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Original Research Article

Conceptual Development of Automated Harvester for Tall Oil Palm Tree

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Abstract: Innovation and invention in field mechanization for oil palm sector has created a variety of advancement in technology. The change in oil palm operation to mechanization will overcome the problem of labour shortage occurrence in oil palm sector. The problem occurs in harvesting tall oil palm is the height of oil palm that causes difficulty to cut the fresh fruit bunch by using manual labour. Moreover, the use of automated harvester also will make the harvesting operation easier without the requirement of skilled labour and ensuring labour safety. The automated harvester has advantages and disadvantages that need to be improved in meeting the oil palm requirement. This study overviews the mechanization that are used in harvesting tall oil palm. This research project has resulted in the development of high technology mechanization based on previously developed machine for harvesting fresh fruit bunches (FFB) at 10 meter and above of oil palm age tress. However, the previous developed machines cannot be accepted in the current and widely practiced Industrial revolution 4.0 (IR4.0). Mechanization approach makes harvesting tall oil palm a reality to overcome the problem that normally occur in oil palm sector due to height of oil palm.

Keywords: Dimension; harvesting; labour shortage; mechanization; tall oil palm

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1. Introduction

Malaysia is the one of the world's largest producers and exporters of oil palm after Indonesia. According to Kamil *et al.* (2017), palm oil in Malaysia is mostly exported to other countries such as India, China, European Union, Pakistan, Egypt and Bangladesh. In 2015, 25.37 tonnes of oil palm products were exported Malaysia to other countries (MPOB, 2016). Milling is a crucial process to extract the crude palm oil from the fruit mesocarp. It also involves the initial detachment of the individual fruit from its bunch. The milling process starts with the bunch reception, and continues with sterilization, threshing, digestion, pressing, clarification and purification. Initially, the FFB including the loose fruits are fed into the sterilizer cages through the hopper. Good management in oil palm plantation, such as in detecting unhealthy plants, fertilization plan, processing plan and irrigation management, is very important as Malaysia is the largest producer (Carolita *et al*., 2015). Therefore, harvesting and collection of oil palm requires a skill to cut the fresh fruit bunch from bunch stalk and for 3D perception of this job, dangerous, dirty and difficult that resulted in minimal involvement of the locals and increased avenues for foreign workers to work in plantation sector (Ismail, 2013). The characteristic of oil palm usually can grow up to 15 m high depends on the varieties or species of the oil palm. The height may cause harvesting problem and difficulties in manual harvesting requiring labor intensity and skillful labor. This situation has also affected the supply of palm oil in the domestic as well as world markets (Ismail, 2013).

There are around 60% of the total work operation in harvesting fresh fruit bunches (FFB) and 50% of total workers in the production cost (Sowat *et al*., 2018). The harvesting of tall oil palm tends to be difficult due to height of oil palm trees and the space of frond within fruit bunches that cannot be seen by the harvesters beneath and far from the focus point level of the eyes. Furthermore, for tall palms (greater than 2.5 metres height), a sickle attached to a long pole is used. The sharpness, shape and profile of the sickle contribute to the effectiveness of the cutting operations through pulling the sickle downwards. Energy for cutting comes mainly from the harvester testing on his endurance and it can be reduced by the tool sharpness and self-skill such as lifting, and handling the long pole, and cutting the fronds as well as fruit bunches. Hence, this would result in low productivity of the skillful labor and harvesting can be up to 2:00 pm in the evening (Jelani, 1997; Jelani *et al*., 2008). Sharence *et al*. (2018) stated that to alleviate issues surrounding the human workforce such as labor shortage and injuries, the proposed climbing robots can be deployed to replace these workers. In addition, climbing robots are smaller than harvesting machines and therefore they are not plagued by problems associated with operating huge machinery in the farm.

The study on harvesting cutter used in the mechanical harvesting was conducted at the Malaysian Palm Oil Board (MPOB). Oil palm industry Malaysia was entrusted serve by MPOB and become one of the most premier government agencies under the Ministry of Plantation Industries and Commodities The roles of MPOB are to promote and develop policies, objective and priorities that are created by national government as well as to make sure the oil palm industry is well managed and controlled by the national government. The effective service and international focus in oil palm industry that have more than 20 years was responsible by MPOB to provide best services in oil palm industry (Palm Oil World, 2019).

Based on the main geometric concept of common normal between two lines, Denavit and Hartenberg (1995) introduced a conventional technique for selecting joints of reference in robotics application that used homogeneous transformation and represented minimally as product of four basic transformations. Denavit and Hartenberg (D-H) representation has become the standard way of representing robots and modeling their motions (Denavit and Hartenberg, 1995). The method begins with a systematic approach in assigning and labeling an orthonormal (x, y, z) coordinate system to each robot joint. It is then possible to relate one joint to the next and ultimately to assemble a complete representation of a robot's geometry. D-H convention was mainly implemented in robot manipulators, which consist of an open kinematic chain in which each joint contains one DOF with either revolute or prismatic joint. The transformation was described by the following four parameters known as D-H parameters, which are a is length, α is twist, d is twist and θ is angle.

Bouketir (1999) has developed a vision-based interface for a three degree of freedom (DOF) agricultural robot that involved the D-H approach. Experiments were carried out for the robot to grab the target, which was a red fruit bunches with the help of vision (Charge Couple Device camera) and back to the home position. While Razali (2003) has developed the system able to retrieve real time dynamic video scene and from there the three coordinate axes of object target and generated using mouse click action. The coordinates were calculated using triangulation principle based on the video scene of two different locations of cameras. These 3-axis coordinates were measured from the Cartesian robot coordinate that was taken as reference point to calculate a mathematical model for robot simulation and kinematics. The workspace in the simulation software was calibrated to be the same with real robot workspace.

2. Materials and Methods

2.1 Location of Study Area

The study and data collection were conducted on harvesting cutter available at Malaysian Palm Oil Board (MPOB), Bangi.

This study utilized a descriptive analysis approach. The data has been collected, summarized and compared in the simplest way. Qualitative method was used for the case study in measurement, simple calculation and dimension method.

2.2 Parameters of Mechanization

The dimension of the object is required to make a topological measurement size of the object in covering the properties and coordinate to specify the point of the object. There are two types of dimensions such as rectangle in two-dimensional or cube in three-dimensional. The dimension of an object also called as “dimensionality”, was required to study and use in calculation because it provides the parametrization for the conceptual or visual complexity (Eric, 2017).

The comparison of several types of tractors or harvesters used in harvesting tall oil palm based on operated mechanization were conducted in this study: (1) track, (2) wheel, (3) half-track. The advantages and disadvantages were evaluated on which mechanization brings more benefit when operated in the field. The findings from comparison and evaluation of mechanization will be used for future benefits. Economic analysis was conducted by calculating the cost mechanization usage in harvesting oil palm. It included the following factors: (1) machine price; (2) economic life; (3) productivity; (4) total cost; (5) effective field capacity.

3. Results and Discussions

3.1 Parameter of Machines

Figure 1 shows the dimension of half-track mechanization from the side view of the dimension: (a) driver seat, (b) hydraulic power steering, (c) hydraulic oil tank, (d) bucket, (e) stabilizer, (f) hydraulic telescopic boom, (g) vertical telescopic boom, (h) claw cutter; (i) grapple. The important parts use for harvesting process are the hydraulic telescopic boom, claw cutter, grapple and bucket. The function of hydraulic telescopic boom is used to extend the boom to achieve suitable length to cut the FFB. Claw cutter is used to cut the FFB from the stalk and to cut the frond of the oil palm. The grapple is used to hold the oil palm fruit bunch after the cutting process and transfer of FFB to the bucket. The use of grapple is important to avoid the damage of FFB due to fall from the high elevation to the ground and to preserve the quality of the FFB. The bucket is used as a storage of FFB throughout harvesting and collecting of FFB. The track system in the movement of machine signifies the difference from this half-track mechanization to track and wheel type.

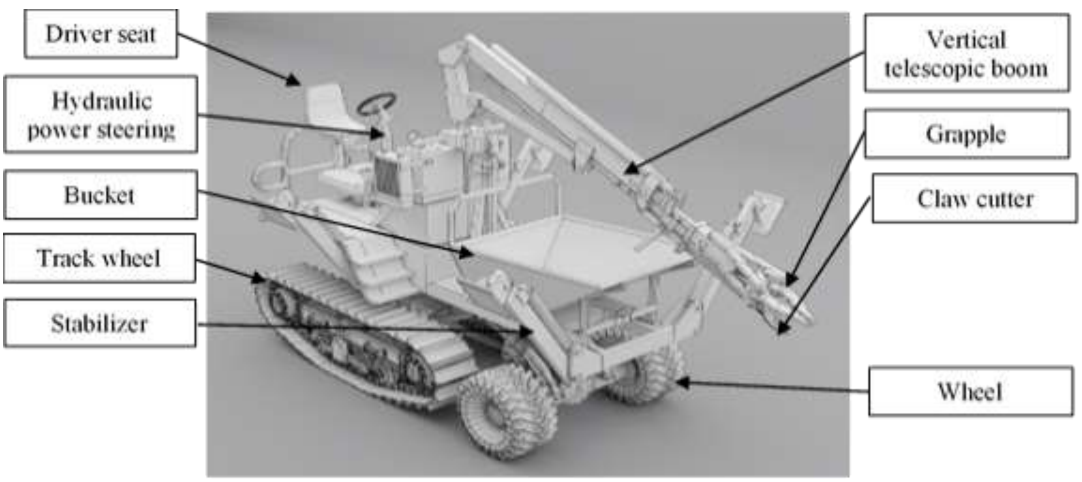

Figure 1. Side view dimension for half-track mechanization.

3.2 Motion Study for Harvesting Activities

Table 1 shows that the track type mechanization carried out the longest time to carry out harvesting activities in 112 sec from reaching the bunch, cutting, reacting and bringing FBB to bin and moving the machine to the next oil palm tree and resume its cutting activities. The wheel type contributed to moderate time taken to carry out complete cycle of harvesting activities in 103 sec. The half-track type shows the least time taken to carry out harvesting activities in 98 sec. This shows that the track type has poor performance in harvesting oil palm that need higher time to complete one cycle. Half-track type shows the best performance in harvesting process among the mechanization available in MPOB.

Table 1. Average time taken to carry out harvesting activities.

Movement/activity	Average time taken for track type (sec)	Average time taken wheel type (sec)	Average time taken half-track type (sec)
Telescopic boom extends until reaching the bunch	12	8	8
Cutting process	34	35	34
Telescopic booms react and bringing FFB to bin	28	26	26
Machine move to the next palm and resume its cutting activities	38	34	30
Total	112	103	98

Table 2 shows that track type mechanization resulted to slow speed of movement of machine to the field with the maximum average speed of 10 km/h and 3 km/h to complete one cycle of harvesting process before resuming to the next. Wheel type exhibited moderate speed of movement of machine to the field at 15 km/h maximum speed and 5 km/h to complete one cycle of harvesting process. The half-track type the best performance by ranking as the highest speed of movement of machine to the field. This shows that track type has the poorest performance in speed of movement mechanization because of the type of movement that used is track system. Average speed of mechanization moving from one palm tree to another affected the productivity of the mechanization when used in the field. However, the wheel type shows better performance than track type, which moved to the field with speed higher than track type. Integration of track type and wheel type mechanization would bring more efficiency in speed travel when used in the field in the form of half-track type. Speed of movement is important to make sure the mechanization is suitable with the topography of the oil palm field interacting with the mode of movement used that impacted the productivity of operation.

Table 2. Speed of movement of machine to the field.

Movement/activity	Average speed for track type (km/h)	Average speed wheel type (km/h)	Average speed half-track type (km/h)
Maximum speed	10	15	20
Minimum speed	5	10	15
Machine move to the next palm and resume its cutting activities	3	5	8–10

3.3 Economic Analysis of Mechanization Types Used in FBB Harvesting

Table 3. Economic analysis of mechanization types used in FFB harvesting.

Particular	Track type system	Wheel type system	Half-track system
Machine price	RM 140 000	RM 160 000	RM 180 00
Economic life	6 years	6 years	6 years
Productivity	250 FFB / 6 tonnes days	300 FFB / 8 tonnes days	350 FFB / 10 tonnes days
Labour cost	(RM 0.24 x 250 FFB) = RM 60 days	(RM 0.24 x 300 FFB) = RM 72 days	(RM 0.24 x 350 FFB) = RM 84 days
Working days	25	25	25
Fuel consumption	(18 l/day x RM 1.80) = RM 32.40	(15 l/day x RM 1.80) = RM 27.00	(17 l/day x RM 1.80) = RM 30.60
Lubricants (15% from fuel cost)	RM 4.86	RM 4.05	RM 4.59
Repair and maintenance cost	RM 60	RM 60	RM 60
Total cost	RM 277.26	RM 231.05	RM 255.19

Table 3 shows that the track type mechanization totaled up to the highest cost of harvesting. The wheel type has lowest total cost of harvesting activities and followed by half-track type shows high total cost of harvesting, but lower than track type. This shows that track type has higher total cost because the price of machine is higher because of track system usage. The wheel type has moderate total cost because of wheel system usage and will gain higher productivity based on FFB output. However, in meeting the objective of the study in solving the labour shortage and increase in productivity, half-track system shows the best productivity of 350 FFB/10 tonnes collected in 25 given days. With the half-track system, there shall be no more issues on labour shortage and low productivity in oil palm harvesting and collection.

3.4 D-H Parameters Representation of Harvester

The transformation between two successive joints was written by substituting the D-H parameters from Table 4 into the *A* matrix. The θ and d were the joint variables for revolute joints and prismatic joints, respectively with $C1$ as $\cos\theta 1$ and $S1$ as $\sin\theta 1$ designation.

Table 4. D-H parameters representation of harvester.

Joint	θ (Link angle)	*D* (Link Offset)	*a* (Link Joint)	α(Link Twist)
1(z0-z1)	$\theta 1$	0	0	90
2(z1-z2)	0	$d2$	$a1$	90
3(z2-z3)	$\theta 3$	0	$a2$	90
4(z3-z4)	$\theta 4$	0	0	0
5(z4-z5)	0	$d5$	0	0

Figure 7 show the image and schematic diagram of the harvester manipulator used to cut and harvest the oil palm FFB that currently located at MOPB, Bangi Lama, Selangor. Helena and Wan Ishak (2010) mentioned that the harvester has five DOF, where the first joint 1 was between link 0 (the fixed base) and link 1($z0 - z1$), joint 2($z1 - z2$) between link1 and 2, and so on.

Figure 2. Image and schematic diagram of the harvester manipulator for tall oil palm tress.

Wan Ishak *et al*. (2011) mentioned that present work of agricultural robotic studies in Universiti Putra Malaysia could be considered as initial research in developing of an intelligent robot eye for agriculture harvester robot. By using the concept of non- contact measurement like video-grammetry to detect the object and measure it in 3D coordinate, the development of the robot eye was explored (Razali, 2003). For further research, the robot eye must use the RGB camera, which will be automatically recognizing the mature object by pattern or by color or wave character manipulation without human intervention by clicking the target image. By using the concept of non-contact measurement like video-grammetry for the measurement and detection of coordinate of the target object, the developments of the "robot eye" were explored in agriculture sector. Camera vision recognizes the fruit maturity through forced learning concept. This concept means that the matured fruit to be harvested will be attached at placement on harvester arm if it is done manually. However, camera vision applied the current value of hue digital image of oil palm outdoor and on the field. The programmed system compares the hue value between this trained or dummy output, which can be represented as the benchmark for the input of targeted maturity fruit in reality. In outdoor condition, the vision system will be influenced by illumination changes by sunlight, temperature of environment and humidity on surface target color itself. After the vision system recognized the matured fruit, the system controller proceeds and performed the kinematic calculation for transforming the movement harvester arm automatically through auto pilot concept that had been done by Jayaselan and Wan Ismail (2010). The user shall be assisted by the arm harvester during initial fruit recognition, then when the fruit is recognized through the vision system, then this auto pilot activation took place for machine operation until the harvester automated with gripping and cutting process. This pilot operation includes loading process of fruit into the bin. SCADA system and Arduino components were integrated into the automation part. ERDAS software of GIS were used to retract the information of targeted for mapping process system. The concept of this integration system between D-H conversions, videogrammetry, and outdoor vision recognition were required for development of tall oil palm trees harvester.

4. Conclusion

There is no mechanization for harvesting has been applied on the field, except the use of motorized cutter for oil palm trees less than five meters height. However, other sectors in the oil palm industry have utilized mechanization in the processing of the output of oil palm production. Various technologies have been developed by MPOB as well as its contribution to the industry from oil palm harvesting to production of the FFB until the end process to the mill. The importance of producing machine to suit the terrains on Malaysian land is the major limitation for designer to develop appropriate design to overcome the problem that normally occur in oil palm sector due to mechanization usage. Strategic plan is crucial to choose the suitable mechanization with the good specification of mechanization, well-planned dimension or design to fulfil the requirements for mechanization to promote easy access and user-friendly to reduce labour shortage and encourage more skilled workers to be involved in the well paid 3D job (i.e. dangerous, dirty and difficult) of the oil palm sector The employed workers or labours are required to undergo training to learn the mechanism of the mechanization type and handling the machine safely and efficiently during harvesting and collection of FFB.

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