Innovation of Fresh Fruit Bunches (FFB) Harvesting Tools, Using Environmentally Friendly Electronic Mechanical System

M. Sabri 1, Arif Fadillah Nasution 2 and Syafruddin Hasan 3.
1,2,3 Mechanical Engineering, Faculty Engineering, Universitas Sumatera Utara, Medan, Indonesia

E-mail: m.sabri@usu.ac.id, ariffnasution64@gmail.com, syafruddin7@usu.ac.id

Abstract. Today, oil palm becomes a prime commodity in Indonesia. The land area where oil palm trees are planted is rapidly developing; it is not only monopolized by state and private plantation companies but also by small holders. One of the main factors which influences its growth and productivity is harvesting factor. To fulfil the need for harvest, it is necessary to have a tool used for a supporting facility in harvesting fresh fruit bunches (FFB) so that it is easier to harvest them; besides that, it also helps solve the health problems and environmentally friendly work safety. Some innovations in tools for harvesting FFB have been carried out even though they have some weaknesses. One of them is the use of burning motor system as the its source of energy while many activists throughout the world are campaigning for the change in lifestyle toward more eco-friendly which teaches people to be aware of their environment in order to decrease the level of pollution and the garbage which is thrown away. Therefore, the researches were performing a renewal innovation to yield a tool of harvesting oil palms which are safer, lighter, easier, affordable, and environmentally friendly.

1. Introduction

To cut off the fronds and the bunches of oil palm fresh fruit, people use sickles made of high quality spring steel through inductive plating with its working method is like the movement of a saw (back and forth); it is moved by electric motor in linear actuator as the power cutting off while telescopic pole using non-conductive material which able to resist electricity, powerful, flexible, light, and not slippery in hands. The telescopic pole can also be extended with 3 extensions with 42 mm in diameter, and it can be easily removed. A connecting joint is installed in its every extension in order to make it easier to be moved by its operator by adjusting it to the height and to the angle of cutting of the fronds and FFB by paying attention to the problem of safety engineering. The objective of the research on FFB harvesting tool, using environmentally friendly electronic mechanical system was to analyze the kinematics and dynamics of each telescopic pole toward the stability of control and controller system in harvesting process.
The result of this research was expected to be the basic guidelines for in employment in oil palm plantations as follows: i) yielding innovation as the combination between environmentally friendly mechatronic performance and environment, ii) yielding FFB harvesting tools as a alternative in contributing ideas in oil palm plantation sector, iii) accelerating the work so that it can increase the capacity of production in the process of FFB harvest, iv) being able to cope with the problem of manpower, v) making the performance of harvesting process easier according to K3 (work safety and health) standard, and (vi) getting affordable and qualified FFB harvesting tools which can be owned by all people.

2. Literature Review
The performance of this FFB harvesting tools is assumed as similar to the function of the hands of a robot. Kinematics can be defined as a study of a robotic motion without considering its force or its other factors which influence the movement. In a kinematics analysis, the position, speed, and acceleration of all links are calculated without considering the force which triggers the movement. Robotic kinematics is generally divided into two: forward kinematics and inverse kinematics. Forward kinematics is also known as direct kinematics in which the length of each link and the angle of each joint are given, and the robotic position is calculated. In inverse kinematics, the length of each link and position is given, and the angle of each joint is calculated. Robot kinematics can be divided into serial manipulator kinematics, parallel manipulator kinematics, mobile robot kinematics, and humanoid kinematics.

Forward kinematics is a kinematics analysis to obtain position coordinate (x, y, z) when the angle of each joint is already known. For example, if we have an n-DOF robot, and the angle of each joint is known, we can use forward kinematics analysis to get the position coordinate of the robot. Inverse kinematics is a kinematics analysis to obtain the angle area of each joint if we have the data of position coordinate (x, y, z) [1].

Figure 2. Relation between forward and inverse kinematics.

One of the easiest methods to settle robot kinematics analysis is by using trigonometry equation; for example, robot kinematics analysis with 3DOF. When we use forward kinematics, we can get \( P_3 \) (\( x_3, y_3 \)) coordinate.

\[
x_T = l_1.\cos \theta_1 + l_2.\cos (\theta_1+\theta_2) + l_3.\cos (\theta_1+\theta_2+\theta_3) \tag{1}
\]

\[
y_T = l_1.\sin \theta_1 + l_2.\sin (\theta_1+\theta_2) + l_3.\sin (\theta_1+\theta_2+\theta_3) \tag{2}
\]

with,

\[
\Psi = (\theta_1 + \theta_2 + \theta_3) \tag{3}
\]

\( \Psi \) is the angle toward arm 3 on axis x.
When we pay our attention to Fig. 3, P coordinate $\Psi = (\theta_1 + \theta_2 + \theta_3)$. For example, if the tip of the arm in position P is held by hands in a permanent position, and joint-2 and joint-3 are shaken, the configuration of joints 1, 2, and 3 can move with the tip of coordinate P remains in its position. In other words, if $\Psi$ direction is not calculated, the robot will have redundant kinematics function (exceeding) since the settlement of equation to obtain $(\theta_1 + \theta_2 + \theta_3)$ of a P is not a single (more than one settlement).

This redundancy can decrease the degree of freedom of robot. A redundant 3 DOF robot has the same function as 2 DOF if it is only oriented in only P coordinate.

P $(x_T, y_T)$ coordinate can also be calculated by using the result of calculation in a robot with forward kinematics of planar 2 arm joint in equation (6) and (7) with the following formula:

$$x_T = x - l_3 \cdot \cos \Psi$$  
(4)

$$y_T = y - l_3 \cdot \sin \Psi$$  
(5)

$$x = l_1 \cdot \cos \theta_1 + l_2 \cdot \cos \theta_1 \cdot \cos \theta_2 - l_2 \cdot \sin \theta_1 \cdot \sin \theta_2$$  
(6)

$$y = l_1 \cdot \sin \theta_1 + l_2 \cdot \sin \theta_1 \cdot \cos \theta_2 + l_2 \cdot \cos \theta_1 \cdot \sin \theta_2$$  
(7)

For inverse kinematics, if $(x_T, y_T)$ and $(x, y)$ is $\theta_2$ and $\theta_1$ can be found by using $\theta_2$ and $\theta_1$ equation. From $(x_T, y_T)$ and $(x, y)$, $\Psi$ can also be found so that $\theta_3$ can be determined [3].

$$\theta_2 = \cos^{-1} \left( \frac{x^2 + y^2 - l_1^2 - l_2^2}{2l_1l_2} \right)$$  
(8)

$$\theta_1 = \tan^{-1} \left( \frac{y (l_1 + l_2 \cos \theta_2) - x l_2 \sin \theta_2}{x (l_1 + l_2 \cos \theta_2) - y l_2 \sin \theta_2} \right)$$  
(9)

3. Research Methodology

3.1. Diagram of Design Flow

![Figure 3. Diagram of the Flow of Making the Tool.](image-url)
The design method is a method or procedure that contains clear and systematic steps in the process of designing the tool. Each stage or part that determines the next stage must be passed with high accuracy.

3.2. Design of FFB Harvesting Tools
In designing the product of FFB harvesting tools, there are some parts the main components of the tools such as Telescopic Pole, Connecting Joint, Linear Actuator, Egrek Sabit (sickle), and dry-cell battery.

Figure 4 is assembly of the prototypes of the product of FFB harvesting tools which have been made. The source of dynamic energy of this FFB harvesting tool uses potential energy of 12-volt conventional electric battery with electrical set system, using relay timer, etc. This electrical set system functions as energy transfer system for moving motor in connecting joint and stator in linear actuator. This battery is hung on the back of an operator. The weight and the power of the energy depend on the future technology.

![Assembly design of FFB harvesting tool](image)

**Figure 4.** Assembly design of FFB harvesting tool

The design of these FFB harvesting tools has the length of 3 meters in the 1st rod, 2 meters in the 2nd rod, and 1 meter in the 3rd rod. The 1st rode is connected with the 2nd rod with connecting joint in manual system, and its evaluation angle can be adjusted in that joint according to what is wanted by the operator. However, it is different in the 2nd rod and the 3rd rod which are connected with connecting joint using motor system. This joint can also be adjusted by the operator himself. The difference lies on its elevation angle which can be moved freely by a motor gear according to what is intended by the operator. A linear actuator is installed on the tip of the 3rd rod to move the sickle placed on the tip of linear actuator which can be moved in axial movement (back and forth).

4. Research Result and Discussion

4.1. Kinematics Analysis on FFB Harvesting Tool
In this part the researchers will analyze the stability of controlling system on the kinematics and the dynamics of each telescopic pole during the process of harvesting with the height of cutting off target of 6 meters, and the distance between the operator and the oil palm tree is 5 meters.
4.2. Analysis on the Forces of FFB Harvesting Tools

Figure 5 is used for the power in each point of pipe joint:

\[
\begin{align*}
F_1 & = 0.96 F_2 + 0 F_3 + 0 R_H + F_N + 0 a = 21.178 \\
-0.96 F_1 & + 0.94 F_2 + 0 F_3 + 0 R_H + 0 F_N + 0 a = 16.231 \\
0 F_1 & - 0.94 F_2 + 0.26 F_3 + 0 R_H + 0 F_N - 22.1 a = 13.49 \\
0.282 F_1 & + 0 F_2 + 0 F_3 + R_H + 0 F_N + 0 a = 6.221 \\
-0.282 F_1 & + 0.331 F_2 + 0 F_3 + R_H + 0 F_N + 0 a = -7.567 \\
0 F_1 & - 0.331 F_2 + 0.97 F_3 + 0 R_H + 0 F_N + 0 a = -1.95 \\
\end{align*}
\]

The equation above becomes matrix function so that the matrix notation can be solved by using numerical methods which one of them is with Gauss-Naive elimination model.

**Table 1.** Result of force analysis calculation

| F_1 (N) | F_2 (N) | F_3 (N) | F_N (N.m) | R_H (N) | a (m/s^2) |
|---------|---------|---------|-----------|---------|-----------|
| -238.56 | -226.37 | -79.78  | 250.2     | 73.55   | 8.08      |

From the calculation above, it can be found that the force values of human energy is \( F_N = 250.2 \, \text{N.m} \) or 3.6 kcal/minute which can be seen in the reference Table below [2].

**Table 2.** Classification of human work load

| Job Level | Energy Expended Kkal/minute | Kkal/ 8 hour | Heart Rate Beats/minute | Oxygen Consumption Litre/minute |
|-----------|-----------------------------|--------------|-------------------------|-------------------------------|
| Heaviest  | > 12.5                      | > 6000       | > 175                   | > 2.5                         |
| Very Heavy| 10 - 12.5                   | 4800 - 6000  | 150 - 175               | 2 - 2.5                       |
| Heavy     | 7.5 - 10                    | 3600 - 4800  | 125 - 150               | 1.5 - 2                       |
| Moderately| 5 - 7.5                     | 2400 - 3600  | 100 - 125               | 1 - 1.5                      |
| Very Light|                           | 1200 - 2400  | 60 - 100                | 0.5 - 1                       |
| Light     | < 2.5                       | < 1200       | < 60                    | < 0.5                         |

It can be concluded from the Table above that the level of energy spent by human beings, viewed from ergonomic point of view in harvesting activity, is in the category of “Very Light.”

4.3. Data of the Research Result of FFB Harvesting Tools

The data of the research result below will be observed in some variations toward the distance between an operator and an oil palm tree during the process of harvesting and toward the height of the cutting
target from an oil palm tree. The purpose is to analysis the effectiveness and the capacity of the performance of FFB harvesting tools [4].

**Table 3.** Safe distance from the height of cutting target

| No | Cut target height (h) | Harvester's height (t) | The angle between poles and the tree (°) | The distance between the harvester and the tree (d) |
|----|------------------------|------------------------|----------------------------------------|--------------------------------------------------|
| 1  | 3                      | 1.3                    | 26°                                    | 1.5                                              |
| 2  | 6                      | 1.3                    | 26°                                    | 2.5                                              |
| 3  | 12                     | 1.3                    | 26°                                    | 5.5                                              |
| 4  | 18                     | 1.3                    | 26°                                    | 8.5                                              |

* The unit of length is in (m) and the unit of angle is in degrees (°)

In this research, it can also see some variables which occur in FFB harvesting tools – the forces which occur in telescopic pole pipes, the maximum of flexible tension and deflection, rod angles and position, and the stability of the tool function as they will be showed in the following table:

**Table 4.** Optional comparison of elevation angles and the position of the tip of the pole [5].

| Tree Height (m) | Tree Spacing (m) | Angle and Position Analysis | Analysis Results |
|-----------------|------------------|----------------------------|------------------|
| 5               | 2,1              | 73.6°                      | Safe Distance    |
| 4               | 3.94             | 86.1°                      | Safe Distance    |
| 3               | 0.99             | 90°                        | Pole 1 Upright   |
| 6               |                  |                            |                  |
| 5               | 3.65             | 57°                        | Safe Distance    |
| 4               | 3.94             | 76°                        | Safe Distance    |
| 3               | 2.98             | 100°                       | Pole 2 Horizontal|
| 4               |                  |                            |                  |
| 5               | 3.95             | 41°                        | Safe Distance    |
| 4               | 3.94             | 72.6°                      | Pole 2 Horizontal|
| 3               | -1               | 100°                       | Too Upright      |

![Figure 6. Simulation of harvest distance vs elevation angle on some height of cutting target](attachment:image.png)
Table 5. Optional comparison on forces

| Tree Height (m) | Tree Spacing (m) | Force and Acceleration Analysis |
|----------------|-----------------|--------------------------------|
|                |                 | F1  | F2    | F3    | FN    | RH    | A     |
| 6              | 5               | -238,6 | -226,4 | -79,78 | 250,2  | 73,55  | 8,08  |
|                | 4               | -39,51 | -26,57 | -13,4  | 61,4   | 4,24   | 0,34  |
|                | 3               | -29,51 | -16,23 | -10,5  | 51,6   | 0      | -0,09 |
| 5              | 5               | 140,9  | 154,9  | 73,2   | -99,6  | -64,7  | -6    |
|                | 4               | -46,2  | -31,9  | -22,8  | 64,1   | 23,45  | 0,2   |
|                | 3               | -25,1  | -9,53  | -9,75  | 45,74  | 11,53  | -0,57 |
| 4              | 5               | 148,7  | 162,9  | 116,8  | -82,66 | -95,94 | -4,61 |
|                | 4               | 29,7   | 41,9   | -2,17  | -7,24  | -2,27  | -2,5  |
|                | 3               | -52,85 | -42,9  | -1,97  | 73,8   | -13    | 1,38  |

Figure 7. Simulation of harvest distance vs forces on some height of cutting target

5. Conclusion

The conclusion of the research result of “Innovation of Fresh Fruit Bunches (FFB) Harvesting Tools by Using Environmentally Friendly Electronic Mechanical System is that

- Simulation of the calculation of the height of 6 meter cutting target and the safe distance of 5 meters between an operator and an oil palm tree, when it is adjusted to Table-V (Classification of Human Work Load) clarifies that the energy of work level spent by human beings in the application which becomes an FFB harvesting tool alternative is still the category of Very Light.
- When a comparison is made in each height of the tree and in different harvest distance in the Tables and the Graphs toward the analysis on angles and position, the analysis on the forces, and the analysis on deflection and tension, it can be concluded that with 5 meter height of a tree and 4 meter harvest distance, it is more ideal than the others since it has moderate force, tension, and deflection.
• In the process of selecting materials for telescopic poles, if it is compared between nylon materials and carbon fibers, it is proved that nylon materials are better than carbon fibers. If it is viewed from simulation test toward the force in an 8 meter telescopic pole without joint, nylon materials are bigger than carbon fibers. Therefore, carbon fibers are selected for this research on FFB harvesting tools.

References
[1] Budhiharto W 2014 Robotika Modern - Teori & Implementasi (Edisi Revisi) Edisi 1 (Yogyakarta: Andi)
[2] Christian A, Asmara S, Sugianti C and Telaumbanua M, 2018. Ujuk Kerja Alat Pemotong Pelepah Sawit Tipe Dodos Manual Dan Mekanis. Jurnal Teknik Pertanian Lampung 7(1) pp 15-24
[3] Pitowarno E 2006 Robotika Desain, Kontrol Dan Kecerdasan Buatan Edisi 1 (Yogyakarta: Andi)
[4] Syuaib M F 2015 Studi Gerak Kerja Pemanenan Kelapa Sawit Secara Manual Jurnal Keteknikan Pertanian 3(1) 49-56
[5] Andriani M, Dewiyana and Erfani E 2017 Perancangan Ulang Egrek Yang Ergonomis Untuk Meningkatkan Produktivitas Pekerja Pada Saat Memanen Sawit Jurnal Integrasi Sistem Industri 4 (2) pp 119-128