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Analysis of Oil Palm Leaf Phyllotaxis towards Development of Models to Determine the Fresh Fruit Bunch (FFB) Maturity Stages, Yield and Site-Specific Harvesting

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ABSTRACT

In order to ensure the optimum quality of palm oil, oil palm fruit needs to be harvested at the optimum maturity to avoid free fatty acid (FFA) accumulation. The high content of FFA not only reduces the quality of palm oil but also increases the refining cost. Optimum maturity based on plantation standard operating procedure (SOP) is determined by identifying the tree with loose fruit on the ground. The matured bunch is further identified based on the colour of the bunch. This paper presents a research work on formulation and validation of mathematical equations to estimate the maturity stages (age in weeks) of fresh fruit bunch (FFB) based on FFB position in oil palm phyllotaxis (spiral leaves arrangement) as an additional feature to confirm the maturity level of oil palm FFB. Regression analysis showed that the proposed method was able to estimate the maturity stages of oil palm FFB with the coefficient of determination $R^2 = 0.9$ and a root mean square error (RMSE) of 1.58 weeks. The FFB yield estimation model and harvesting can be created based on the extracted data using the formula which will help in the planning of harvesting operation. Plantation manager can use this information to generate yield variability map and estimate the appropriate number of workers and machine. Planned harvesting operation can save a significant amount of time in site harvesting operation.

Keywords: Oil palm maturity stages, oil palm harvesting model, oil palm phyllotaxis

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INTRODUCTION

Malaysia is known as the second world largest producer of oil palm after Indonesia followed by Nigeria, Thailand, and Colombia (Ali et al., 2013). Oil palm is the major agriculture product in Malaysia which covers up to 5 million hectares of Malaysia's land (Hazir et al., 2012). High demand for oil palm product has encouraged researchers to study possible ways to increase the productivity of the oil palm yield production (Corley, 2009). Oil palm can produce two types of oil which are palm oil and palm kernel oil. Palm oil is the oil extracted from the flesh of oil palm FFB, whereas palm kernel oil is the oil extracted from the seed of the oil palm fruitlet. Oil palm products such as vegetable oil, cosmetic, pharmaceutical and biofuel are important in our daily life. In order to ensure optimum quality of palm oil, oil palm FFB should be harvested at its optimum maturity to avoid high FFA content (Ishak & Hudzari, 2010; Rajanaidu et al., 1988).

Oil palm FFB harvesting and collecting is a very laborious operation. These operations are carried out within 10 - 12 days' intervals. A common tool used to harvest FFB is using a sickle attached to a bamboo or aluminum pole for oil palm tree higher than 12 m, or a chisel for shorter oil palm tree (Azhar et al., 2012). The first process in harvesting is searching for the ripe FFB. Harvester carries the harvesting tool and moves from one tree to another without prior information on the exact location of the tree that has the ripe bunch. This process can be accelerated if the harvester is equipped with a harvesting map. A harvesting map requires information of the maturity levels of the FFB on each tree. The second process of harvesting operation is to determine the maturity level of the bunch; this process is simply observing the colour of the FFB and the number of loose fruits that fell under the oil palm tree. However, because of the harvesting cycle of every 10 – 12 days on particular site, harvester tends to harvest over-ripe FFB causing lots of loose fruits to fall on the ground. Plantation manager does not have a proper tool to rectify this problem. The FFB needs to be sorted at the mill level by a human expert before processing. Payment deduction will be imposed to the batch of FFB delivered to the mill if the bunch does not meet the maturity standard.

Time-consuming process in searching for matured bunches, tedious harvesting task and sorting process at mill, have encouraged researchers to study method of detecting matured FFB such as on oil palm maturity sensor (Saeed et al., 2012), motorized harvesting tool (Jelani et al., 2008) and integrated harvesting, collecting and transporting machine (Lin, 2011). The result from the research findings could lead to improvement in oil palm plantation productivity, increased machine efficiency, and satisfied economic return. Development of machines should be reliable to agronomic aspect in order to solve the laborious process.

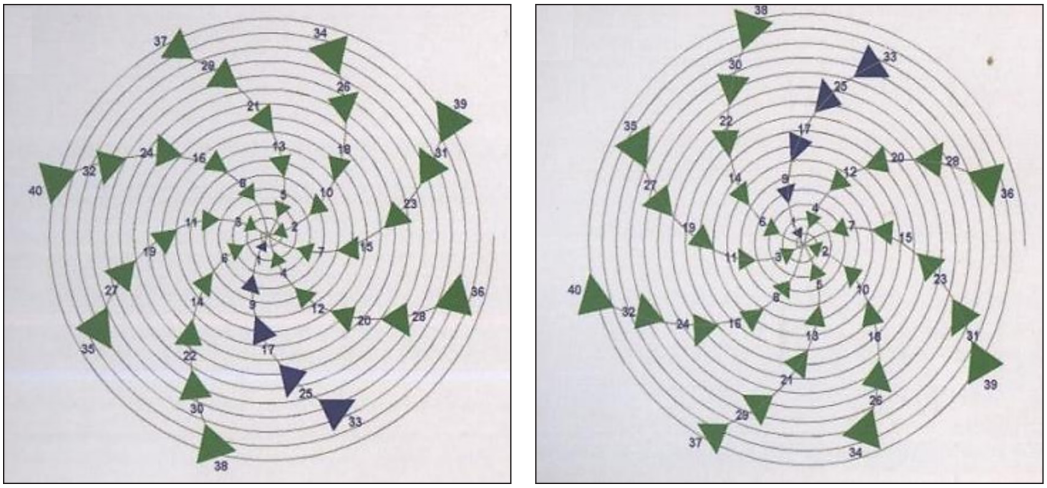
Harvesting a high quality bunch is the ultimate goal of the plantation in order to generate profitable investment out of all input costs for plantation management. Hence, a reliable harvesting support system that can provide sufficient and relevant information needs to be developed to improve harvesting operation. The support system must be able to feed information on the number of available FFB on a particular tree, maturity level of each bunch on a single tree, location of the tree, estimated number of FFB to be harvested at each harvesting cycle, number of workers to be allocated and estimated time to complete harvesting operation.

A common way for researchers to develop a method to determine oil palm FFB maturity stages is by analyzing the FFB colour features. Various image based systems have been developed to determine the maturity levels of FFB (Razali et al., 2011). Determining the maturity stage of oil palm FFB by colour still has some drawbacks due to the variation of biological conditions between individual palms and between geographical areas (Kassim et al., 2012). According to Abdullah et al. (2001), an accurate estimation of oil palm FFB maturity based on red, green and blue (RGB) colour index requires more than 100 samples per class. The growth model and colour recognition system developed by Kassim et al. (2014), was able to sort oil palm FFB into several maturity classes based on RGB and Hue colour space. Junkwon et al. (2009) and Groß et al. (2016) had successfully determined oil palm FFB maturity stages using hyperspectral and multispectral imaging methods. However, these methods are costly and meant for harvested bunch.

Therefore, alternative feature needs to be explored to determine the maturity of oil palm FFB in order to support the decision making based on the colour feature. The additional feature proposed in this research is the formulation and validation of mathematical equations to estimate the maturity stages (age in weeks) of FFB based on FFB position in oil palm phyllotaxis (spiral leaves arrangement). GIS coordinate system is a useful feature to create the real time harvesting map with the actual location of the targeted oil palm tree (Mat et al., 2016).

Oil Palm Phyllotaxy

An oil palm tree normally produces two new leaves per month, but young palm trees (below seven years old) produce three new leaves per month (Corley & Tinker, 2003). An oil palm tree has a phyllotaxy leaf type. There are two types of phyllotaxy spiral arrangements, namely right-handed spiral and left-handed spiral. The difference between the right and left-handed arrangements was the clockwise and counter-clockwise arrangements. There are five spirals and each spiral has eight leaves. Figure 1(a) shows the left-spiral arrangement and Figure 1(b) shows the right-spiral arrangement.



(a) (b)

Figure 1. Graphical representation of oil palm spiral. (a) Left-handed spiral (b) Right-handed spiral (Fairhust, 1998)

The leaves spiral starts with leaf number 1 which is characterised by the feature of having fully opened leaflets. An oil palm FFB can be found in the axil of its leaf and subtends onto the leaf in a lower whirl. The leaf axil has an equal potential to produce flowers in between leaf 17 to 20 depending on the varieties (Corley & Tinker, 2003). The development of FFB to ripeness takes six months from the anthesis stage. Oil palm FFB is supported by a leaf below it during the growth period. The leaf that subtends by the oil palm FFB is cut together with the bunch during harvesting process.

Matured oil palm FFB can be determined with the presence of loose fruits. Loose fruits scattered on the ground is a sign of a ripened bunch. As low as one detached loose fruit is enough to decide that the bunch is matured (Kassim et al., 2014; Ghani et al., 2004). Once the oil palm bunch is matured, the number of loose fruits detaching from the bunch will increase. At the same time, FFA content will gradually increase in the fruitlets. An under-ripe bunch appears blackish purple whereas a ripe bunch appears reddish orange (Ismail & Razali, 2012).

This research introduces FFB maturity determination by identifying FFB's position in oil palm phyllotaxis. The harvesting model formula is derived using the rate of leaf production per month, duration of FFB to mature, and position of FFB inflorescences during anthesis. The actual harvesting data were compared with the predicted harvesting date using this formula. Based on this information, FFB yield model and harvesting plan route model can be developed.

Harvesting matured bunches involves cutting the bunch from the tree and allowing it to fall to the ground by gravity. An overripe bunch will release many fruitlets due to the impact when the bunch falls to the ground. Those loose fruits which have a high oil content are often left uncollected which contributes to the losses in Malaysia oil palm industries. It is clearly important to harvest oil palm FFB at its optimum ripeness to avoid this problem.

MATERIALS AND METHODS

Data collection process was performed at Ladang 15 (2.979524 latitudes, 101.728368 longitudes), Universiti Putra Malaysia, Serdang, Selangor. Thirthy oil palm trees aged 9 years old were monitored. The location of each monitored tree was taken using Trimble JUNO handheld GPS unit for mapping purposes. Each available FFB on the tree was recorded together with its position in the leaf spiral. This process requires a skillful worker to identify the position of the leaf in the spiral.

Oil Palm Tree Leaf Spiral Arrangement

Figure 2 shows an oil palm leaf spiral with its position number. This 3D oil palm tree was created by using cloud point data acquired by using Terrestrial Lidar Scanner (TLS). The first step in the process of labelling the leaf position is identifying the position of the first leaf (the first fully-opened leaf) around the centre of the leaves spiral. A non-fully opened leaf is considered as leaf number 0 (also known as spear leaf). The remaining leaf number is identified using the graphical representation of oil palm leaf spirals as shown in Figure 1. Figure 3 shows the oil palm leaf spiral number arrangement starts with center spear leaf.

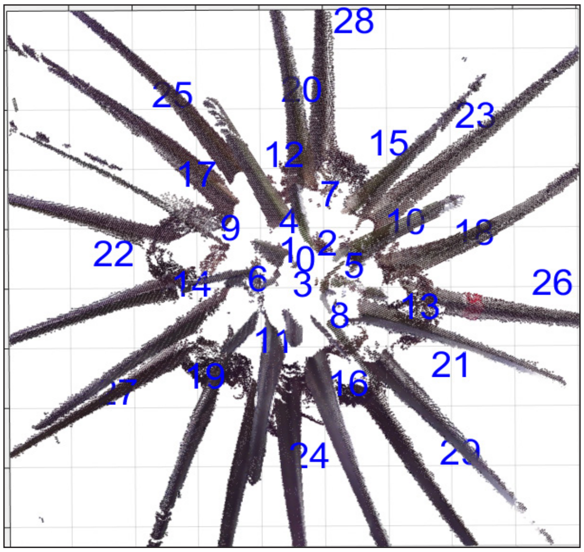


Figure 2. Oil palm leaf spiral with position number

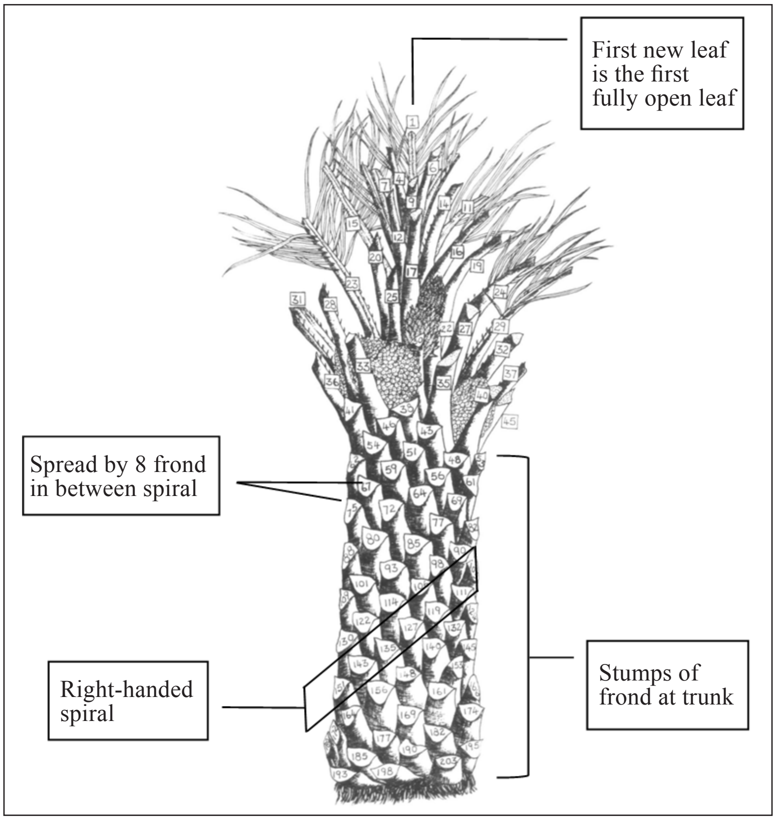


Figure 3. Oil palm leaf number starts with centre spear leaf (Thomas et al., 1969)

Oil Palm FFB Data Collection

Each oil palm FFB observed for this research was given a specific identification name (ID). Figure 4 shows an example of the ID tag for a particular sample bunch. Tree identification, *P2,* shown in the figure 4 indicates that it was the second tree from the sample. FFB identification, *A,* shows the first sample of oil palm FFB for a particular tree. *L23* indicates that the bunch was located at leaf number 23 in the leaf spiral. Lastly, date of data acquired (DODA) was also recorded.

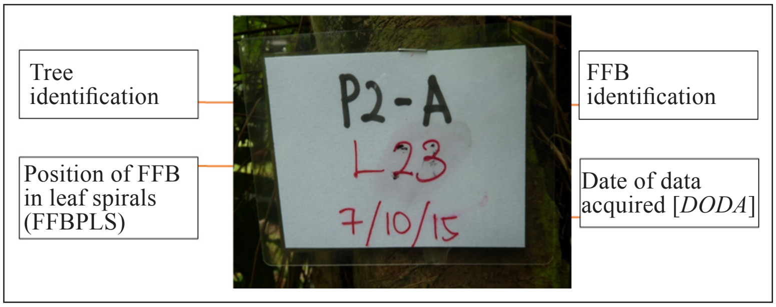


Figure 4. Example of oil palm FFB sample tagging

Tagged FFB sample was monitored until they were harvested based on the harvester judgment. The cycle of harvesting for this research site was once a week. Farmers identify the presence of matured bunch by observing the loose fruits on the ground. This was the standard operating procedure (SOP) that is used by most of the oil palm plantations in Malaysia during the harvesting operation. Figure 5 shows the loose fruits indicating mature bunch. The date of harvest by farmers of each FFB sample was recorded as actual harvesting date.

Figure 5. Loose fruits indicating mature bunch

Formulation of FFB Maturity Model

Once the positions of all the leaves have been identified, the information on the position of FFB in leaf spirals can be obtained. Based on the biological information of the oil palm tree (rate of leaf production per month, duration of FFB development to mature, and position of FFB at anthesis), together with the position of FFB in leaf spirals, a formula is derived to calculate the estimated oil palm FFB's age in weeks. Equation 1 is the derived formula to estimate the age of FFB in term of the weeks.

$$W_{HM} = 4\left[\frac{FFBPLS - FFBALS}{RLP}\right] \text{------------------> Equation 1}$$

where
W_{HM} = Harvesting model estimated age of FFB (weeks)
$FFBPLS$ = FFB position in leaf spirals (x^{th} leaf)
$FFBALS$ = FFB at anthesis in leaf spirals (20^{th} leaf)
RLP = Rate of leaf production (2 leaves per month)
4 = Constant (number of weeks in a month)

The rate of leaf production per month (*RLP*) was taken as two leaves per month for mature palm since the age of oil palm tree is above seven years old. The position of FFB in leaf spirals can be determined using the graphical representation of the oil palm leaf spirals (Figure 1) as a guide. In order to determine the age of FFB (W_{HM}*), the position of FFB in leaf spiral (FFBPLS)* was subtracted with a constant value 20 *(FFBALS, 20th leaf)* which is the position of inflorescences at anthesis in leaf spiral. The result was divided by the rate of leaf production per month *(RLP),* which is two leaves, per month and multiplied by 4 (number of weeks per month).

Based on the information of the FFB development from anthesis to the matured stage (*DOFFB*), date of FFB data acquisition (*DODA*) and estimated age of FFB (W_{HM}), Equation 2 was derived to calculate the estimated harvesting date for oil palm FFB (DOH_{HM}).

$DOH_{HM} = DODA + [DOFBB - (W_{HM} \times 7)]$ ------------------> Equation 2

where
DOH_{HM} = Harvesting model date of Harvest (DD/MM/YYYY)
DODA = Date of Data Acquired (DD/MM/YYYY)
DOFBB = Days of FFB Development (6 months = 180 days)
W_{HM} = Predicted age of FFB (weeks)
($W_{HM} \times 7$) = Predicted age of FFB (days)

The estimated age of FFB (W_{HM}) obtained from Equation 1 was substituted into Equation 2. The duration of FFB development *(DOFFB)* is six months, which is 180 days. *DODA* is the date of data acquired for each oil palm FFB sample. The date of harvest *(DOH_{HM})* can be calculated by adding *DODA* with the days left to be harvested, *[DOFFB-($W_{HM} \times 7$)*] which is the subtraction of the duration of FFB development (180 Days) with an estimated age of FFB (Days).

RESULTS AND DISCUSSION

Table 1 presents a sample of the calculated data for tree ID P4, for oil palm FFB A, B, and C. The information in Table 1 is divided into two sections, in which one is the estimated data based on the proposed harvesting model method and the other one is the actual in-field data.

The estimated harvesting date based on the proposed harvesting model method consists of the position of FFB in leaf spiral, estimated age of FFB in weeks (W_{HM}), estimated harvesting date (DOH_{HM}). Below is an example of the calculation to estimate the harvesting date of FFB P4-A using equations 1 and 2.

$W_{HM} = 4[(FFBPLS - FFBALS)/RLP]$ Equation 1

W_{HM} = 4 week/month [(25 leaf - 20 leaf) / (2 leaf/month)]

W_{HM} = 10 week

DOH_{HM} $= DODA + [DOFBB - (W_{HM} \times 7)]$ Equation 2

DOH_{HM} = 9 0ct 2015 + [180 day - (10week × 7 day/week)]

DOH_{HM} = 9 0ct 2015 + [110 day]

= 27 January 2016

Estimated harvesting week left to be harvested is calculated by subtracting DOH_{HM} with DODA and dividing by 7 days per week. For example, the FFB sample of P4-A; Subtraction of 27-Jan-2016 and 9-Oct-2015 is equal to 110 days. 110 days is then divided by 7 days per week to equal 15.7 weeks to harvest. In-field data consist of actual in-field harvesting date (DOH_{IF}) and the actual age of harvesting in weeks is calculated as the subtraction of DOH_{IF} from DODA and dividing by 7 days per week. For P4-A sample actual age of harvest (week) is calculated as subtraction of 29-Jan-2016 from 9-Oct-2015 equal to 102 days. 102 days is then divided by 7 days per week to equal 16 weeks.

The estimated week left to be harvested was compared with the actual in-field week left to be harvested. Figure 6 shows a scatter plot of the data; this plot shows that the proposed method was able to predict the harvesting week of oil palm FFB sample with a coefficient of determination, R^2=0.90, and root mean square error, RMSE=1.58 weeks. Therefore the proposed method to determine maturity stages of oil palm FFB based on position in leaf spiral can be used to estimate harvesting week of oil palm FFB.

Single Tree Data Analysis

Figure 7 shows the scatter plot for a single tree. Oil palm tree sample ID P4, P11, P13, P15, P16, and P18 was chosen for this analysis because it has more than 4 bunches per tree during the date of data acquisition. The result shows the value of the coefficient of determination R^2=0.94, 0.98, 0.97, 0.88 and 0.93 respectively. The result shows that the proposed method was able to estimate the maturity of oil palm FFB.

FFB Yield Data

From the estimation of harvesting week based on the proposed method, FFB yield model can be developed to determine the number of the readily harvested mature bunch at every harvesting schedule (1 week Interval). Figure 8 shows a bar chart number of mature FFB. The data shows a high number of mature bunches in December 2015 and January 2016. Based on this information a yield variability map can be created. Such yield model will be useful for plantation or farmers to plan their workers and harvesting machine for harvesting operation. Further investigation on the course of yield variability in relation to crop management and environmental factors can be carried out. For a cycle of FFB data collection, the result of the analysis is valid for six months considering the development of FFB from anthesis to mature stage is six months.

Table 1
Recorded and calculated data using the leaves spiral equation

Tree FFB	Date of data acquired, *DODA*	Position of FFB in leaf spiral	Estimated data based on the proposed models			Actual data	
			Estimated age of FFB in weeks, W_{HM}	Estimated harvesting date, DOH_{HM}	Estimated week left to be harvested $\frac{DOH_{HM} - DODA}{7\ \text{day/week}}$	Actual In-filed harvesting date, DOH_{IF}	Actual Week left to be harvested $\frac{DOH_{IF} - DODA}{7\ \text{day/week}}$
P4-A	9-Oct-15	25	10	27-Jan-16	15.7	29-Jan-16	16
P4-B	9-Oct-15	29	18	2-Dec-15	7.7	4-Dec-15	8
P4-C	9-Oct-15	27	14	30-Dec-15	11.7	30-Dec-15	11.7

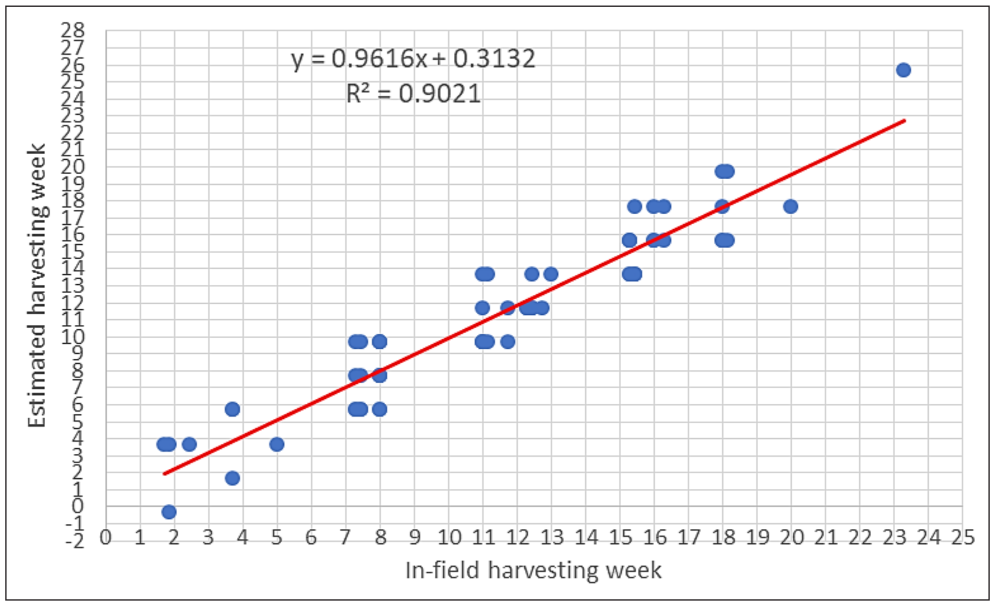


Figure 6. Scatter plots of in-field and estimated harvesting week of oil palm FFB

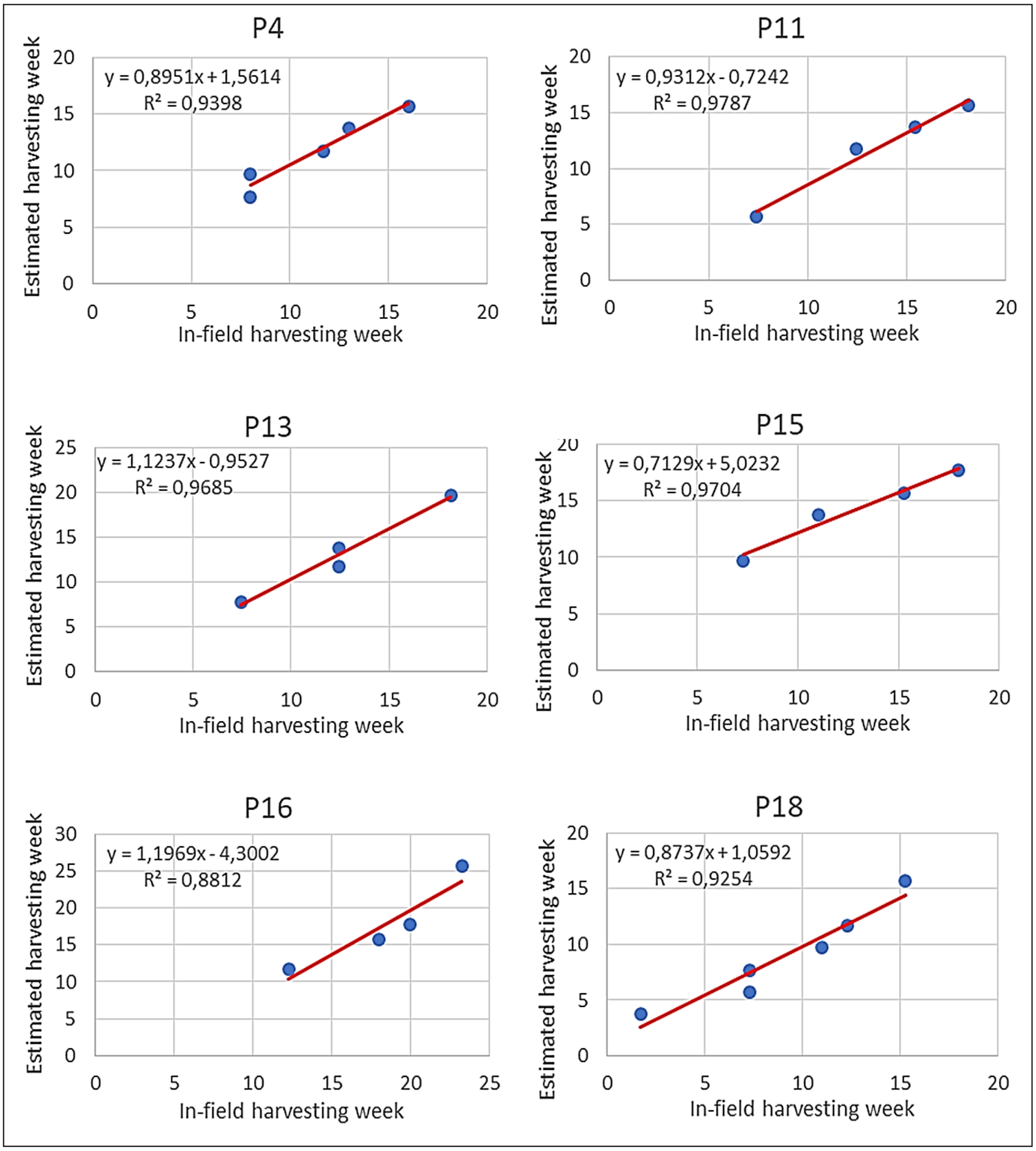


Figure 7. Scatter plots of in-field and estimated harvesting weeks for single tree analysis

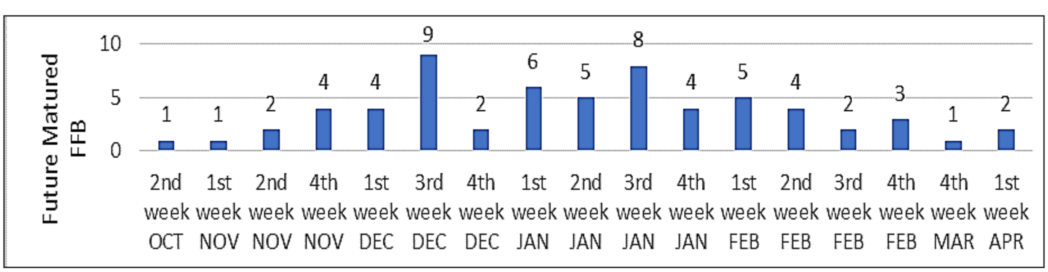


Figure 8. Expected number of matured between October 2015 to April 2016

FFB Harvesting Map and Route

A harvesting route provides information on the tree with mature bunches based on the collected data and GPS coordinate. Figure 9(a) shows the proposed harvesting route based on the information of specific trees with mature bunches; whereas Figure 9(b) shows the typical/standard harvesting pattern without information of trees with mature bunches. Typically, a harvester will stop at each tree to assess the presence of mature bunches. A planned harvesting route is clearly the better option because harvester only needs to stop at the targeted tree, hence saving time and energy during the harvesting operation.

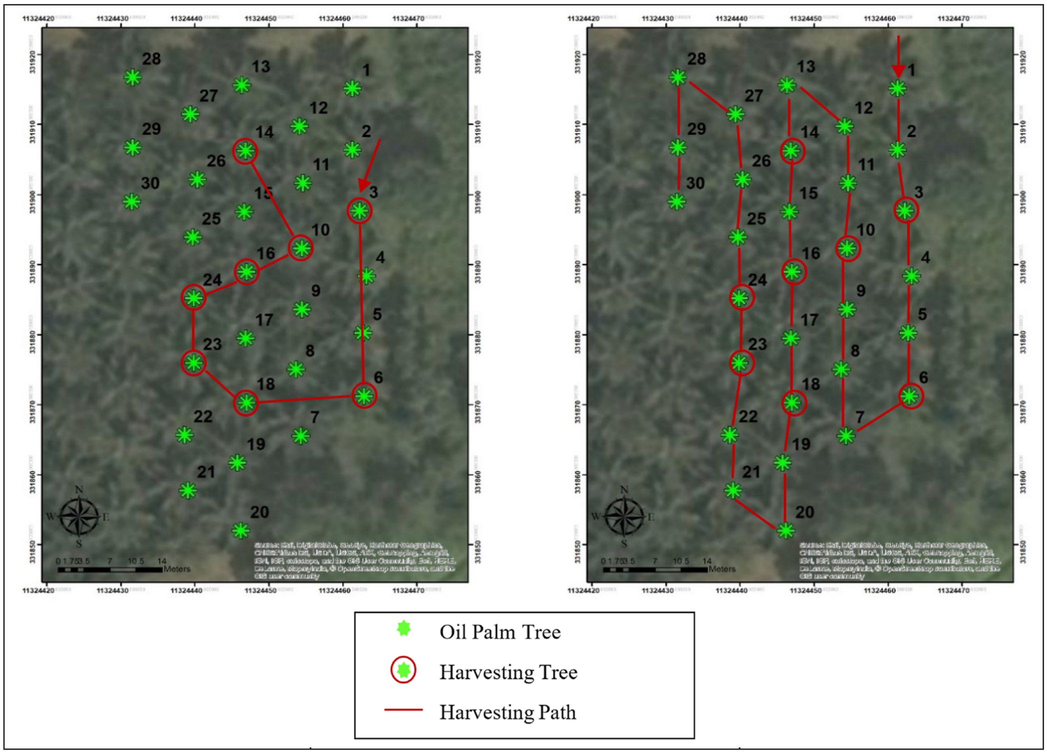


Figure 9. Harvesting plan route for 3rd week of January

CONCLUSION

This paper proposes and describes a new method of determining maturity stages of oil palm FFB based on its position in leaf spiral using harvesting model equation. The coefficient of determination of the proposed method is R^2=0.9 and RMSE = 1.58 weeks. FFB yield model and harvesting route can be made by combining the result from the harvesting model and the GPS coordinate of the oil palm tree. Planned harvesting route is clearly the better option to save time and energy during the harvesting operation. Farmers only need to stop at the targeted oil palm tree rather than go through all of the trees in the field. In future studies, the data collection process for this research can be improved by using current technology. The technology of rapid imaging, 360 imaging, and 3D point cloud can be used to identify the position of the FFB in leaf spiral rather than manual identification used in this research. Further improvement can be done to save time on data collection process and to be cover a larger area of oil palm field.

Harvesting route with the actual geographical coordinate of the oil palm tree could lead to the robotic application in the oil palm industry. The robotic application is useful for data collection such as bunch counting, tree monitoring, and can determine the location of oil palm tree containing matured FFB. This technology and information on oil palm site is an introduction to the futuristic autonomous vehicle and operation in oil palm industry.

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