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Automation of agricultural machinery: Development and validation of a portable automation module for oil palm plantation machinery

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Abstract: This paper explores the possibilities of mechanization and automation to enhance the performance of various machines within the agricultural sector, with a selected focus on the oil palm plantation machinery. To begin, the OREC Bull Mower machine was chosen as the initial pilot study. Five major machine components were identified through meticulous analysis, laying the groundwork for the automation process. Several functions, including gear shifting, clutch operation, and other critical tasks, were successfully automated. Extensive testing and measurements were performed to identify the best actuators for precise and efficient control. The actuators and controllers were thoughtfully integrated into the enclosure, resulting in a versatile automation module that can be programmed for remote or autonomous operation. Lab and on-site testing proved the module's efficacy in real-world scenarios, validating its successful implementation. While the project has produced promising results, future improvements are required, particularly in mechanical fitting, design for assembly, and the use of reliable electronic components.

Keywords: Portable automation module, agricultural automation, agricultural machinery, agricultural technology innovation, oil palm machinery, bull mower

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1. Introduction

The agricultural sector has witnessed big improvements in mechanization and automation, revolutionizing conventional farming practices. From manual labor-in-depth approaches to the integration of robotics and complex machinery, the world has undergone a transformative journey, leading to accelerated efficiency, productivity, and sustainability.

The manual processes involved in agriculture operations have been characterized by labor-intensive obligations such as planting, fertilizing, harvesting, and maintenance. These methods relied heavily on human effort, which led to challenges like inconsistent fines, excessive exertion costs, and barriers to scalability. Recognizing those boundaries, researchers and enterprise experts launched a quest to broaden mechanized solutions that might enhance productivity while lowering dependency on manual exertions (Bujaczek et al., 2013).

The creation of equipment caused approximately a paradigm shift in the oil palm plantation area. Various mechanization techniques, which include tractor-established planters, mechanized fertilization systems, and mechanical harvesters, drastically improved operational performance (Hitam & Yusof, 2000; Zahid & Aziz, 2018; Radzi et al., 2020). These improvements allowed for specific planting, the highest-quality fertilizer application, and efficient harvesting, leading to expanded yields and improved quality.

However, the progression did not conclude with mechanization. With the arrival of automation and robotics, the oil palm plantation playmaker witnessed another leap forward. Automation technologies, which include GPS and GIS structures, permit accurate mapping and monitoring of plantations, facilitating higher planning and resource allocation (Aini et al., 2014; Jusoff, 2009; Khuzaimah et al., 2022). Robotic planters and self-sufficient automobiles have further reduced the need for manual labor, ensuring constant and precise operations while minimizing human error. Mechanization and automation were used to improve productivity, reduce labor costs, and enhance protection (Al-Jawadiab et al., 2018; Cramb & Thepent, 2020; Ibragimov et al., 2019). For instance, machines have evolved to harvest oil palm fruits, observe fertilizers, and spray insecticides (Ahmad et al., 2012; Masag, 2018). These machines have helped boost productivity and reduce labor fees at the same time as improving employee safety.

Today, the oil palm plantation industry is at the forefront of automated agriculture. Equipped with sensors, drones, and machine learning algorithms, the integrated farm management system can collect, analyze, and make decisions in real time (Khan et al., 2021; Juman et al., 2016; Yarak et al., 2021). This combination ensures proper vegetation management, including irrigation, pest management, and crop rotation. These improvements not only increase productivity but also encourage sustainable practices by reducing environmental impact (Gorjian et al., 2021; Junos et al., 2021; Nawik et al., 2015).

Before starting to mechanize or automate a process, it is important to have a detailed understanding of the application or task at hand This requires a detailed analysis of the existing process, with each step including a detailed analysis of the relevant work. Manual system evaluations enable engineers and analysts to identify potential bottlenecks, inefficiencies, and areas for improvement.

Once the process is fully understood, the next step is to clearly identify the sequence. This involves breaking down the procedures into individual steps and determining a logical order of execution. Understanding the sequence is essential for the proper and accurate simulation of automated systems or devices capable of performing manual tasks.

In addition to understanding the system, it is important to consider the relevant forces, kinematics, or dynamics involved in the process. This requires a thorough analysis of physical interactions, such as applied forces on a variety of materials and the speed and position required. The system may operate within desired parameters, obtaining optimal performance and safety.

Additionally, identifying the appropriate machinery, facilities, or machinery is an important part of the machinery or machinery process. Depending on the specific requirements of the process, different motors or actuators may be required to provide the power and speed control required Materials must also be carefully measured to ensure durability, stability, and alignment with the automation process. Moreover, it is important to select the right processing equipment, such as sensors and controllers, to achieve the desired automation and efficiency.

Therefore, before imposing mechanization or automation, intensive knowledge of the process, explicit identity of the sequence, calculation of associated forces and dynamics, and identification of suitable vehicles, structures, or automation devices are essential. This systematic approach ensures that the automated or mechanized machine appropriately replicates the guide method, optimizes performance, and promotes performance.

In this study, the primary goal is to automate an existing manual machine with minimal modifications to the original equipment. The objective is to develop an automation method using an external module that can be easily attached and detached without extensive alterations. This ensures the machine's core functions remain intact, allowing normal operation even when the module is removed. The external module interfaces with the manual machine to enable automation and can be customized to meet specific machine requirements. Dedicated hardware components within the module can be interchanged to optimize performance, providing flexibility and scalability. This modular approach leverages the existing machine's capabilities while adding automation functionalities, offering a practical solution for integrating automation into manual machines across various industries, thereby enhancing productivity, efficiency, and reducing downtime during the transition to automated processes.

2. Automation process

A flail mower is a versatile piece of agricultural equipment characterized by its ability to efficiently cut through tall grass, heavy weeds, and thick brush. It is commonly used for property maintenance and professional landscaping due to its robust design and precision. Prominent brands in the market include Victory, John Deere, Maschio, OREC, Betstco, Alamo, Kubota, Titan, and Woodmaxx. These brands offer various models designed to manage demanding vegetation management tasks, ensuring durability and high performance in diverse applications.

The chosen machine for automation is the OREC Bull Mower, particularly the model HRC664 as shown in Figure 1. This rugged and effective mower is equipped with a Mitsubishi engine boasting 5.8 kW or 8.0 ps, supplying adequate energy for various cutting duties. With a coverage width area of 650mm and an adjustable cutting height ranging from 20mm to 80mm, the OREC Bull Mower guarantees precise and versatile reducing abilities suitable for distinctive terrains and grass lengths (Wide Agro Ventures, 2023).

Figure 1. OREC Bull Mower.

One of the key functions of the OREC Bull Mower is its user-friendly layout, which imparts three forward speeds and one reverse pace for clean maneuverability. This permits operators to conform to the demands of different landscapes and efficiently navigate around obstacles. Additionally, the machine's rubber crawler mechanism ensures easy and steady movement, granting superior traction even in tricky situations.

2.1. Identification of machine control elements

The OREC Bull Mower system consists of five essential components, which are the handle, crawler, crusher, engine, and power transmission. Each component plays a critical role in its operation, as shown in Figure 2. The handle serves as the control center, housing all the important devices needed to manage the system. The crusher hardware is geared up with a flail cutter, enabling powerful clearing of overgrown bushes and trees. To facilitate easy navigation on soft soil terrain, the system is equipped with rubber crawler wheels, which provide advanced traction and balance. Lastly, the energy transmission system is predicated on a belt-type mechanism, correctly shifting energy from the engine to power the cutting and crawling movements. Of all five components, two have been identified as related to the control system.

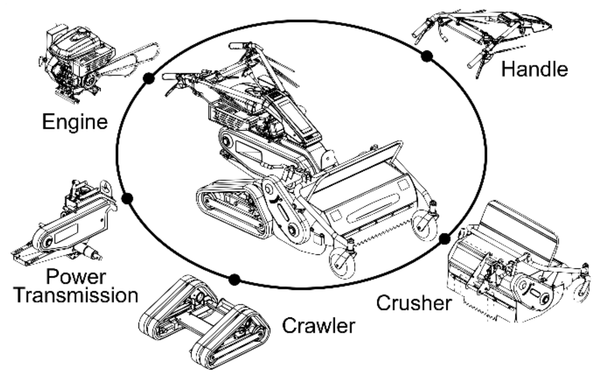

Figure 2. Five major elements in Bull Mower machine.

In the development of the portable automation module for the machine, the handle section has been identified as the controller for all functional capabilities, as shown in Figure 3. This section encompasses diverse management levers, which include the throttle lever, engine switch, flail clutch lever, side clutch lever, travel clutch lever, and gear shift lever. Through a system of steel wires, each lever is connected to specific hardware, which includes the engine, gearbox, power transmission, and crusher. The engine switch serves as a failsafe button, at once connected to the engine for fast shutdown if vital. The gear shift lever offers multiple stages, along with reverse, neutral, and forward Gears 1 to 3, allowing for specific speed and directional control.

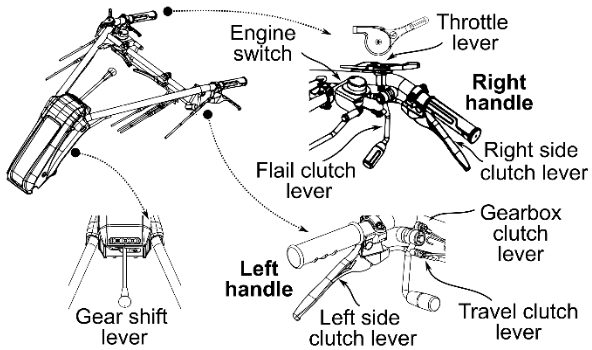

Figure 3. The handle section has been identified as the main controller for the machine.

The handle function can be summarized in Table 1. Each lever is connected to its functional device through steel wire while the engine switch is connected to the engine through electrical wire.

Table 1. Connections for each lever and switch.

Item	Connection	Control element
Engine switch	Electrical wire	On/Off engine
Throttle lever	Steel wire	Engine speed
Flail clutch lever	Steel wire	To engage flail knife tension arm with intermediate belt
Right side clutch lever	Steel wire	To stop gearbox, which controls the right wheel shaft
Left side clutch lever	Steel wire	To stop gearbox, which controls the left wheel shaft
Travel clutch lever	Steel wire	To engage gearbox tension arm with gearbox belt and to release gearbox clutch
Gear shift lever	Steel wire	Gear level displacement in gearbox

2.2. Power transmission and connections

The gearbox tension arm and the flail knife tension arm, which are both shown in Figure 4, are the two tension arms that primarily control the machine's power transmission system. When both tension arms are not engaged with the belts, the engine pulley will rotate freely.

When the flail knife tension arm is engaged with the flail knife belt, the flail knife initiates rotation, enabling green grass and plant slicing. Simultaneously, when the gearbox tension arm engages with the gearbox belt, the gearbox commences motion, adhering to the selected gear level setting.

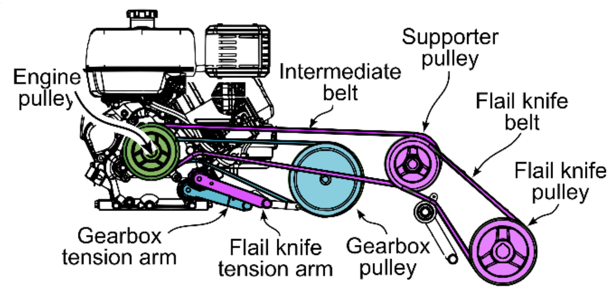

Figure 4. Power transmission system.

The gear shift lever in the machine is linked to the gearbox through two steel wires, enabling the management of gear disc rotation in either clockwise or anticlockwise directions, as shown in Figure 5a. To ensure seamless gear shifting, the shift gear lever must be correctly adjusted to specific slots corresponding to each gear level, ranging from reverse (R) to gear Level 3. Additionally, the right and left side clutch levers are connected to the side clutch arms at the gearbox, facilitating the selective engagement and disengagement of gears for the left and right shafts. Moreover, the travel clutch lever operates with two interconnected steel wires, each appearing to follow a different direction. One steel wire is linked to the gearbox tension arm (as in Figure 5b), while the other connects to the gearbox clutch arm, enabling precise and responsive control of the machine's movement.

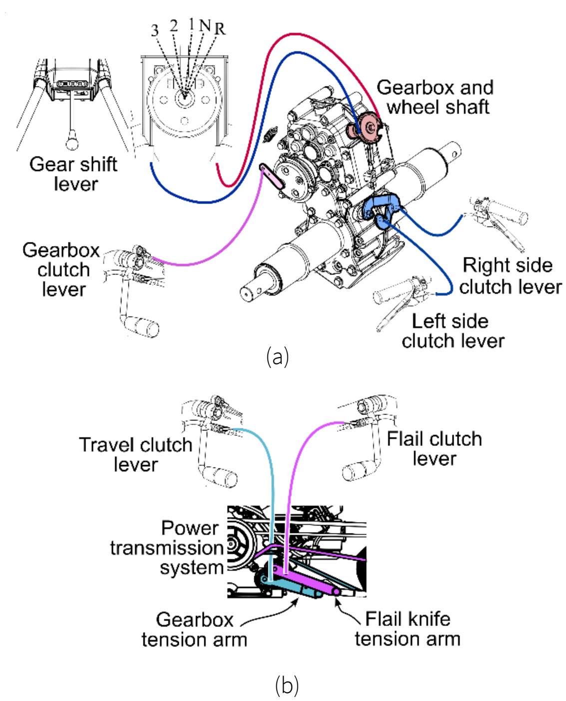

Figure 5. Gearbox and power transmission connections with the levers.

2.3. Determination of mechanism force

A critical step in developing the machine's portable automation module is replacing all lever mechanisms with appropriate actuators. To ensure optimal performance, these actuators or motors must be selected based on precise force measurements. As shown in Figure 6, all lever mechanisms can be categorized into three distinct categories: Toggling, vertical pull, and horizontal pull mechanisms. An analog weight scale is used to measure the force applied during these movements, providing accurate readings for the force required to pull or push the levers. The force measurement is repeated three times for each mechanism, and the average value is recorded to ensure consistency and reliability, as shown in Table 2.

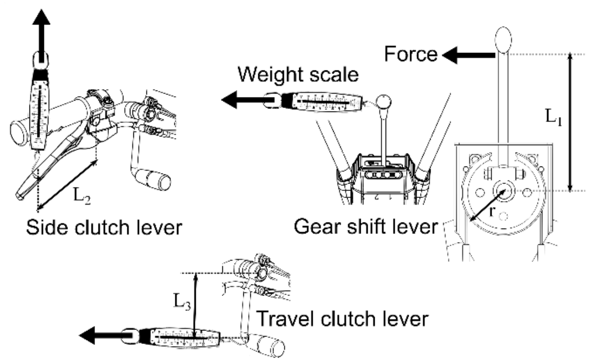

Figure 6. Three categories of lever mechanisms.

Table 2. Force measurement for each category of lever.

Mechanism	Related lever	Length (mm)	Average force measured (kg)
Toggling	Gear shift lever	$L_1 = 280$	13.1
Vertical pull	Left side clutch lever, right side clutch lever	$L_2 = 150$	3.3
Horizontal pull	Travel clutch lever, gearbox clutch lever, flail clutch lever	$L_3 = 100$	6.1

2.4. Actuators and controllers

The actuators for each mechanism were chosen based on the results from Table 2. A servo motor is found to be the most suitable for the toggling mechanism that controls the gear shifter, providing precise control over the specific angle changes required. With a minimum torque requirement of 370 kg.cm, a high torque servo motor is selected to ensure smooth and accurate gear shifting operations. For the vertical and horizontal pull mechanisms, where the maximum force required is 6.1 kg, a medium-speed DC motor with high holding characteristics is recommended. From the torque calculation, the minimum required torque is about 92 kg.cm. Given that the motion's requirement is just one specific displacement forward-backward, a worm gear DC motor is identified as the best choice for these mechanisms. With these carefully chosen actuators, all of which are wired to the driver boards and controller as shown in Figure 7, they can effectively replicate and automate the machine's functions.

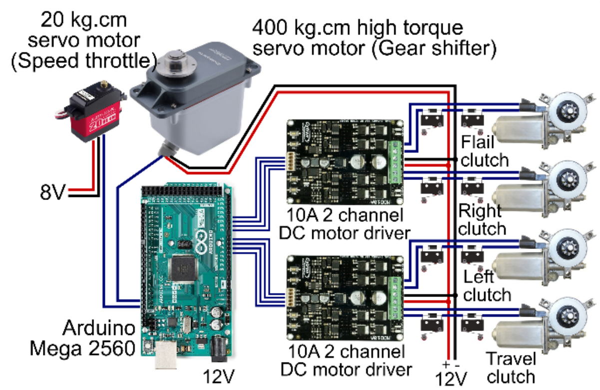

Figure 7. Selected actuators to replace lever functions and controller.

2.5. Automation module

In the portable automation module implementation, the selected motors are strategically placed within the enclosure, as shown in Figure 8, each with a specific orientation to optimize their functionalities. The enclosure is securely fastened to the machine's top, ensuring that the motors are well-protected and seamlessly integrated into the system. Each motor is carefully linked with steel wires and precisely connected to their respective arms to achieve effective control over the machine's functions.

A 400 kg.cm servo motor is installed with a bracket and an 8.8 cm circle plate diameter to facilitate precise gear shifting. The servo motor is calibrated to ensure that its rotation corresponds to the measured angle displacement, ensuring precise gear changes. As an example, to shift the gear from Gear 1 to Gear 2, the servo needs to rotate precisely 17o. The same DC motor mechanism is used to control the flail clutch, right clutch, and left clutch, providing consistent and reliable control for these functionalities. Besides that, the travel clutch and gearbox clutch share the same motor, but the steel wire is attached in opposite directions, allowing them to perform their respective functions.

Furthermore, to improve the operator's view and convenience, a 20 kg.cm servo motor is mounted on the side of the enclosure, providing a clear vantage point for speed monitoring and control during operation. This thoughtful placement ensures that the operator can easily monitor the performance of the automation module, ensuring safety and precision throughout.

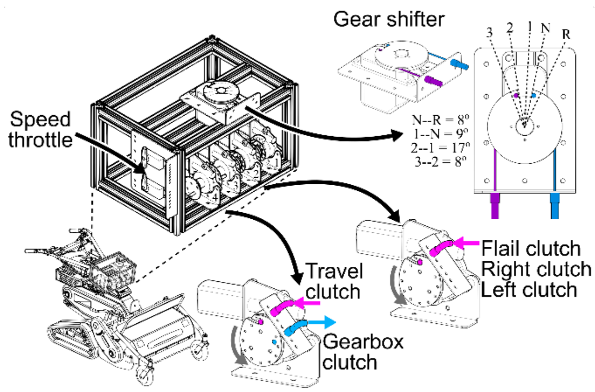

Figure 8. Servo motor and DC motor connection with the steel wire.

2.6. Control algorithm design

The automation module's successful operation is dependent on a thoroughly defined sequence of operations, which includes critical tasks such as engine startup, shutdown, and gear changes. It is critical to precisely map these sequences into a flowchart to avoid mechanical failures, such as potential gearbox damage. To ensure smooth execution, the module's controller must be precisely programmed to follow the prescribed sequence, reducing the risk of errors, and promoting reliable performance. Figure 9 shows the programming sequence for the gear shifter servo to change its current position to the new assigned position. Besides the gear shifter servo, the gearbox tension arm also needs to be controlled to provide smooth gear transition in the gearbox. By carefully integrating and programming these sequences, the automation module can run smoothly, improving efficiency and safety while protecting against potential mechanical complications.

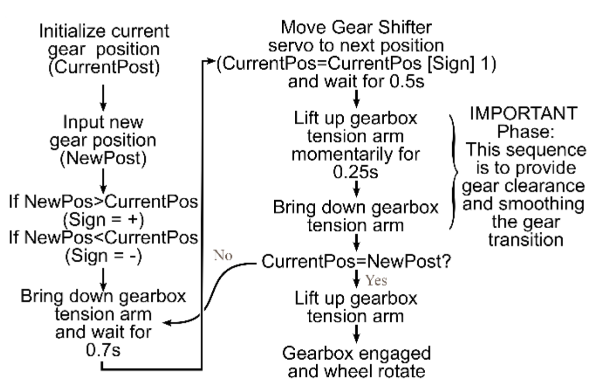

Figure 9. The programming sequence for gear shifter.

2.7. Final integration and testing

The automation module is assembled on the machine, which is outfitted with a damper system to reduce vibrations, which is a significant accomplishment. A light array tower added to the module provides a clear visual indication of the current operating mode, including the gear mode in use, as shown in Figure 10. The controller was programmed to communicate effectively with the remote-control module during testing, allowing for smooth and reliable operation. The machine's excellent performance during testing matches expectations, as shown in Figure 11, where the response is very quick and maneuvering capability is within the accepted path area, confirming the module's efficiency and performance.

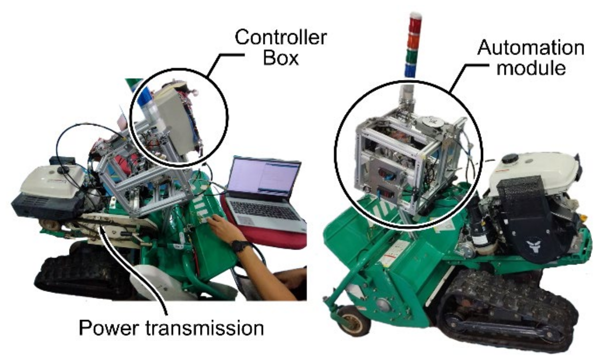

Figure 10. Final assembly of the automation module and the machine during programming and operation.

Figure 11. In-lab testing with remote control for path maneuvering and system control testing.

The successful installation and programming of the automation module on the machine, as well as the positive lab testing results, validate the module's design and effectiveness. Furthermore, its seamless integration with remote control during in-lab and field testing demonstrates its adaptability and user-friendliness, as no complicated procedures are required. This adaptability indicates that the module is well-suited for integration with a wide range of other control systems, such as autonomous controllers, GPS guided autonomous systems, and various other modules.

The module's detachable feature allows for easy removal from the machine by a single operator, allowing manual control to take over when necessary. This feature increases the machine's versatility by allowing it to be used in both automated and manual modes, depending on the situation. However, it is critical to address the current design's lack of waterproofing considerations. Excessive vibration in rough terrain can cause mechanical or electronic failures, emphasizing the importance of implementing waterproofing measures and improving module durability to withstand harsh environmental conditions. This advancement in automation technology has the potential to revolutionize the industry, promoting sustainable and efficient practices while minimizing the risk of mechanical or electronic failures, ensuring a successful and reliable future for the oil palm plantation sector.

3. Conclusions

The successful development of the automation module is a key achievement in this project. The process involved identifying functions, measuring force, choosing actuators, integrating controllers, designing in CAD, fabrication, and thorough testing. These steps were carefully conducted. The module's functionality was confirmed through both lab and onsite testing, proving its efficiency and practicality as proof of concept. This success highlights the potential to transform heavy machinery in the oil palm plantation industry, boosting productivity and efficiency. The detailed and organized approach used in designing and developing the module has set a solid foundation for future improvements.

The automation module currently used on the Bull Mower can also be adapted for other manual machinery with similar operational purposes, enhancing the automation and efficiency of equipment such as manual lawn mowers, brush cutters, and other vegetation management tools. For instance, it can be utilized in walk-behind mowers, hedge trimmers, agricultural tillers, and small-scale harvesters, providing versatile solutions for various landscaping and agricultural tasks. By integrating this module, these machines can achieve greater precision, reduce manual labor, and improve overall productivity in tasks ranging from lawn maintenance to field preparation and crop harvesting.

Conflict of interest

The authors have no conflict of interest to declare.

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