

## TREND IN THE DEVELOPMENT OF OIL PALM FRUIT HARVESTING TECHNOLOGIES IN MALAYSIA

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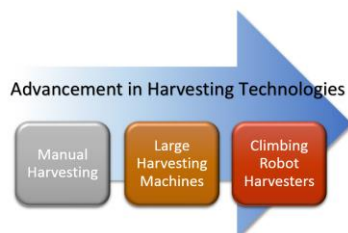
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### Graphical abstract



### Abstract

Harvesting oil palm fresh fruit bunches (FFB) on tall oil palm trees is a laborious and hazardous task. Lately, with the escalating problem of labor shortage, the exigent demand to mechanize the harvesting task cannot be overlooked. Over the years, many harvesting methods and technologies have been used and developed to increase the harvesting productivity. This paper reviews the conventional manual harvesting using manual labor, mechanization of harvesting task using harvesting machines as well as research on climbing robots for harvesting FFB in Malaysia. In essence, it provides an overview of the trend in the development of harvesting technologies in Malaysia. Realizing the potential of climbing robots for harvesting, the morphological structures and physical characteristics of oil palm trunks in its natural surroundings are examined closely to identify the challenges in the climbing and harvesting processes. Next, a set of design criteria is introduced to overcome those challenges. In addition, several mechanisms are proposed which play integral parts in enhancing the climbing and harvesting tasks.

**Keywords:** Oil palms fresh fruit bunches, manual harvesting, harvesting machines, tree climbing robots, mechanization in harvesting

### Abstrak

Penuaian buah tandan segar kelapa sawit (FFB) pada pokok kelapa sawit yang tinggi merupakan satu tugas yang berat dan berbahaya. Kebelakangan ini, dengan masalah kekurangan buruh yang semakin meruncing, keperluan untuk memekanisasikan tugas penuaian tidak boleh diabaikan. Selama ini, banyak kaedah penuaian dan teknologi telah digunakan dan dibangunkan untuk meningkatkan produktiviti penuaian. Artikel ini mengkaji kaedah penuaian konvensional menggunakan buruh, penggunaan jentera penuaian serta penyelidikan robot pemanjat sebagai penuai di Malaysia. Pada dasarnya, artikel ini memberikan gambaran corak keseluruhan dalam pembangunan teknologi penuai di Malaysia. Menyedari potensi robot pemanjat untuk penuaian, struktur morfologi dan ciri-ciri fizikal batang kelapa sawit di dalam persekitaran semulajadi diperiksa dengan teliti untuk mengenal pasti cabaran-cabaran dalam proses pemanjat dan menuai. Seterusnya, satu set kriteria rekabentuk diperkenalkan untuk mengatasi cabaran-cabaran tersebut. Di samping itu, beberapa mekanisme turut dicadangkan yang memainkan peranan penting dalam meningkatkan prestasi pemanjatan dan penuaian.

**Kata kunci:** Buah kelapa sawit segar, penuaian manual, jentera penuai, robot pemanjat pokok, mekanisasi penuaian

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## 1.0 INTRODUCTION

Palm oil is a very important commodity in Malaysia. Globally, in 2015, Malaysia exported approximately 25.37 million tonnes of palm oil products [1]. In 2016, Malaysia produced approximately 30% of the total palm oil in the world [2]. In the same year, the oil palm planted area reached 5.74 million hectares, an increase of 1.7% from the previous year [3]. The oil palm industry has progressed tremendously since 1960, where originally the planted area was only 600,000 hectares [4]. Harvesting is a difficult process since mature palms can grow as tall as 18-20 m. On a mature palm, the crown may have between 30 to 50 leaves [5]. Throughout the productive lifetime of 25-30 years of each tree, its oil yield is at the most productive stage from 9-18 years before gradually declining from there onwards [6]. In total, the oil palm can remain productive up to the age of 32 years [7]. In order to improve Malaysia's competitiveness in this sector, huge emphasis has to be placed on mechanizing or automating the harvesting task, especially on tall palm trees.

Harvesting fresh fruit bunches (FFB) process makes up 60% of the total work operations and accounts for 50% of the production cost [8]. Reaching in and cutting the bunch stalks on tall palm trees is an extremely complex task due to the tight space afforded by the densely packed fronds and fruit bunches. Based on the papers by Saibani, *et al.* [9] and Syuaib & Dewi [10] and from our observation that has been conducted in the oil palm field, the manual harvesting tasks comprises the following steps:

- I. Search for FFB on trees.
- II. Adjust the length of aluminum pole and sickle.
- III. Position the pole's sickle for pruning.
- IV. Perform pruning.
- V. Position the pole's sickle for harvesting of FFB.
- VI. Perform harvesting of FFB.
- VII. Collect FFB bunches.
- VIII. Move harvesting tool to another tree.
- IX. Repeat.

Unfortunately, due to the complex nature of the tasks listed above, current harvesting technology has not been able to match the efficiency of human workforce. Hence, Malaysia still depends mostly on human labor especially foreign workers to perform this task. According to a study, harvesters and fruit collectors make up the most labor intensive category, providing a labor land ratio of 1:17.19. In other words, one worker can harvest an area of 17.19 ha [11]. Shortage of labor is a major problem in this country [12]. According to the latest statistics, 70% of the workers are foreigners and the industry is still in need of additional 38,000 workers [13]. For instance, a reduction of workers by 30% will cost Malaysian export earnings as much as RM 10 billion [14].

Currently, the average labor cost for harvesting oil palm fruits in the tall palm field is approximately RM30 – RM50 per tonne [15]. In the future, as the

labor shortage issue persist, the labor costs are projected to increase. The reason is, although the plantation sector in Malaysia offers numerous employment opportunities, it is not attractive enough to entice the local workers to take up these jobs [16].

The terrain layout of the plantation area also heavily influences the productivity of the harvesting technology. Usually, the terrains on most oil palm plantations are not flat. Instead they are located on rough and sloping areas. According to an article by MPOB [1], in 2015, approximately one-fifth of Malaysia's land or approximately 5.64 million hectares is covered by oil palm trees alone. As the plantation area increases rapidly, depletion of flat land areas means that new oil palm trees have to be cultivated in marginal areas such as hilly and sloping lands, which comprises of 65% of the marginal land areas in Malaysia [17]. Accessibility is the main issue here where harvesting by manual labors is still considered as the most efficient option. However, as stated earlier, it is getting increasingly expensive.

The scope of discussion of this paper is mainly on the harvesting tasks I to IX, as listed previously. This paper presents the evolution and trend of different harvesting technologies that have been developed and implemented in this industry to improve the harvesting process throughout the years. In addition, a new type of technology has been proposed as a mean to solve the harvesting issue in the future.

## 2.0 MANUAL HARVESTING

At the early stage when the trees are short, harvesting is a relatively simple operation. For trees below 3 m height, manual harvesting are normally performed with a chisel attached to a steel pole [18]. On the other hand, for trees above 3 m height, the combination of a sickle attached to a long pole is used. As the trees grow taller, manual harvesting with a sickle-pole method is a hindrance since the harvesting process becomes increasingly difficult (Figure 1). Handling and maneuvering the long flexible pole that is two to eight times the length of human body with a sickle at its end is an extremely arduous and hazardous task. The long pole increases the moment acting on the worker. Therefore, the worker has to be highly skilled in handling the tool besides having enough energy to perform the cutting task [19]. Working under this circumstance also increases the risks of injuries and musculoskeletal disorders [20]. To overcome this, mechanization of the harvesting process have to be implemented with the introduction of new harvesting technology which is more economical and efficient [21].



**Figure 1** Manual harvesting with pole-sickle on tall oil palm trees (<http://www.etawau.com/OilPalm/OilPalm.htm>)

From the data obtained from MPOB in [22], it clearly shows that an increase in tree height entails a higher cost of harvesting per tonne of FFB. To increase productivity, a new technology, Cantas was then introduced by Jelani *et al.* [23], [24] as a mean to mechanize the cutting process.

Figure 2 shows two types of Cantas and a worker operating a Cantas sickle to harvest an oil palm fruit. Cutting with Cantas is 37% faster than the conventional manual sickle-pole combination. As a comparison, studies have shown that Cantas significantly increases the productivity level equal to two to three human harvesters [23]. Labor requirement was reduced by as much as 50% whereas the productivity increased from 4.19 to 11.6 t FFB day<sup>-1</sup>. Although Cantas has been proven to increase the harvesting efficiency, this innovation is still short of meeting the industry's needs [25].



**Figure 2** Harvesting oil palm FFB with Cantas sickle (Source: <http://www.palmeka.com>)

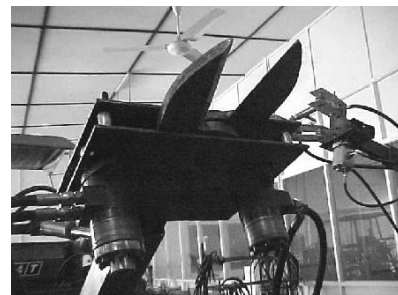
From an ergonomic aspect, a worker operating a mechanized cutter is exposed to vibration as high as 300 cycle min<sup>-1</sup> [10]. One of the models of Cantas with a maximum reach of 6 m weighs as much as 9 kg. Not only does the worker has to cope with the vibration, the strain on the body is exacerbated since

he also has to bear the entire weight of the cutter throughout the entire operation. A short-term study conducted on Cantas revealed that the level of vibration is permissible to the user [26, 27]. However, several studies stated that the risk of developing HAVS which affects the circulation, sensory, motor nerves as well as causing muscular-skeletal injuries increases with the magnitude of vibration and the length of exposure [28], [29], [30].

Although Cantas is more efficient than manual harvesting for short palms, its use is only limited for trees below 6 m tall. The device still have to go through huge improvement in terms of its design and technology to enhance its ergonomic aspect, which will ultimately ensure the safety and health of its operator.

### 3.0 HARVESTING MACHINES

The concepts of mechanized harvesting for tall palms are discussed by Rahim *et al.*, [31]. They are listed as follows: 1) mounting the cutting mechanism on a mobile climbing platform which enables harvesting at close proximity; 2) attaching a cutting tool at the end of a boom where operation is controlled from the ground. Research on Option 2 is more popular and different types of cutting mechanisms have been developed at Universiti Putra Malaysia (UPM), which were mounted on tractors for testing purposes. Figure 3 shows a scissor cutting mechanism which derived its power from a hydraulic power source. It could generate a lot of force needed to cut through the fronds or the bunch stalks.



**Figure 3** Scissor cutting mechanism (Source: Mat Soad, 1998)

On the other hand, Figure 4 shows a circular blade cutting mechanism. Similar to the previous device, it was also powered by a hydraulic motor. Using this blade, cutting of the fronds was able to be performed from the top to bottom, which was the ideal approach. However, fibers started to accumulate in between the blade teeth rapidly and cutting efficiency suffered from the poor blade design. Furthermore, the blade would get stuck and completely halt the entire operation.



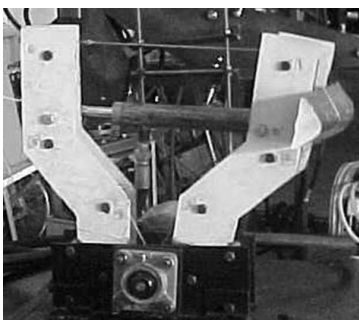


**Figure 4** Circular blade cutting mechanism (Source: Guan, 1999)

Figure 5 shows the string cutting mechanism mounted on the tractor [32]. In Figure 6, when the frond was placed on the string cutting mechanism, cutting was achieved through a continuous rotation of the string at rapid speed and the wire tension is controlled by the extension of the hydraulic actuator [33]. For a continuous rotation system, joining the string to form a loop introduces a knot and this is the major drawback of this mechanism. Occasionally, the wire loop snapped due to the excessive force and the lack of bonding strength on the knot. During trials, cutting was performed by placing the rotating string cutter under the fronds or bunch stalks and applying the cutting force upwards. Cutting would then stop abruptly when the string was clamped under the weight of the frond or fruit bunch.



**Figure 5** Wire cutting mechanism mounted on tractor (Source: Wan Ismail, 2010)



**Figure 6** Cutting frond with wire cutting mechanism (Source: Omar, 1999)

To transport these cutting devices for harvesting purpose, several types of machinery have been used. As depicted in Figure 7, through a research collaboration between MPOB-UPM and a local engineering firm, a wheel-type harvesting machine for oil palm was developed in 2004 [34]. It is a 4-wheel drive machine powered by 33 hp diesel engine. Its telescopic arm has a claw-type cutter and a grapple mounted as its end effector. The machine was designed such that it consists of only four modules: chassis, crane/broom, cutter and bucket. Due to its modular design, replacement of parts and maintenance process can be performed in less time.



**Figure 7** MPOB-UPM's wheel-type mechanical harvesting machine (Source: Shuib, et al., 2011)

Another harvesting machine is a track-type with a scissor-type cutting blade and fruit catching mechanisms attached to the boom was developed by MPOB [35], as shown in Figure 8. This is a modified prime mover which has a 500kg loading capacity and is powered by a 31.5 HP diesel engine. Utilizing tracks instead of wheels slightly reduce the soil compaction besides providing better traction. An operator onboard moves the joystick to signal the hydraulic cylinders to extend and retract the telescopic boom and it is capable of reaching fruits up to only 10 m in height.



**Figure 8** Track-type harvesting machine for tall trees (Source: Shuib, et al., 2004)

A study was conducted in a palm field with an average palm height of 8m to compare the productivity of a harvesting machine and manual harvesting [8]. In terms of productivity, harvesting machines can harvest from 3 to 6 t day<sup>-1</sup>. The productivity of manual harvesting and harvesting machine are 100 – 150 bunches man<sup>-1</sup> day<sup>-1</sup> and 200 – 250 bunches man<sup>-1</sup> day<sup>-1</sup>, respectively. The additional increase in output was achieved by extending the working hours of harvesting machines from 8 to 10 hours. From an economic analysis perspective, the study also shows that the cost per tonne for mechanical harvesting machine was slightly higher than manual operation. To reduce the machine harvesting cost, these were the three recommended methods: i) increasing productivity ii) extending working hours and iii) reducing the machine capital cost.

Harvesting productivity of a harvesting machine is significantly influenced by different factors such as ground condition, terrain layout and variability of palm height. One of the main disadvantages of these harvesting machines is the reachability aspect or the maximum height at which it can harvest. To increase the maximum reach, a longer boom is needed, which is heavier and this entails increasing the size of the prime mover and the actuators. However, equipping the tractor with a longer boom will negatively affect its stability and this could be detrimental to both the operator and the tractor.

In addition, accessibility issue arises when deploying tractors in uneven terrain. A tractor is usually huge, heavy and moves extremely slow. Maneuvering the tractor is not an easy task, especially on hilly and sloping terrain. Therefore, getting from one tree to another consumes a lot of time and fuel. Since a tractor is a complex machinery, the probability of failure associated with its myriad electrical and mechanical components is also high.

Huge tractor exerts a large force on the ground and this causes soil compaction. These heavy machines or tractors can weigh between 10 to 30 tons. Soil compaction is a function of machine weight, tire inflation pressure and tire size. Unlike lighter loads which cause compaction near the surface, heavy loads cause compaction at depths that cannot be fixed by tillage [36]. As soil compaction increases, root penetration is impeded, leading to soil degradation and decreasing crop yields [37].

Using tractor or other heavy machinery for harvesting is seen as having limited potential in the oil palm industry and other avenues should be explored to overcome this problem.

#### 4.0 CLIMBING ROBOTS FOR OIL PALM TREES

Research on climbing robots is gaining popularity and they will be expected to play a significant role

especially in the agricultural sector in the near future. Research on tree climbing robots has hitherto focused on a small array of applications, such as in the forest management and coconut industry [38, 39, 40]. From a research point of view, it is necessary for this type of research to look into designing, utilizing and harnessing the full potential of climbing robots to perform labor intensive, time consuming and dangerous tasks.

Realizing the need to mechanize the harvesting process, MPOB developed an enormous hydraulically powered electromechanical climber in 1989. Climbing was achieved by four 700 mm-diameter wheels with protruded triangular teeth to enhance traction and to prevent the robot from slipping. The square shaped-platform design however was not optimized for use on trees with circular cross section. It would prevent the cutting tool from reaching all the fruits around the trunk. In addition to its enormous size, most parts in the structure were made of steel and this increased the weight of the robot considerably. Furthermore, the wheels and the arm mechanisms that were used for gripping the tree trunk were all driven by a huge and heavy hydraulic power source.

The diameter of the wheel was large in order to allow it to generate as much contact as possible with the trunk surface. However, the circular shape of the wheel only allowed a small portion of the wheel to make such contact. The rest of the wheel surface did not contribute to the traction generation at all. Another problem encountered when operating the MPOB robot was that it did not have the ability to ensure that the platform was level. Failure to maintain its balance caused it to tilt to one side and the trunk started to impede the frame of the robot and this affected its movements.

Another version of a lighter climber was developed at UPM [41]. Unlike its predecessor, it has integrated tilt sensors to detect its own orientation. During trials, it was able to remain levelled when climbing the tree, as shown in Figure 9.

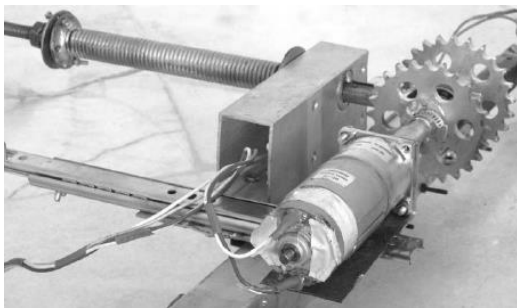


**Figure 9** Climbing robot with tilt sensors (Source: Shokripour, et al., 2010)

Instead of using rubber wheels, this robot uses 16 small sprockets for climbing (Figure 10). Its traction was generated with the help of a passive spring mechanism, as shown in Figure 11. This type of mechanism is a passive-gripping mechanism designed for climbing trees with relatively smooth trunks of approximately 300 mm to 420 mm. For trees with different diameters, the power screw connected to the spring has to be manually adjusted to stretch and contract the spring. This is to ensure sufficient gripping force but it comes with a tradeoff in terms of flexibility of the sprockets in negotiating irregularities on the trunks.



**Figure 10** Robot climbing smooth trunk using small sprockets (Source: Shokripour, et al., 2010)



**Figure 11** Passive spring mechanism (Source: Shokripour, et al., 2010)

Another major issue is the absence of the controllability aspect of the spring gripping mechanism. There is no sensor or mechanism involved to control the gripping force, especially when navigating tree trunk with frond stubs. Climbing from a smaller diameter segment to a bigger diameter segment of the trunk requires the robot to expend additional energy to overcome the increase in gripping force. In the study conducted by Shokripour et al. [41], there was no experiments or trials indicating whether it could successfully climb tree trunks full of frond stubs.

#### 4.1 Challenges of Climbing Oil Palm Trees

The focus of future research on climbing robots for harvesting oil palm fruits is on replacing human labor

in performing tasks II to VI, as described in the Introduction section. Mechanizing the climbing and harvesting process is still an unsolved problem since there are no robots currently that have demonstrated the ability to climb an oil palm trunk full of frond stubs. The development of a new version of a climbing robot will also extend the capability of currently available harvesting technologies. It will be able to reach higher than Cantas and the aforementioned harvesting machines. Based on the detailed study and observations performed in several plantation areas, the following morphological structures of oil palm trunks and its physical characteristics in natural environment have been identified which are crucial aspects in the development of a new version of climbing robot.

*Irregular Tree Surface:* Oil palm trees produce an average around 20 - 40 fronds each year, depending on its age [42]. On average, around 24 fronds are pruned per palm tree on annual basis [43]. Standard and conventional method of pruning does not remove the fronds completely from the trunk. These remnant of chopped fronds or frond stubs form irregular surface which covers the entire trunk, as shown in Figure 12. On most oil palm trees, irregularities on the trunk surface due to uneven frond stubs can form a recess as deep as 4 inches or 101.60 mm.



**Figure 12** Irregular trunk surface of oil palm tree

*Height of the Oil Palm Trees:* Oil palm trees can grow as tall as 18 – 20 meters, which means that harvesting has to be performed at approximately this maximum height too.

*Variation of Trunk Diameter:* The diameter of the tree trunk varies with height with the largest and smallest diameters can be found at the bottom and at the top of the tree, respectively. According to a paper by Sulaiman et al. [44], at replanting age of 25 years, the measured diameter of the oil palm trunk ranges from 450 to 650 mm, measure 1.5 m above ground level with a height ranges from 7 to 15 m. Above 1.5 m height, the size of the diameter gradually decreases.

*Habitats for Plants and Insects:* Habitation by plants and insects presents another problem that can hinder the climbing process. Factors such as tree



height, shade and shelter provided by the leaves attract all kinds of insects and plants to inhabit the tree trunk. Despite the harsh surroundings and unpredictable weather in Malaysia, the canopies provide ample shelter from the sweltering heat and torrential rain whereas the trunks provide water and nutrients. Most of the time, one can spot bee hives, bird nests and parasitic plants on the tree trunk.

*Adverse Climbing Surface:* Utilizing robots to perform tasks in the oil palm fields makes it susceptible to wet and dry conditions. The trunk is especially slippery when it is wet and it is important that the climber is equipped with a locomotive mechanism capable of generating sufficient traction to propel it up the tree.

Having identified the challenges, a climbing robot can be designed. In order for it to perform well, it needs to have the following features: small size, low complexity, high adaptability, high maneuverability, high robustness and high speed [45].

## 4.2 Design Criteria For Climbing Robot

To successfully climb on any oil palm trees, a set of design criteria has been developed. Each of the design criterion has one or more functions to assist in the climbing and harvesting processes.

*Size and form factor:* In general, the robot has to be lightweight so that it can be conveniently transported from one place to another using a small and agile vehicle which has higher maneuverability than large tractors. Unlike harvesting machine, a climbing robot is significantly lighter and consequently, power consumed by the robot is considerably less. Hence, it leaves minimal adverse impact to the environment, especially to the soil.

*Actuators and power source:* The choice of actuator type and power source are also essential. For this purpose, electric DC actuators and DC power source are chosen as they come in a small and compact form factor but packing the necessary power. To reduce the weight further, the climbing robot is tethered to a power source located in a mobile ground vehicle which can prolong the operation hours.

*Speed:* High speed propulsion system will reduce the climbing time as much as possible and this allows for more time for harvesting, which is a more complicated process. The main aim is to exceed the harvesting productivity of harvesting manually and harvesting with machines.

*Adhesion:* To attach itself on the trunk, the climbing robot has to depend on its adhesion mechanism. There are five types of adhesion mechanisms: suction, gripping, magnetic, rail-guided and biomimetic type [46]. Without implementing a proper adhesion technique to suit the climbing surface, the chosen locomotive mechanism will not enable the robot to travel from one position to another. For this application, a gripping mechanism is the most suitable option. An active-gripping mechanism using an electric actuator plays an

extremely important role in two scenarios. Firstly, the mechanism enables the robot to squeeze and release its grip according to different cross section diameters of the trunk as it ascends or descends the tree. In this aspect, parasitic plants along with hives, nest and debris can be overcome with minimal effort. Secondly, the mechanism allows the robot to secure itself firmly on the tree when harvesting or pruning process takes place.

*Locomotion:* Climbing an irregular surface and moving against gravity at the same time is a very challenging and energy demanding process. There are six categories of locomotive mechanism in climbing robots, namely: legged, cable, wheel, track, translation and combined type [46]. To generate sufficient traction, it is important for the chosen locomotive mechanism to be able to conform and to adapt to the extremely uneven surface of the tree trunk. A locomotive mechanism with a large tractive surface is suitable for this application because the large surface allows it to easily traverse over frond stubs. Using track over other locomotive mechanisms prevents it from getting stuck in recesses formed in between old frond stubs. In this case, the track has to be made from a flexible, tough and durable material. In addition, it needs to have a high coefficient of friction with respect to the surface of the trunk. With the help from the active-gripping mechanism described above, the track can enable the robot to climb in wet and dry conditions as well.

*Balancing control system:* A responsive balancing control system is required to maintain the stability of the robot when climbing trees covered with frond stubs. The protrusion of frond stubs from the trunk may vary significantly and without a proper balancing sensor and algorithm, the robot may get stuck and this will significantly increase the climbing duration. Since the robot is expected to be moving at high speed, the balancing algorithm must have a fast response time when attempting to level itself [47].

*Reachability:* On each oil palm tree, there are usually a couple of ripe fruits and sometimes it can have as many as 5 to 6 ripe fruits ready for harvest. Therefore reaching each fruit requires a movable cutting unit. A circular-shaped frame is chosen instead of a rectangular or a hexagonal one because it conforms to the cross section of the trunk. At the top of the circular frame are the cutting unit and the guide rail. The guide rail enable to cutting unit to move seamlessly on the flat surface around the frame. This increases the reachability of the cutting unit to enable it to harvest all fruits around the trunk.

*Cutting tool:* In addition to having a movable cutting tool on top of the climbing robot, the cutting unit must have a high degrees of freedom to enable it to maneuver and adjust its angle to cut. Higher degrees of freedom allows higher maneuverability of the cutting tools in order to reach in between densely packed fronds. Replicating the harvesting steps performed by human worker is the best way for a robot to eventually match the efficiency of its

human counterpart. With a combination of high degrees of freedom and small dc actuators, a small cutter can be developed that can perform cutting from top-down to prevent branch 'bite'.

*Machine learning and machine vision:* The inclusion of machine vision is the next crucial step in assisting the operator of the climbing robot to perform harvesting. In a more advanced mode, machine vision together with machine learning can be integrated to enable fully automated harvesting process by the robot itself without any human intervention. For instance, in weeding task, a machine vision algorithm was developed and implemented in the oil palm plantation [48]. Likewise for harvesting, machine vision and machine learning algorithm may incorporate and build on the results obtained from studies conducted by Hudzari *et al.* to develop the FFB maturity index based on the optical and color properties of the FFB and to develop a maturity prediction model which enables the determination of the exact time for FFB harvesting [49, 50].

## 5.0 CONCLUSION

Different kinds of harvesting methods from manual harvesting to mechanization in harvesting process as well as research on climbing robots to be used as harvester have been discussed. There are many disadvantages associated with using human workforce and huge machinery to perform harvesting. To alleviate issues surrounding 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.

In order to build a climbing robot specific for oil palm trees, a set of design criteria was introduced after close examination of the tree morphology and its physical characteristics. In addition, to fulfill certain design criterion, a mechanism was proposed that can enhance the performance of the robot. Although the development of climbing robots is still in its infancy, current research indicates that this can potentially be the future direction for automating the harvesting task in this industry.

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