the demand increase, the total field area also increases making the total 5.9 million hectares. However, limitation of labour to harvest the yields causing production of palm oil cannot be maximized. In most area, the collecting of oil palm loose fruit is done manually. The process of collecting loose fruit require longer time than cutting the fresh fruit bunch itself.

Currently, there is a method that have been created to collect oil palm loose fruit, but it still requires labour workers to be involve. The most efficient method that currently being used to collect oil palm loose fruit is using roller picker as the debris percentage is minimum. The robotic system will be using roller picker as the picker in the robotic component, the robotic system will collect loose fruit from oil palm plantation itself to ensure it is functional.

1.3 Objectives

The aim of this study is to measure the properties of oil palm loose fruit and the field condition of oil palm plantation to design a robotic system for loose fruit collector to be used in the plantation field. The specific objectives are as followings:

1. To study field terrain condition.
2. To study the physical characteristics of oil palm loose fruit.
3. The vegetative under palm tree.
4. To design an indoor testing to evaluate the performance parameter of the loose fruit collector.

1.4 Scope and Limitation

The study is being conducted in Taman Pertanian Universiti's Oil Palm Plantation area. The data and observation that being done is based on the study area, there may be different at another plantation as it will depend on the plantation management.



Chapter 2

Literature Review

2.1 Taxonomy and origin

The origin of oil palms refers to Africa, particularly West Africa. Fossil pollen, close to today's oil palm, has been found in Miocene and more recent strata in the Niger Delta. Portuguese explorers on the coast of Guinea have reported the presence of oil palm trees as early as 1434. Palm groves in Liberia and palm oil trading on the Forcados River in Nigeria were already listed in 1508. Later, Portuguese, Dutch and English travellers refer to palm wine and oil palm in the area.

Elaeis guineensis is a tropical tree cultivation, primarily grown for its industrial production of palm oil. This is a standard estate plantation, grown and harvested in large areas (3,000 to 5,000 ha) around a central oil mill which permits quick industrial handling after harvest.

Palm fruit oil is consumed in more than 100 countries worldwide (“ABOUT - The Oil Palm,” n.d.). Palm fruit oil is frequently consumed throughout certain parts of the world, even in its unrefined state, as an ingredient in traditional dishes where its distinctive golden red colour and special taste contribute.

Oil palm is a typical rainy tropical lowland crop. The tree requires a deep soil and a steady high temperature and constant moisture all year round. “Soil fertility is less important than physical soil properties” (Verheye, 2010). Dry periods of more than 2-3 months do not directly adversely affect vegetative growth but have a significant impact on fruit bunches' production and quality. The productivity of oil palm is not only dictated by the growth and production of crops, but also by the control or eradication of pests and diseases.

The oil palm industry in Malaysia has grown dramatically since the Tennamaran Estate in Selangor in 1917, which formed the basis for this industry in Malaysia. In the early 1960s, oil palm cultivation expanded rapidly under the government's policy of agricultural diversification to minimize economic dependence on rubber and tin.

2.2 Variety of Oil Palm

The oil palm fruit can be divided into several categories as shown in figure 3. Dura, Tenera and Pisifera are typical varieties of oil palm.

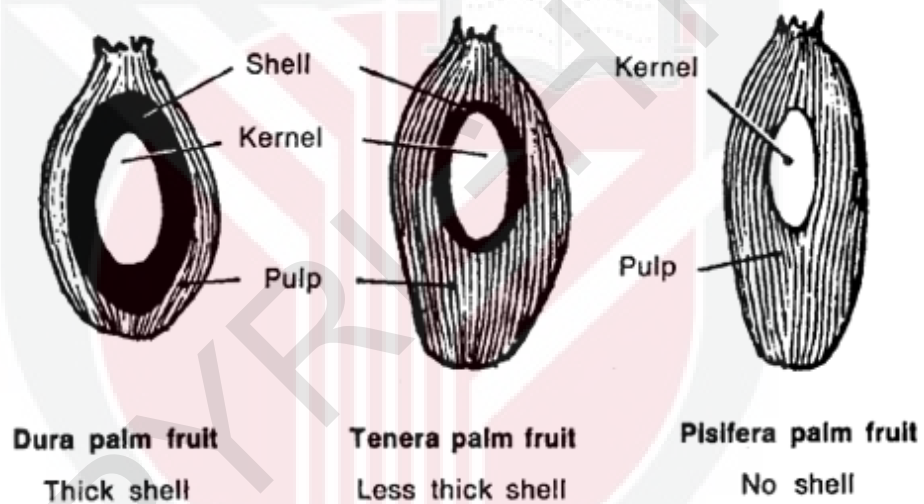


Figure 3 Variety of Oil Palm

The oil palms planted in Malaysia are primarily the tenera, a hybrid of dura to pisifera. Tenera produces about 4 and 5 tons of crude palm oil (CPO) per hectare per year and about 1 ton of palm kernels per year.

2.3 Production Area

Oil palm is planted in 43 countries throughout the World (“ABOUT - The Oil Palm,” n.d.). Indonesia is the largest producer of palm oil followed by Malaysia that can be seen in figure 5. Accounting for 84% of global palm oil production in both countries. The production of palm oil in South America has recently increased through Colombia, Ecuador and Guatemala.

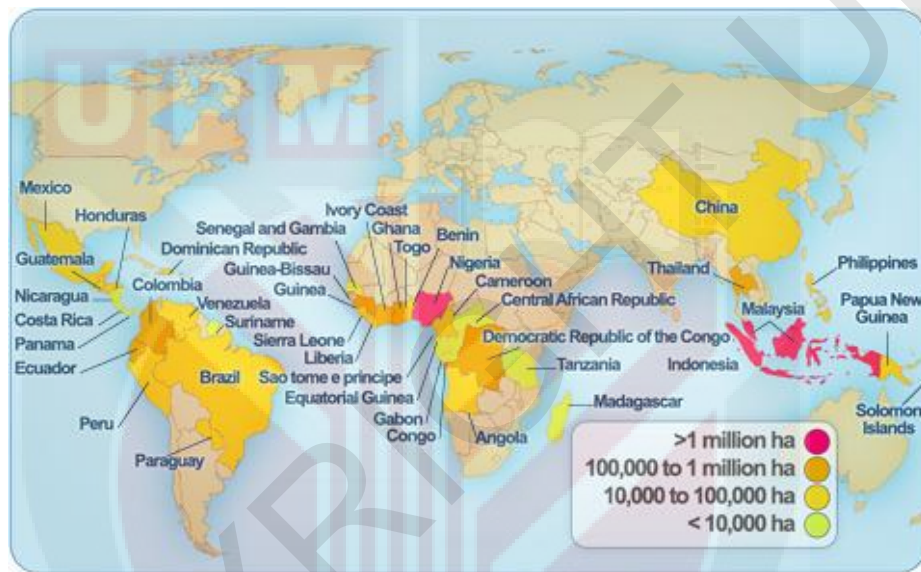


Figure 4 Production Area of Oil Palm

It is estimated that 17 million hectares of oil palm plantations are planted across the equator and that total palm oil production in 2019 was 74 million tonnes. 120 million hectares are used for the second largest vegetable oil in the world, soya, producing 48 million tonnes of soya oil (“GreenPalm,” n.d.).

In Malaysia, palm oil production becomes an important source of income and be planted in most state in Malaysia. Every state in Malaysia is planting oil palm and the total number of areas that been planted of oil palm is 5.74 million hectares in 2016 and Malaysia accounts for 28% of world palm oil production and 33% of global

exports (Ahmad Kushairi, 2017). As one of the largest producers and exporters of palm oil, Malaysia has an important role to play in meeting the growing global need for oils and fats on a sustainable basis.

2.4 Yield

Oil palm can start yielding fresh fruit bunch (FFB) in year 3, but peak yields are achieved between years 8 and 18. Sustainability is Malaysia's primary priority and concerns in the oil palm industry (USDA, 2018). One initiative to achieve sustainability is the adoption of the Malaysia Sustainable Palm Oil (MSPO) standard by both plantations and small-scale farmers. The objective of this standard is to coordinate the management of oil palm production with national legislation and regulations. By the end of 2019, all plantations and smallholders must be accredited by the MSPO. Some of the advantages of standardization in the oil palm sector are that it would improve sustainability, traceability, and better reflect negative perceptions of oil palm deforestation.

High oil yield remains a strong primary objective to improve oil palm breeding. Corley (1985) estimated an annual yield potential of 45 t/ha of fresh fruit (FFB) and 17 t/ha of oil (mesocarp and kernel oil) based on a theory based on factors modified from other crops. Fresh fruit bunches (FFB) yields of almost 45 t/ha have been reported in commercial fields and test plots, while palms with almost 40% oil from crude oil to kernel oil have been reported in breeding materials (Rosenquist, 1990), although these palms have no high FFB yield.

However, a more cost-effective collection of light through an optimum leaf area expansion rate, tolerance to high-density palm plants and reduced respiratory

losses, and an attempt at breeding through a higher harvest index (HI) were suggested (Breure, 2010; Breure & Corley, 1983).

Malaysian oil palm is harvested, usually every 10 days. Sabah and Sarawak are the major producing regions, accounting for approximately 31% and 17% of total output, respectively (Figure 5).

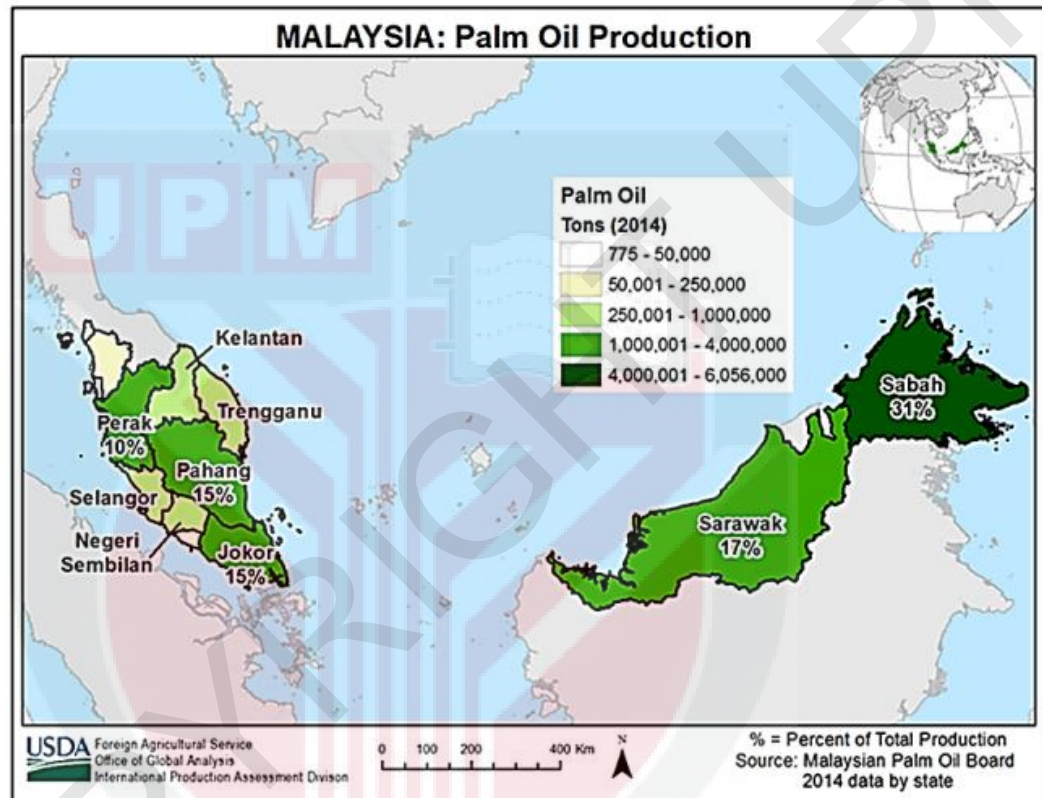


Figure 5 Palm Oil Production

2.5 Harvesting

The oil palm is harvested when it reaches maturity, which is approximately three (3) years after it is planted in the field. The fresh fruit bunch (FFB) of oil palms was harvested only when the correct amount of loose fruit is fall from the FFB, indicating peak maturity. The maturity of the harvested fresh fruit bunch (FFB) is necessary to optimize the quality and quantity of the extraction of palm oil. Loose fruits with fresh fruit bunch (FFB) harvested are collected to reduce losses.

2.6 Loose Fruit

Loose fruit (as shown in figure 5) was still one of the hottest subjects in the daily upstream plantation service (Palm Oil Facts and Figures, 2013). Loose fruits are the ripest in the bunches and naturally fall on the ground. In estates where five (5) loose fruit on the ground, the situation indication is that the bunch is ready for harvest (Mohd Nadzri and Ahmad, 2016).



Figure 6 Loose Fruit Image

The matured fresh fruit bunch (FFB) in the standard operating phase is highly associated with the number of drops of loose fruit under the oil palm tree. It is used as an indicator for fresh fruit bunch (FFB) harvesting and has a negative effect because uncollected loose fruit is losses in the oil palm industry.

2.6.1 Challenge in Loose Fruit Collecting

Employees must bend their bodies in order to collect fruit above the ground and move from tree to tree. Time gathers fruit that usually takes nearly 30% of the harvest time (Mohd Zohadie, 1992). This method causes consume time, and always causes a sick waist for employees.

The presence of debris and impurity causes a major problem for oil processing stage on oil palm in the factory. It is estimated that almost 20 percent of debris is transported to the factory. It takes a long time for employees to remove the presence of debris.

2.6.2 The Current Method

The conventional method (as shown in figure 7) has been used because this method is one of the efficient methods when collecting the loose fruit and the cost is low. The amount of debris collected also will be minimum.



Figure 7 Conventional Method Collecting Loose Fruit

2.7 Mechanical Method for Collecting Loose Fruit

Generally, most oil palm plantations have to deal with the collection of loose fruit on a daily basis. Mechanization is the solution to this problem and a loose fruit collecting machine is urgently needed, with minimal waste, to maximise the amount of fruit collected and to reduce the number of employees required. Some designs of loose fruit collecting machines have been developed in Malaysia.

2.7.1 Mechanical Loose Fruit Collector

In 1995, the Palm Oil Research Institute of Malaysia (PORIM), currently known as Malaysia Palm Oil Board (MPOB) and Universiti Pertanian Malaysia (UPM), currently known as Universiti Putra Malaysia (UPM) jointly developed a Mechanical Loose Fruit Collector (MK I). MK I consists of an air-cooled petrol engine and a push-cart fitter with two separate compartments, one for loose fruit and the other for waste compartments.

Figure 8 shows MK I, which is the core concept of a direct suction machine. The field trial revealed the ability of the machine to collect 300 kg to 400 kg of relatively clean loose fruit per day from dispersed sites on the ground. The productivity his field trial was a little less than expected because the pushcart had a small container and the workers had to go and push the collector.



Figure 8 Image of MK I

In 1999, PORIM introduced another version mechanical loose fruit collector that improved version of the earlier machine. Known as MK II, it has been developed, covered and easily managed by higher capacity workers. The MK II consisted of a 3-wheel fresh fruit bunch (FFB) carrier, a fan and two container suppliers, to suck the two containers separately from the clean loose fruit and waste. The main method for collecting the loose fruit is the direct suction mechanism. The MK II prototype is shown in Figure 9. The field test was carried out and the daily productivity in the loose fruit group was 1,400 kg to 1,700 kg per day or 5 times higher than the productivity in the MK I collection. In addition, the MK II was able to operate in full compared to the manual collection of three employees. The field trial, however, showed that the MK II could still be improved in terms of engine capacity, as the vacuum generated by the engine was not strong enough to prevent the loose fruit choking. This problem may lead to lower collection rates and higher collection times. The Malaysia Palm Oil Board (MPOB) introduced MK III in 2012.



Figure 9 Image of MK II

The new suction design, cyclone vacuum, was introduced by the MK III as illustrated in Figure 10. This vacuum can increase the suction power to create a cyclone atmosphere inside the cylinder barrel and loose fruit were being suck in. The heavier fruit drops to the bottom of the barrel, while the lighter material is removed

from the system. The damage of the loose fruit are minimal, and the choking problems are insignificant, especially during the wet weather when the fruits are moist, which slows down the process of harvesting. The field test showed that MK III can collect 1200 kg to 1500 kg of loose fruit on a daily average.



Figure 10 Image of MK III

As the oil palm industry continues to grow, productivity is a key parameter that needs to be continuously measured. As shown in Figure 11, MK IV was introduced with a larger capacity in 2017. Although the suction concept was maintained as in MK III, where loose fruit was sucked in cylindrical barrels, the additional feature, including the barrel, now acting as a temporary storage area, was enhanced. At least 500 kg of loose fruit can be stored in this barrel. The field test was conducted, and the average loss of collection ranged from 1,500 to 2,000 kg, an increase in productivity of 20% to 25% over MK III.



Figure 11 Image of MK IV

2.7.2 Roller Picker

The Loose Fruit Picker roller type represents a different method of mechanical collection of loose fruit. The roller picker is primarily designed as an oval case, without the use of a motor, and is made of a plurality of wires and rods. The basic function is to collect all the fruit on the ground using a simple mechanism, such as hand selection.

The roller picker shall be operated by a single operator. The roller picker is pressed against the ground, which opens and traps loose fruits in the case of wires or bars. The case returns to its normal position after the loose fruit is trapped between the wires and the rods. All debris smaller than the space between wires and rods will drop, and only loose debris-free fruit will be collected.

Figure 12 shows the operation of the roller picker at the base. Due to the relatively small operation of the roller picker, the roller picker is considered suitable for all types of field conditions in the plantation environment. Due to its ease of use and minimal maintenance requirements, the roller picker can be used with some enhanced design functions in oil palm plantations.

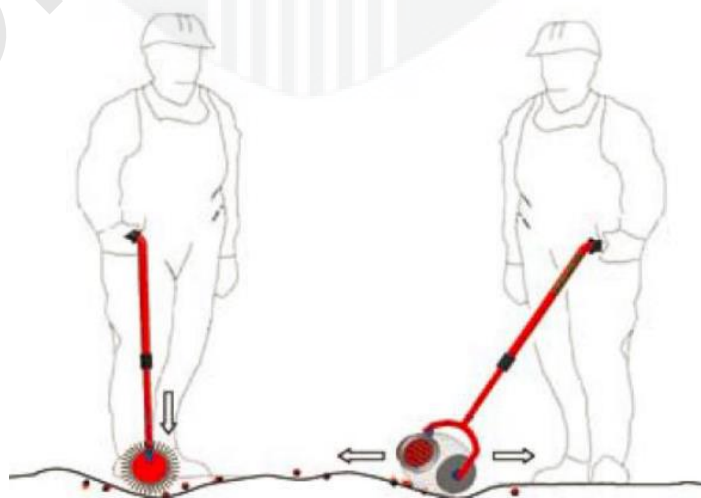


Figure 12 Process of using Roller Picker

2.7.3 Advantages and Disadvantages of Mechanical Method

The mechanical loose fruit collector is a machine that include the engine, the vacuum, the container, and the prime mover. This machine can optimize the operating efficiency and significantly increase the productivity of the fruit collected. The productivity of at least 300 kg to 2,000 kg / debris can be collected by 25%, as examined. In comparison, the relatively simple roller picker with a roller made of wires and rods is at least 40 % lower than the mechanical loose fruit collector. As a result, the mechanical loose fruit collector appears to be a more attractive option in terms of productivity, particularly for larger oil palm plantations. In addition, the presence of a primary mover allows increased mobility and reduces the number of workers; however, there are also some limitations on mechanical fruit collectors, such as the large size and heavyweight that could damage the path.

In addition, the size of the machine makes it difficult to access some of the plantation grounds. Flat and undulating areas are suitable for the mechanical loose fruit collector, but the stability of the prime movers and the safety of the operator should be considered when it comes to hilly and terrace areas. In addition, the costs of repair, maintenance, and service life of the machines, as well as the initial capital investments, must be considered. In this situation, the roller picker is an effective way to solve the problems posed by mechanical loose fruit collectors. The designs of the roller picker are lightweight, small, and easy to use and can cover different types of terrain. In addition, maintenance should be considered considerably less, and the price of the roller picker appears to be generally viable for the oil palm industry. The roller picker, however, has problems with manpower and productivity. The roller picker requires the operator to move from one palm to another in order to collect the loose palm based on the palm. The productivity of the roller picker is therefore heavily

dependent on the operator, even if more roller picker operators can increase their productivity if work is available.

With the industry's labour shortage and the demand to harvest loose fruits because of the high oil content of loose fruits, researchers should therefore look at the Industry 4.0 revolution. Industry 4.0's basic principle is to connect machines, workplaces and systems and create intelligent networks that can control each other autonomously throughout the entire value chain. Researchers and development of loose fruit collecting machinery should explore the possibility of deploying self-employed fruit pickers or loose-pickers in the oil palm industry to address labour shortages.

CHAPTER 3

METHODOLOGY

3.1 Study Area

In this project, the experiment was carried out at Taman Pertanian Universiti's Oil Palm Plantation area at Serdang, Selangor (shown in figure 13) which located in Universiti Putra Malaysia with coordinate of (2°59'18.73"N, 101°43'38.26"E).

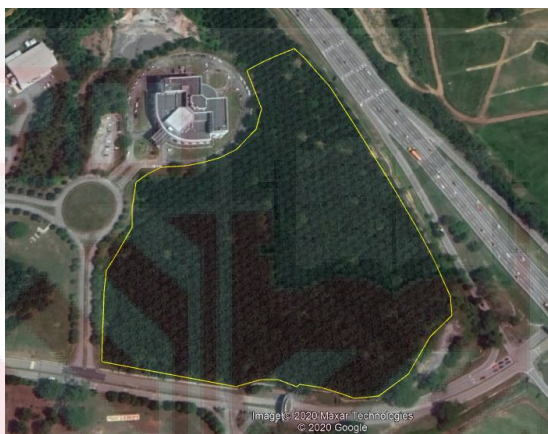


Figure 13 Satellite Image of Study Area

From the observation, there were about three staff handled the activity of harvesting that usually start early at 7.30 am in the morning. The terrain condition is hilly, and the area has other vegetation (weed) below the oil palm canopy as shown in figure 14.



Figure 14 Oil Palm Plantation at Taman Pertanian Universiti

3.2 Data Measurement and Observation

The data measurement and observation has been taken, and it can be used to get an idea to develop the robotic system of oil palm loose fruit collector.

Data measurement taken from the plantation field:

1. Time motion for harvesting
2. The radius of loose fruit spread.
3. Time taken to collect loose fruit manually using hand and roller picker.

There is also some observation have been made to the plantation field such as:

1. The vegetation under oil palm canopy.
2. The loose fruit location.

Data from satellite also being obtained to know the condition of the oil palm plantation. The data is being obtain using Google Earth Pro that using vertical datum WGS84 EGM96 Geoid. This method can obtain the elevation profile in the oil palm plantation.

3.2.1 Time Motion for Harvesting

Time motion for harvesting is the most important thing that needed to identify because from the data, we will calculate the field capacity of harvesting to ensure the efficiency of harvesting.

Stopwatch was used to take the time taken for harvesting process including hooking the fresh fruit bunch (FFB) from the tree, collecting the loose fruit and moving to another tree. The time was taking when the workers hooking the FFB and going to another palm tree, the time will be stop after harvesting undergo in about 3 palm trees.

3.2.2 Time Motion Collecting Loose Fruit

Collecting loose fruit is one of the most important tasks in oil palm harvesting, as it takes time to get fresh fruit bunches together. Seventy percent of the harvest time is spent collecting loose fruit.

Time to gather loose fruit was taken in two ways, hand-held and roller-picker (as shown in figure 15), to gather loose fruit. As the vegetative and the surface of the field make it difficult to gather loose fruit below the tree, the distance from the tree was also variable.



Figure 15 Collecting the Loose Fruit using Roller Picker

3.2.3 Radius of Loose Fruit Spread

The radius between the loose fruit and the palm tree (as shown in figure 17) was also taken because the vegetation and the condition of the field could vary, making it difficult to gather the loose fruit. The distance shall be determined by the measuring tape.



Figure 16 Taking the distance of loose fruit from Oil Palm Tree

3.2.4 Vegetative Condition

The vegetative (like in figure 17) in the oil palm plantation is observed and studied as the vegetation may affect the process of collecting loose fruit. Vegetation can also have an impact on the spread of loose fruit, making the process of collecting loose fruit more time-consuming.



Figure 17 Example of Vegetation under Oil Palm Tree

3.3 Determination of Physical Parameter

The tenera and dura varieties of palm fruits used for this study were collected from the Taman Pertanian Universiti of Universiti Putra Malaysia, Serdang, Malaysia in August 2020. The physical properties considered in this analysis are size, shape, true density, bulk density and porosity. Loose fruits were collected from oil palm plantation. Half of the collected loose fruits samples belonged to Tenera variety while another half belonged to Dura variety.

3.3.1 Sample Selection

The loose fruit samples collected is being sorted (like figure 18) by its physical appearance to ensure we get the right measurement when determined the physical properties. The loose fruits are distinguished by its physical appearance, whether it is damaged or not. This selection is been done by choosing 50 samples of each variety, dura, and tenera.



Figure 18 Sample Selection Process; A is the selected loose fruit, and B is the rejected

3.3.2 Determination of The Physical Parameter

Three dimensions like length (L), width (W) and thickness (T), were determined for each fruit by using Vernier Calliper as in figure 19 with accuracy 0.05 mm (Mitutoyo, Japan). Figure 20 show on how the dimension of loose fruit is taken.



Figure 19 Vernier Calliper

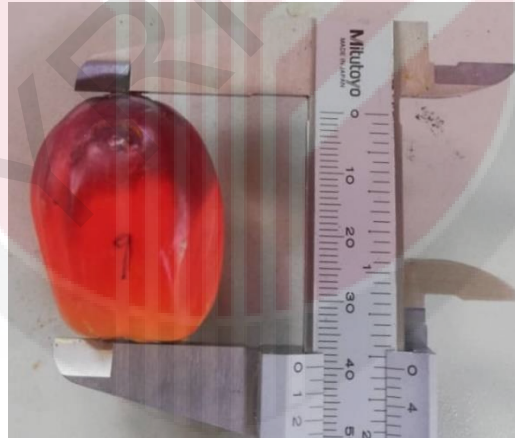


Figure 20 Measuring the Length of Loose Fruit Sample

3.3.3 Determination of The Shape

The loose fruit's shape was determined in terms of its sphericity index and aspect ratio. The dimensions achieved form in section 3.3.2 were used to calculate the Sphericity Index based on Mohsenin(1978) recommendation as

$$S_c = \frac{(LWT)^{\frac{1}{3}}}{L}$$

Equation 1

L = Length of loose fruit, mm

W = Width of loose fruit, mm

T = Thickness of loose fruit, mm

The aspect ratio (R_a) recommended by Maduako and Faborode (1990) was determined as follows:

$$R_a = \frac{W}{L} \times 100$$

Equation 2

R_a = Aspect ratio

L = Length of loose fruit, mm

W = Width of loose fruit, mm

3.3.4 Determination of Mass

The mass of the individual loose fruit of both dura and tenera varieties was determined using Shimadzu Precision TX423L Electronic Balance as shown in figure 21 (Shimadzu, Japan) with an accuracy of 0.001 g.

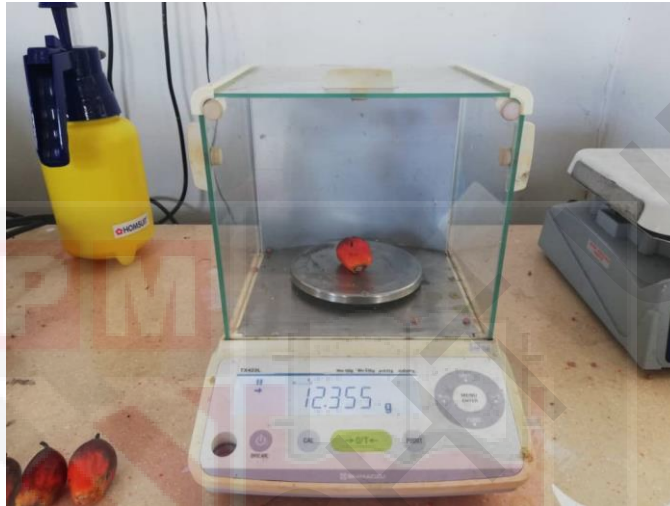


Figure 21 Individual Loose Fruit sample was weighed

3.3.5 Determination of True and Bulk Density

The true density of the loose fruit was determined by the technique of water displacement (Dutta, Nema, & Bhardwaj, 1988; Owolarafe et al., 2007). The samples were lowered into a standard measuring cylinder containing 100 ml of water as shown in figure 22. The loose fruit was made to be submerged during immersion in water. The net volumetric water displacement of each fruit is recorded. The density ρ_t was then calculated using equation 3 as shown below:

$$\rho_t = \frac{m}{v}$$

Equation 3

$$\rho_t = \text{True Density, } \frac{kg}{m^3}$$

$m = \text{mass of loose fruit, kg}$

$v = \text{volume of loose fruit, m}^3$



Figure 22 Make sure that the fruit is fully submerged

In order to measure the bulk density, an empty cylindrical container of 200 ml was filled with loose fruit and the bulk weight was recorded. This was done 10 times replication. The bulk density (ρ_b) was then determined for each repeat using the above equation 3. This process was used in each variety of palm fruits, dura and tenera.

3.3.6 Determination of Density Ratio and Porosity

The density ratio D_r is the ratio of true density to bulk density expressed as a percentage of the following:

$$D_r = \frac{\rho_t}{\rho_b}$$

Equation 4

D_r = density ratio

ρ_t = True Density, $\frac{kg}{m^3}$

ρ_b = Bulk Density, $\frac{kg}{m^3}$

Porosity (P) was calculated using equation 5 suggested by Jain and Bal (1997) as

$$P = \frac{\rho_t - \rho_b}{\rho_t}$$

Equation 5

P = Porosity

The reported values of all density characteristics are a mean of 10 replications.

3.4 Determination of Colour Code for Loose Fruit

From the sample at section 3.3.1, the colour of the loose fruit from the 10 samples that selected randomly is being capture the colour code using smartphone with Physic Toolbox Sensor Suit (Vieyra Software) as shown in figure 23. Each of the varieties, dura and tenera was go through the process to obtain the colour code.

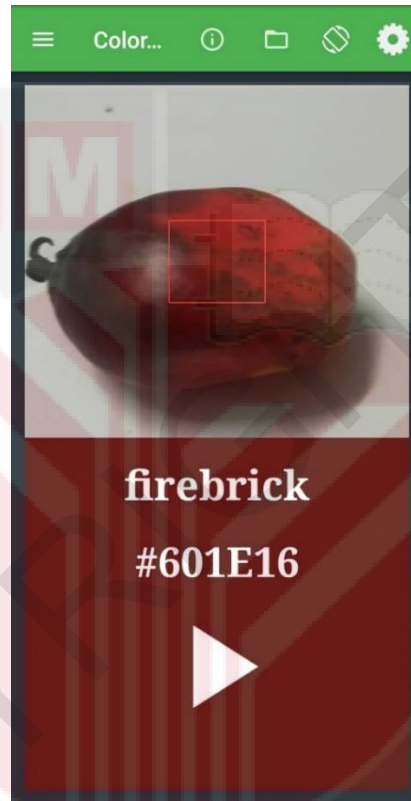


Figure 23 Colour Code obtain Using Physic Toolbox Suite Software

3.5 Test Rig

A test rig was designed to evaluate the parameter of the loose fruit collector. The test rig design will be based on the sketch as shown in figure 24. The data obtained during the study such as the terrain condition of the oil palm plantation will be simulated at the circular track. The behaviour of loose fruit collector also will be monitor using the test rig and quality of the loose fruit after entering the loose fruit collector will be determined.

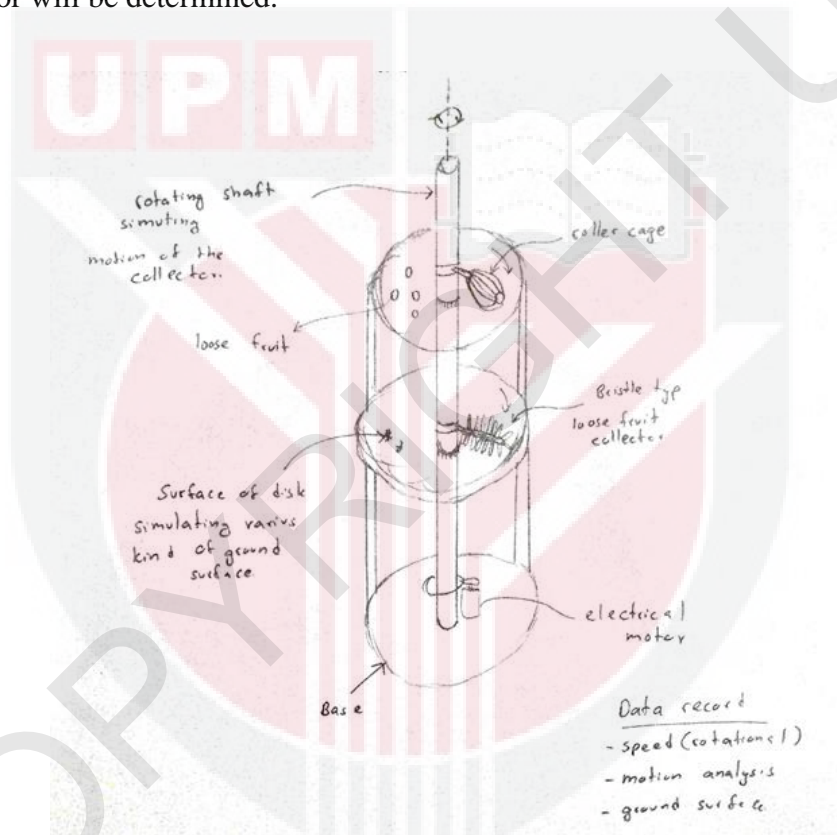


Figure 24 Test Rig sketch design

3.5.1 Theoretical Speed at Surface

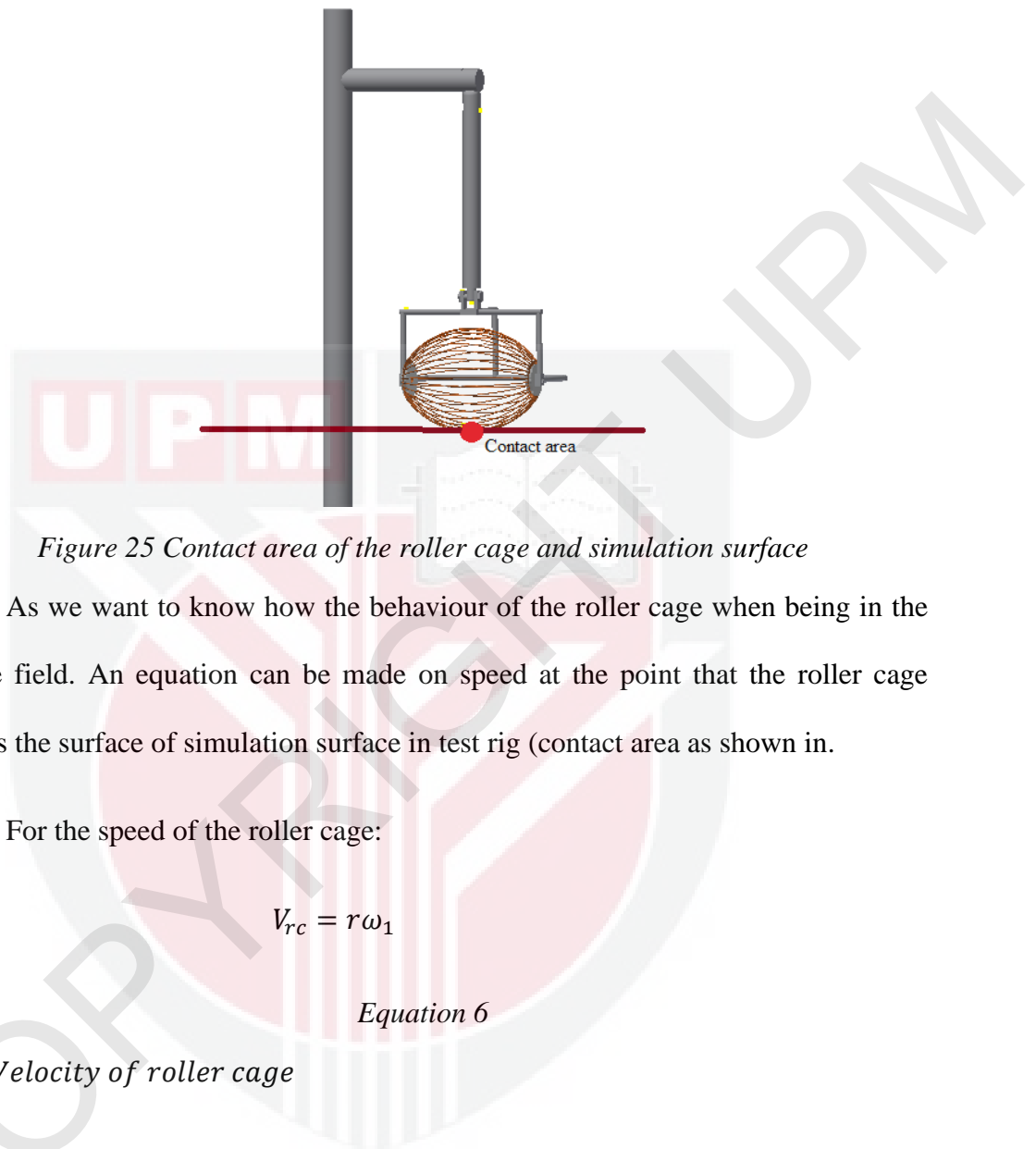


Figure 25 Contact area of the roller cage and simulation surface

As we want to know how the behaviour of the roller cage when being in the surface field. An equation can be made on speed at the point that the roller cage touches the surface of simulation surface in test rig (contact area as shown in.

For the speed of the roller cage:

$$V_{rc} = r\omega_1$$

Equation 6

V_{rc} = Velocity of roller cage

r_{rc} = radius of roller cage

ω_1 = angular speed of roller cage

The roller cage rotates on a circular path of radius of L (length of the arm). The time period of the rotation at axis perpendicular to the track and pass through the pole:

$$\begin{aligned} \text{Time period, } T &= \frac{2\pi L}{V_{rc}} \\ &= \frac{2\pi L}{r_{rc}\omega_1} \end{aligned}$$

Equation 7

$L = \text{Length of pole arm}$

So, the angular velocity of the roller cages the axis:

$$\begin{aligned} \omega_0 &= \frac{2\pi}{T} = \frac{2\pi}{\frac{2\pi L}{r_{rc}\omega_1}} \\ &= \frac{r_{rc}\omega_1}{L} \end{aligned}$$

Equation 8

$\omega_0 = \text{angular speed of pole}$

Velocity of the touching point at roller cage to the simulate surface point is

$$V_s = r\omega_1$$

Equation 9

Acceleration at the surface will be:

$$A_s = r\omega_1^2$$

Equation 10

To obtain the angular velocity of the roller cage, which is unknown, we may use the angular velocity of the pole. The time span can be used to calculate the angular velocity, since the time would be the same for the rotation of the pole and the rotation of the roller cage.

Chapter 4

Result and Discussion

This chapter describes a study on the properties of oil palm loose fruit physically and the fruit colour, and field condition, in order to develop a robotic oil palm loose fruit collector system that is productive and suitable for field use. We will also develop a test rig to observe the roller picker mechanism for collecting loose fruit.

4.1 Terrain Condition

From Google Earth Pro, the elevation profile (figure 26) show that the elevation in the study area. The elevation minimum, maximum and average in the study area are 59 m, 79 m and 69 m. This show that the terrain condition at the study area is hilly.



Figure 26 Elevation profile at study area

This type of data cannot be in surveying but can be used to obtain simple data as wanted to know the type of surface area.

4.2 Vegetative Under Oil Palm Canopy

Oil palm plantations may be susceptible to weed invasion, especially as growth in the early stages is extremely slow and the soil open to sun and weeds. The crop is also grown under abundant water and nutrient supply conditions that make the weeds as well as the crop. Weed control is most important at the beginning of the years before

the palm canopy closes across the centre of the path. Heavy weeds may also interfere with the production of palm oil by increasing the cost of production. A weed that is left alive to grow more seeds would increase weed problems in the years to come. In table 1 will show the weed that have been found in study area.

Table 1 List of weed species found in Study Area

No.	Species
1	<i>Nephrolepis biserrate</i>
2	<i>Chromolaena odorata</i>
3	<i>Axonopus compressus</i>

Nephrolepis biserrate (as in figure 27) is a tropical fern, which is existed in Florida, West India, Central America, South America, Southeast Asia, and Africa. The stalks are greyish brown, 10 to 50 cm and about 4 mm brownish-green, 14 to 30 cm wide, and 0.7 to 2 meters long. Also known as paku larut or paku uban (Malaysia Biodiversity Information System, n.d.).



Figure 27 Image of Nephrolepis spp.

Nephrolepis biserrate grows in an oil palm plantation at the oil palm trunk as shown in Figure 28. It is invasive as it grew on the trunk of the tree. The method of collecting loose fruit may be disrupted because some loose fruit may be stuck on the old trunk mark.



Figure 28 Nephrolepis spp. in Oil Palm Plantation

Chromolaena odorata (figure 29) in the Sunflower family is a tropical and subtropical flowering shrub. It is native to the Americas, from Florida and Texas to Mexico, and from the Caribbean to South America. Tropical Asia, West Africa and parts of Australia have been introduced.



Figure 29 Image of Chromolaena odorata

Chromolaena odorata grown in the oil palm field is approximately 21 cm away (based on the average distance between 3 of the same plant species). This plant is grown near the oil palm tree shown in figure 30, it can be considered a weed because it disrupts the process of extracting loose oil palm fruit. At a young age, *Chromolaena spp.* will disturb the growth of the oil palm tree. If the oil palm tree is big enough, it will have little effect on the oil palm crop.



Figure 30 Chromolaena in oil palm plantation

Axonopus compressus (figure 31) is one of Malaysia's native soft grass species used as an oil palm cover crop. It is often used as permanent pasture, surface and peat in damp, low fertility soils, especially in shaded situations. In general, it is too poor to be used in cutting and transport systems or for the protection of feed.



Figure 31 Axonopus compressus

The *Axonopus* spp. found in oil palm plantation study area shown in figure 32, and this plant species is found about 35 cm from the oil palm tree. This plant growth in similar area which the population is not so high as there only about 1-2 plants grow near the oil palm tree.



Figure 32 Image of Axonopus compressus in Oil Palm Plantation

Oil palm is one of the most valuable vegetable oil crops and is of critical importance to developing countries such as Malaysia and Indonesia. However, the impact on biodiversity is also highly controversial. Herbicide inputs in plantations are high in the control of understory vegetation, which may affect native biodiversity, but may be unnecessary in the protection of palm oil yields (Ser Huay Lee et al., 2018).

4.3 Location of Loose Fruit Spread

When the fresh fruit bunch is harvested, about 10% of the oil palm fruit will be scattered to the ground (shown in figure 33) and will be called loose fruit. 10% is a large volume that can be a loss if the loose fruit is not collected.



Figure 33 Image of Oil Palm Loose fruit during the data collection

The spread of the loose fruit to the ground after the fresh fruit can vary and affect the collection time of the loose fruit. This should also be considered when the robotic system is designed to collect loose fruit, as it could be a loss if it is not collected.

Table 2 Spread Distance of Oil Palm Loose Fruit

	Tree 1	Tree 2	Tree 3	Average
Minimum Distance	34 cm	33 cm	21 cm	29.33 cm
Maximum Distance	264 cm	219 cm	244 cm	242.33 cm

The average minimum distance between the oil palm tree and the loose fruit spread is 29.33 cm, which is near the tree. The maximum distance for oil palm loose fruit spread is approximately 242.33 cm, which can be located near the infield route.

The distance of the spread will be determine based on the height of the tree, if the tree is higher, the spread distance will be farther. In this study will refer the height that tree at the study area. Usually it is a standard weeding operation to spray herbicide at around the oil palm tree with radius 3.5 m.

There will be also some fruit that will stuck at old trunk mark which need to be taken care of as it also often happens during harvesting the fresh fruit bunch. During this data collection, there about 150 gram of oil palm loose fruit stuck at the old trunk mark as shown in figure 33.



Figure 34 Image of loose fruit stuck at old trunk mark

4.4 Time Motion

Time motion for the fresh fruit harvesting process is a very critical data to be considered, as it ill defines the performance of the oil palm harvesting process. In this process, the time taken to collect loose fruit using a hand and roller picker is compared. The average time taken to harvest and move from tree to tree (3 oil palm trees) is 469.33 seconds. The time taken is longer maybe because of the oil palm plantation condition and management, as it take more time to find the ripe fresh fruit bunch.

Table 3 Time taken to collect loose fruit using hand and roller picker

	Trial 1	Trial 2	Trial 3	Mean
Using Hand	34 seconds	31 seconds	36 seconds	33.67 seconds
Using Roller picker	16 seconds	19 seconds	20 seconds	18.33 seconds

The mean time taken using the hand is 33.67 seconds and the mean time taken using the roller picker is 18.33 seconds. The difference in the time taken is about half, and this shows that using a roller picker is the optimal way to gather loose fruit.

4.5 Physical Properties

Table 3 shows the effects of the physical parameters of the dura variety and tenera variety. The mean length, width and thickness of the tenera variety was 38.71 mm, 26.80 mm and 22.97 mm respectively. The average length, width and thickness of the dura variety was 33.71 mm, 25.08 mm and 21.40 mm respectively. The variety of tenera is bigger than the variety of dura. The values of length, width and thickness of the tenera are higher than the dura. Mohsenin (1978) and Omobuwajo, etc., (1999) addressed the significance of these and other physical properties in determining the opening size of the machinery, in separating materials. These measurements can be useful for estimating the size of the device components.

Table 4 Physical Properties of Loose Fruit for Tenera Variety and Dura Variety

Properties	Mean Value (\pm Standard Deviation)	
	Tenera	Dura
Length, mm	38.71 (\pm 3.47)	33.71 (\pm 2.84)
Width, mm	26.80 (\pm 2.44)	25.08 (\pm 2.17)
Thickness, mm	22.97 (\pm 2.69)	21.30 (\pm 2.22)
Sphericity, %	74.41 (\pm 4.93)	77.98 (\pm 5.10)
Aspect Ratio, %	59.59 (\pm 7.37)	63.81 (\pm 7.75)
Fruit mass, g	12.29 (\pm 2.78)	11.32 (\pm 2.90)
True density, kg/m ³	954.31 (\pm 99.42)	901.75 (\pm 193.30)
Bulk density, kg/m ³	1091.62 (\pm 29.13)	1061.82 (\pm 29.06)
Density Ratio, %	87.42 (\pm 3.41)	83.92 (\pm 6.65)
Porosity, %	14.39 (\pm 0.71)	17.75 (\pm 0.84)

The dura variety sphericity and aspect ratios were 77.98% and 63.81% respectively. The high sphericity of the palm fruit shows the inclination of the shape to the sphere. Taken in conjunction with a high aspect ratio of 63.81% (reflecting fruit

width to length), it can be concluded that the palm fruit rolls instead of sliding on its flat surfaces. But the aspect ratio value is near to the spherical values, which also mean that the palm fruit is rolling and sliding on its flat surfaces.

The tenera variety sphericity and aspect ratio were 74.41% and 59.59% respectively. The high sphericity of the fruit has shown the inclination of the form to the sphere. Important findings are the highest values of the sphericity index of 77.98% and the aspect ratio of 63.81% respectively for the dura variety compared to 74.41% and 59.59% respectively for the tenera variety. This indicates that dura has a higher tendency to have shape of a sphere.

The mean fruit mass of the tenera variety was 12.29 g, while the average fruit mass of the dura was 11.32 g. The average fruit mass of the tenera is higher than the dura. This can be related to the size of the tenera, as the Dura is smaller.

The total mass, true density, bulk density, density ratio and porosity of the dura variety is 11.32 g, 901.75 kg/m³, 1061.82 kg/m³, 83.92%, and 17.75%. The palm fruit appears to be partially submerged into water for the true density (density 1000 kg/m³). These characteristics can be useful for the hydrodynamic separation and transport of fruits. The lower porosity or percentage of voids in the dura may be due to the higher sphericity and aspect ratios that allow the fruits to be more compact.

Then, the total mass, true density, bulk density, density ratio and porosity of the tenera variety was 12.29 g, 954.31 kg/m³, 1091.62 kg/m³, 87.95% and 14.39%. There is a tendency for the palm fruit to be partially submerged in water or fully submerged in water due to the high value of true density. The true density and bulk density of tenera variety is higher than dura density. Although the tenera variety has a greater tendency to sink in water, its thick mesocarp and its small kernel allow the

tenera variety to be partially submerged in water. Their density is similar, although the low porosity value (17.75% for dura and 14.39% for tenera) may be due to the higher ratios of sphericity and appearance, which allow a more compact arrangement of the fruits. These properties can also be useful for the hydrodynamic separation and transportation of fruits.

Table 5 t-test for Equality of Mean between Tenera and Dura

Properties	t-test for Equality of Means		
	t	df	Sig. (2-tailed)
Length	7.894	98	0.000
Thickness	3.188	98	0.002
Width	3.703	98	0.000
Sphericity	-3.529	98	0.001
Aspect Ratio	-2.789	98	0.006
Fruit Mass	1.709	98	0.091
True Density	1.710	98	0.090
Bulk Density	2.290	18	0.034

The value for length, thickness and width of dura variety and tenera variety is significantly different with each other based on the significant value that is lower than 0.05 (5% significant level) in table 5. This value needs to be considered when designing loose fruit collector.

The sphericity value for tenera variety and dura variety is significantly different, but the aspect ratio is not significantly different based on table 5. This need to consider for transportation as the value of sphericity and aspect ratio will determine either it is rolling or sliding.

The mass of the loose fruit for dura variety and tenera variety is not significantly different based on table 5. This mass of the loose fruit is important value as the mass may affect the power need for robotic loose fruit collector when being deploy in oil palm plantation.

The true density for tenera variety and dura variety is not significantly different based in the significant value in table 10. This data is important to be used in transportation or separation of the loose fruit with the debris.

The bulk density value for tenera variety and dura variety is significantly different as the significant value is lower than significant level (5%) in table 5. This need to consider when designing the container to keep the loose fruit for the loose fruit collector.

4.6 Colour Code of Loose Fruit

Colour was identified as one of the most important parameters for the identification of fruit and fruit quality and is a strong predictor of maturity (Alfatni, Shariff, Saaed & Eshanta, 2008). The colour of the object is determined by the wavelength of the surface light.

Table 6 Mean of colour pixel of oil palm loose fruit

Properties	No of Pixel (\pm Standard Deviation)	
	Dura	Tenera
Red	93.3 (\pm 3.23)	119.1 (\pm 7.28)
Green	26.2 (\pm 6.16)	32.1 (\pm 8.80)
Blue	16.9 (\pm 6.05)	21.9 (\pm 5.86)

The mean number of dura pixels for the red, green, and blue varieties of table 4 is 93.3, 26.2, and 16.9, respectively. In the meantime, the mean number of tenera pixels for red, green, and blue is 119.1, 32.1, and 21.9, respectively. The dura variety is less coloured in red than the tenera variety. Tenera is much brighter than dura.

4.7 Test Rig Design

From the reading, using roller picker is one of the efficient methods to collect loose fruit. The time taken using roller picker is much faster than using hand. The cost for roller picker also low and it requires less maintenance. Test rig will be designed to monitor on how the roller cage mechanism to collect loose fruit. The surface of oil palm field plantation also will be simulated to record on how roller cage reacts to the surface and how the loose fruit enter the roller picker.

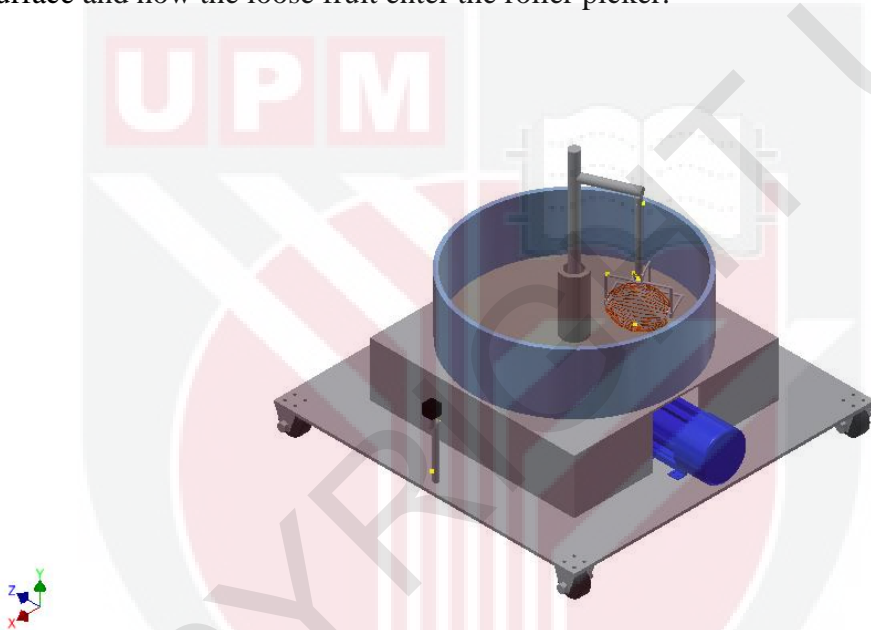


Figure 35 Image of Proposed design of Test Rig

The proposed design of test rig as shown in figure 35 would be used to collect data on the process of the roller picker being collected. The test rig will be fitted with a load cell and a camera to capture the data. The track of the test rig will be a circle and the condition of the oil palm field will be simulated within the track.

4.7.1 Platform

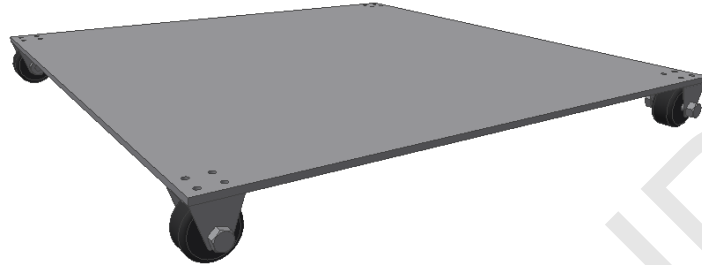


Figure 36 Platform for the test rig

The platform in figure 36 is for the test rig will be equip will roller to make it easy to be move in the laboratory. The size of the plat form is 1.5m x 1.5m.

4.7.2 Housing

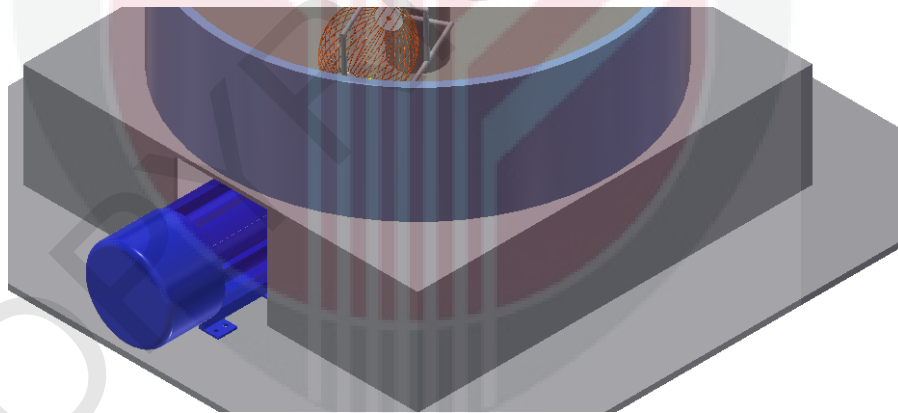


Figure 37 Image of the housing and engine

The engine housing (as in figure 37) is for safety purposes that have a connexion from the gearbox to the pole. The engine would also be positioned outside the housing, since the engine would produce heat, which, if left in a housing, may generate pressure within the housing.

4.7.3 Motor

The desired speed for the roller cage in the track will be about 0.3 m/s in clockwise rotation, and in order to obtain the speed, the test rig will be using gearbox as a reducer to reduce the rotational speed from the motor.

The desired speed is 0.3 m/s and the radius of rotation (length of arm of the pole) is 0.2 m. Using equation 11, the rotational speed value can be determined.

$$\begin{aligned} N &= \frac{60}{2\pi \times r} v \\ &= \frac{60}{2\pi \times 0.2} (0.3) \\ &= 14.32 \text{ rpm} \approx 14 \text{ rpm} \end{aligned}$$

Equation 11

N = rotational per minute, rpm

r = radius, m

v = Speed, m/s

The ratio for the gearbox that will be used is 100:1. Based on the ratio, the speed for the motor that need have is about 1400 rpm in order to achieve the desired speed for the roller cage movement.

4.7.4 Circular Track

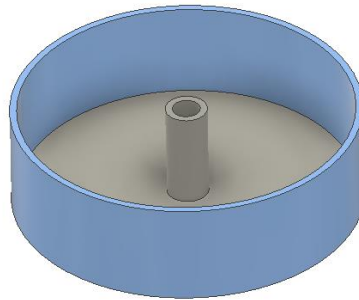


Figure 38 Image of the track

Figure 38 show the track that will be used in the test rig design. The concept for the test rig will be a circular concept because the concept will be required to have a small space. The wall for the track will be transparent in colour to allow the camera to monitor the behaviour of roller cage collecting the loose fruit. The radius of the track will allow roller picker to move inside the track.

The height of the wall which is 30 cm which is enable create a simulation surface of oil palm field condition. The wall also needs to create a barrier to avoid the fruitlet to thrown out of the track.

Chapter 5

Conclusion & Recommendation

5.1 Conclusion

Based on this analysis, the condition of oil palm plantation was observed in Taman Pertanian Univerisiti and several weeds were reported from *Nephrolepis* spp., *Chromolaena* spp., and *Axonopus* spp. The location of the loose fruit is also being observed and recorded. The surface condition of the plantation been determined as hilly. The observation of the oil palm plantation condition is essential to get an idea to design a robotic system for a loose fruit collector.

Physical properties (sphericity and aspect ratio) for 50 samples were evaluated for both dura and tenera. Data is also important as knowing the physical properties of agricultural material is one of the steps in the design of the system.

It can be inferred that the variety of tenera is larger than the variety of Dura. Significant results are the highest values of the sphericity index of 77.98% and the aspect ratio of 63.81%, respectively, for the dura variety compared to 74.41% and 59.59 %, respectively, for the tenera variety. This suggests that dura has a higher tendency than to have to form a sphere.

The time taken to manually gather oil palm loose fruit is about 33 seconds, but the roller picker is about 18 seconds. The performance of the robotics collected must be more effective or equivalent in order to provide better results.

In summary, the goals of the project have been accomplished. Based on the data collected, a test rig to evaluate the performance and parameter of oil palm loose fruit collector can be design.

5.2 Recommendation

At the present time, collecting loose fruit still perform by manual way using hand. Even the activity is carried out by expert workers, there still bad impact that will risk the workers' health such as prone to back pain. The design should consider few aspects which are, the cost effective for collecting the loose fruit and the quality of the loose fruit collected must be in good condition and not damaged. The cost is the main thing that need to consider as the effectivity of the robotic system can counter the current cost for collecting the loose fruit.

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Appendix



Figure 39 Image of Roller Picker Used

Table 7 Time taken to harvest from tree to tree

	Trial 1	Trial 2	Trial 3	Average
Time taken	436 second	513 second	459 second	469.33

Table 8 Data Collection for Tenera Variety

Length, mm (a)	Thickness, mm	Width, mm (c)	Sphericity	Aspect Ratio	Fruit Mass, g	Volume, m3	True Density, kg/m3
42.3	20.45	30.125	70.08846431	48.34515366	17.676	0.000018	982
41.3	20	28.3	69.23177121	48.42615012	12.491	0.000013	960.8461538
41.3	27.4	28.15	76.75552023	66.34382567	16.802	0.000016	1050.125
42.2	22.3	26.05	68.83815623	52.8436019	11.866	0.000012	988.8333333
41	23	27.4	72.10580479	56.09756098	12.111	0.000013	931.6153846
40	24.075	28.15	75.10028252	60.1875	13.858	0.000014	989.8571429
40	22.1	25	70.15696071	55.25	10.646	0.00001	1064.6
38	20.325	26.35	71.84799616	53.48684211	10.953	0.000012	912.75
41	23.25	32	76.20820645	56.70731707	16.671	0.000017	980.6470588
37.125	23.075	25.1	74.90213015	62.15488215	11.317	0.000012	943.0833333
35.275	25.15	29.3	83.97638752	71.29695252	14.037	0.00002	701.85
36.1	24.15	28	80.35635971	66.89750693	11.009	0.000022	500.4090909
37	27	28.05	82.09141228	72.97297297	13.92	0.000014	994.2857143
34.1	18.15	27.3	75.25063565	53.22580645	10.038	0.00001	1003.8
38.125	24.4	25.05	74.91911133	64	12.098	0.000013	930.6153846
37.3	25	28.2	79.72425773	67.02412869	14.585	0.000017	857.9411765
40.375	27.35	30	79.54590702	67.73993808	14.337	0.000014	1024.071429
34.2	16.425	24	69.59127648	48.02631579	6.593	0.000007	941.8571429
43.375	25	30.3	73.84162076	57.63688761	16.872	0.000017	992.4705882
36.325	24.025	26	77.93666767	66.13902271	11.403	0.000011	1036.636364
37	24.25	27.3	78.4916841	65.54054054	12.227	0.000012	1018.916667
41	21	26.25	68.9594247	51.2195122	10.358	0.00001	1035.8
38.925	22.2	24.075	70.65680726	57.0327553	11.092	0.000011	1008.363636
41.8	22.85	27.05	70.72402518	54.66507177	12.356	0.000013	950.4615385
41.85	25.85	29.9	76.13428445	61.76821983	15.229	0.000014	1087.785714
41.7	25.2	28.1	74.12162243	60.43165468	15.723	0.000016	982.6875

43	28	29.25	76.22819978	65.11627907	18.759	0.000017	1103.470588
43	23.1	32	73.66734461	53.72093023	14.6	0.000015	973.3333333
37.275	24	25.1	75.6861742	64.38631791	10.821	0.000012	901.75
38.9	23.275	27.1	74.69988375	59.83290488	10.892	0.000011	990.1818182
37.15	20.875	26	73.26458017	56.19111709	8.68	0.00001	868
41.3	22.225	29.05	72.33735103	53.81355932	13.802	0.000014	985.8571429
42	25	28	73.48518972	59.52380952	14.558	0.000018	808.7777778
42.25	23	26.35	69.76190686	54.43786982	13.075	0.000012	1089.583333
31.225	22.85	27	85.85159303	73.17854283	9.706	0.00001	970.6
33	15.3	17.85	63.06192986	46.36363636	4.669	0.000005	933.8
37.1	25	26.25	78.12208621	67.38544474	12.592	0.000014	899.4285714
34.75	25	26.925	82.29915338	71.94244604	11.703	0.000011	1063.909091
35.65	20.75	27	76.1063567	58.20476858	10.883	0.000011	989.3636364
35	26.85	27.25	84.21541038	76.71428571	14.026	0.000015	935.0666667
34.1	23.85	24	78.95814845	69.94134897	10.158	0.00001	1015.8
42	22.85	25.25	68.89954206	54.4047619	12.904	0.000013	992.6153846
40	23	26.1	72.12449526	57.5	12.751	0.000014	910.7857143
45.25	22.05	24	63.69825809	48.72928177	11.489	0.000012	957.4166667
37.05	20	26	72.35618153	53.98110661	9.932	0.000012	827.6666667
39.7	22.125	26.8	72.19032882	55.73047859	12.164	0.000013	935.6923077
29.05	17	25	79.56075313	58.51979346	6.557	0.000007	936.7142857
39.025	23.225	23.85	71.38156974	59.51313261	11.526	0.000013	886.6153846
36	21.8	22.25	72.065461	60.55555556	8.902	0.000009	989.1111111
43	23.35	25.95	68.94388918	54.30232558	13.166	0.000015	877.7333333

Table 9 Data Collection for Dura Variety

Length, mm (a)	Thickness, mm	Width, mm (c)	Sphericity	Aspect Ratio	Fruit Mass, g	Volume, m3	True Density, kg/m3
37.3	19.45	28.125	73.25964745	52.14477212	17.676	0.000017	1039.764706
36.3	18.5	26.2	71.65061513	50.96418733	11.4	0.000012	950
35.8	25.4	26.1	80.27298083	70.94972067	15.302	0.000016	956.375
36.2	20.3	24.15	72.05520266	56.07734807	10.863	0.000012	905.25
34	22	25.4	78.48129991	64.70588235	11.011	0.000013	847
32.5	22.075	26.15	81.75893541	67.92307692	12.858	0.000014	918.4285714
34.75	20.1	23	72.61139134	57.84172662	9.646	0.00001	964.6
33.3	18.325	24.35	73.82749972	55.03003003	9.953	0.000012	829.4166667
33.95	21.2	29	81.09948578	62.44477172	5.771	0.000017	339.4705882
32.125	21.5	24.1	79.47973491	66.92607004	10.317	0.000012	859.75
30.275	24.1	27.3	89.53725902	79.60363336	13.237	0.00002	661.85
31.1	22.2	27	85.25738087	71.38263666	10.209	0.000022	464.0454545
32	25.1	26.05	86.11136975	78.4375	12.02	0.000014	858.5714286
29.1	17.15	25.3	80.02018588	58.9347079	9.038	0.00001	903.8
33.125	21.4	23.05	76.60509281	64.60377358	11.981	0.000013	921.6153846
32.3	21.9	26.2	81.93072297	67.80185759	13.685	0.000015	912.3333333
35.375	25.35	28	82.77789265	71.66077739	12.237	0.000014	874.0714286
29.2	18.425	22.5	78.63359003	63.09931507	6.993	0.000007	999
36.375	24.1	29.3	81.11345237	66.25429553	14.872	0.000017	874.8235294
31.325	22.025	25.2	82.70112794	70.31125299	10.103	0.000011	918.4545455
32	23.1	25.3	82.94894145	72.1875	11.227	0.000011	1020.636364
35.45	20	25.25	73.79375891	56.41748942	19.358	0.00001	1935.8
33.725	20.2	23.075	74.2784879	59.89621942	10.092	0.000011	917.4545455
33.7	20.5	25.05	76.75392554	60.83086053	11.356	0.000013	873.5384615
36.85	23.85	27.9	78.83865395	64.72184532	14.329	0.000014	1023.5
36.7	23.2	26.1	76.60647069	63.21525886	14.723	0.000016	920.1875

38	26	26.25	77.89540162	68.42105263	17.759	0.000017	1044.647059
37.95	21.1	28	74.30287908	55.59947299	13.6	0.000015	906.6666667
32.275	22	24.1	79.84279664	68.16421379	9.821	0.000012	818.4166667
33.75	21.275	26.1	78.70231502	63.03703704	9.892	0.000011	899.2727273
32.125	19.9	24.8	78.19989349	61.94552529	7.68	0.000008	960
36.3	21.225	27.05	75.8112934	58.47107438	12.802	0.000014	914.4285714
37	23	26	75.87509455	62.16216216	13.581	0.000016	848.8125
38.2	21.7	25.35	72.23876687	56.80628272	11.15	0.000012	929.1666667
30.225	21.45	25	83.72944812	70.96774194	7.706	0.00001	770.6
29	14.3	16.95	66.05462754	49.31034483	5.669	0.000007	809.8571429
31.75	23.4	25.1	83.52196562	73.7007874	12.592	0.000014	899.4285714
29.75	23	25.9	87.63640492	77.31092437	10.803	0.000011	982.0909091
30.55	19.75	20.3	75.45364705	64.64811784	9.483	0.000011	862.0909091
30.3	24.85	25.25	88.08477301	82.01320132	13.226	0.000015	881.7333333
29.1	21.85	23.85	85.05854489	75.08591065	9.158	0.00001	915.8
38	20.85	24.2	70.43438778	54.86842105	11.914	0.000013	916.4615385
34.95	21	25.1	75.56712253	60.08583691	11.551	0.000014	825.0714286
39.2	20.05	23.5	67.43262018	51.14795918	10.589	0.000012	882.4166667
32.05	19.85	24	77.40551332	61.93447738	8.932	0.00001	893.2
34.7	20.125	25.8	75.54960798	57.99711816	11.164	0.000013	858.7692308
33.05	19.4	23.4	74.62623875	58.698941	6.457	0.000007	922.4285714
33.025	21.225	22.85	76.32780095	64.26949281	10.626	0.000013	817.3846154
31.4	19.8	21.25	75.28728041	63.05732484	7.202	0.000009	800.2222222
37.95	21.35	24.95	71.78190112	56.25823452	12.466	0.000012	1038.833333

Table 10 Analysis being done using SPSS for Physical Parameter of Loose Fruit

	Variety	N	Mean	Std. Deviation	Std. Error Mean
Length	Tenera	50	38.70900	3.465286	.490065
	Dura	50	33.70850	2.838172	.401378
Thickness	Tenera	50	22.96900	2.686847	.379978
	Dura	50	21.39800	2.218221	.313704
Width	Tenera	50	26.79650	2.444199	.345662
	Dura	50	25.08400	2.172737	.307271
Sphericity	Tenera	50	74.410451	4.9282593	.6969611
	Dura	50	77.984509	5.1952972	.7347260
Aspect_Ratio	Tenera	50	59.588996	7.3671176	1.0418678
	Dura	50	63.806563	7.7508132	1.0961305
Fruit_Mass	Tenera	50	12.29166	2.777718	.392829
	Dura	50	11.32160	2.898356	.409889
True_Density	Tenera	50	954.311643	99.4222066	14.0604233
	Dura	50	901.750737	193.3013087	27.3369332

Table 11 Analysis being done using SPSS for Bulk Density of Loose Fruit

	Variety	N	Mean	Std. Deviation	Std. Error Mean
Bulk_Density	Tenera	10	1091.6145	29.12822	9.21115
	Dura	10	1061.8175	29.06179	9.19015

Table 12 t-test for Dura and Tenera Properties

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Length	Equal variances assumed	2.252	.137	7.894	98	.000	5.000500	.633458	3.743424	6.257576
	Equal variances not assumed			7.894	94.338	.000	5.000500	.633458	3.742814	6.258186
Thickness	Equal variances assumed	.865	.355	3.188	98	.002	1.571000	.492740	.593173	2.548827
	Equal variances not assumed			3.188	94.608	.002	1.571000	.492740	.592734	2.549266
Width	Equal variances assumed	.599	.441	3.703	98	.000	1.712500	.462491	.794702	2.630298
	Equal variances not assumed			3.703	96.672	.000	1.712500	.462491	.794544	2.630456
Sphericity	Equal variances assumed	.206	.651	-3.529	98	.001	-3.5740573	1.0127078	-5.5837430	-1.5643717
	Equal variances not assumed			-3.529	97.728	.001	-3.5740573	1.0127078	-5.5838128	-1.5643019
Aspect_Ratio	Equal variances assumed	.032	.859	-2.789	98	.006	-4.2175670	1.5122799	-7.2186372	-1.2164967
	Equal variances not assumed			-2.789	97.748	.006	-4.2175670	1.5122799	-7.2187338	-1.2164001
Fruit_Mass	Equal variances assumed	.049	.826	1.709	98	.091	.970060	.567736	-.156593	2.096713
	Equal variances not assumed			1.709	97.823	.091	.970060	.567736	-.156618	2.096738
True_Density	Equal variances assumed	.970	.327	1.710	98	.090	52.5609066	30.7409080	-8.4434248	113.5652379
	Equal variances not assumed			1.710	73.230	.092	52.5609066	30.7409080	-8.7023986	113.8242117

Table 13 t-test for bulk density for Dura and Tenera

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Bulk_Density	Equal variances assumed	.119	.734	2.290	18	.034	29.79700	13.01169	2.46045	57.13355
	Equal variances not assumed			2.290	18.000	.034	29.79700	13.01169	2.46044	57.13356



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Table 14 Colour Code for Tenera

Color Code, Hex	Red	Green	Blue
#80271D	128	39	29
#74140F	116	20	15
#7F1E15	127	30	21
#79241D	121	36	29
#7A281C	122	40	28
#791F15	121	31	21
#752D17	117	45	23
#7C2315	124	35	21
#6E1C15	110	28	21
#69110B	105	17	11

Table 15 Colour Code for Dura Variety

Color Code, Hex	Red	Green	Blue
#5B120B	91	18	11
#61120D	97	18	13
#5B1F1B	91	31	27
#5F2114	95	33	20
#611109	97	17	9
#601E16	96	30	22
#5C1D16	92	29	22
#601A0B	96	26	11
#591D0E	89	29	14
#593A33	89	31	20

