

Low-cost modular remote-control system for two-wheel hand tractors: design and performance evaluation using Fly Sky FS-i6

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Abstract

This research designed and developed a modular remote-control system for two-wheel hand tractors using the Fly Sky FS-i6 transmitter as a low-cost and responsive alternative to existing automation solutions. The primary objective is to improve operational efficiency and operator comfort while maintaining investment costs suitable for Indonesian smallholder farming. The total cost of system components (DC motors, servo motors, relays, solenoids, and receivers) was approximately USD 210, which is significantly lower than comparable IoT- or GPS-based automation kits (USD 600–1,000). Modifications were made to the throttle, clutch, and brake systems, allowing for remote operation via radio frequency without requiring the replacement of the main engine. Performance testing was conducted on various land conditions, measuring response time, tractor speed, theoretical and practical capacity, working efficiency, ploughing depth, wheel slip, and fuel consumption. Results showed that the solenoid-based control system responded reliably with an average delay of <math><1.5</math> seconds across all throttle positions. Average working speeds for throttle positions of 3 cm, 6 cm, and 9 cm were 1.872 km/h, 2.628 km/h, and 3.096 km/h, respectively. Wheel slip remained within the SNI standard of $\leq 25\%$, and fuel consumption averaged 0.33 liters per hour. Straight-line motion tests revealed a maximum deviation of 240 cm on uneven soil surfaces. This deviation is considered acceptable for hand tractor operations in Indonesia, where plot widths typically range from 15–25 m, and does not significantly reduce working efficiency. Overall, the modular remote-control system significantly improves usability and efficiency while providing a scalable, low-cost transition toward precision agriculture technologies in smallholder farming contexts.

Keywords:

Agricultural mechanization, low-cost automation, remote control, hand tractor, precision agriculture

1 Introduction

The country's agricultural sector is the backbone of the Indonesian economy [1] and contributes substantially to national food security and rural livelihoods[2]. Despite abundant natural resources and fertile land [3], the sector faces persistent structural challenges, including a continued reliance on traditional farming methods that limit productivity [4], low rates of technology and mechanization adoption among smallholders [5], and increasing vulnerability to climate change impacts such as droughts and flooding [6]. Land tillage, a critical component of agricultural production, still depends heavily on manual operations using hand tractors, which often leads to operator fatigue, inefficiency, and high fuel consumption [7, 8]. These constraints are compounded by

broader labor force dynamics, where an aging farming population and the outmigration of rural youth into industrial sectors are diminishing the availability of agricultural labor [5]. Numerous studies highlight that mechanization and automation are key to overcoming these barriers by improving field efficiency, reducing labor bottlenecks, and enhancing farmer welfare [9, 10]. Land preparation activities, including soil tillage, initial fertilization, and planting, can be performed more effectively using tractors equipped with rotary tillers and integrated planting implements, which have demonstrated potential to boost yields and ensure food security [7, 11].

Hand tractors, as Indonesia's mainland tillage tool, still have limitations, such as dependence on human labour, exposure to vibration, and uncomfortable environmental conditions for operators [5, 6]. Digital technology and automation development offer opportunities to improve efficiency through remote or autonomous control systems [14], [15]. Several previous studies have developed tractors with automatic transmission and IoT-based control systems, but their implementation in the field is still limited [8, 9]. This indicates a gap between technological potential and real adoption in Indonesia's agricultural sector.

Radio frequency-based control systems, such as the Fly Sky FS-i6 remote control, are recognized for their practical and cost-effective solutions in various agricultural applications [18]. Research indicates that such remote controls can facilitate a communication range of up to 500 meters, which is necessary for dynamic agricultural conditions [19]. These systems utilize radio waves at frequencies aligned with agricultural operational demands, improving communication efficiency and reliability across diverse field conditions [20]. Radio frequency-based control systems have also been shown to provide high responsiveness [14]. However, most previous research on agricultural automation generally focuses on partial controls, such as speed regulation or steering mechanisms, rather than comprehensive systems that integrate all essential tractor functions [15, 21]. Recent literature highlights attempts to integrate Internet of Things (IoT) technologies with radio frequency control systems to enable more holistic automation strategies [22], yet these solutions remain prohibitively costly and less adaptable to the varied land conditions of Indonesian smallholder farms [23][24]

Building upon these gaps, this research aims to design a comprehensive remote-control system for hand tractors using the Fly Sky FS-i6 that emphasizes affordability and adaptability to Indonesia's agricultural conditions. In contrast to IoT- or GPS-based systems that rely on resource-intensive components and are prone to latency issues [17][25][26]. The proposed system optimizes analogue radio waves to reduce latency and operational costs. Its modular design also allows conventional tractors to be upgraded without replacing core engine components [27], making it more economically viable and accessible for smallholder farmers. By leveraging the reduced costs and increased efficiency of radio frequency technologies, this initiative seeks to facilitate a transition toward precision agriculture that improves operational efficiency and farmer comfort without overextending the economic capacity of operators.

2 Research methodology

2.1 Tools and materials

The equipment used in the research are 1) Two-wheel hand tractor (Kubota Yanmar EF 393 DT, 8.5 HP), 2) Red LED, 3) Grinding, 4) Electric welding, 5) Screwdriver, 6) Measuring tape (meter), 7) Pliers, 8) Fly Sky FS-i6, 9) Battery voltmeter, 10) Brake adjuster, 11) FS-iA6B receiver, 12) Solder, and 13) Stopwatch.

The materials used in the research are as follows: 1) Battery (12V), 2) Battery (40 Ah), 3) 2x car starter solenoid (12V), 4) Jumper cable, 5) Project board, 6) Relay, 7) 20 kg servo motor, 8) 3mm red spot cable, 9) 3mm black spot cable, 10) 2mm yellow spot cable, 11) Switch, 12) 2x male cable terminal (lug, locally known as *skun*), 13) 4x female cable skun, 14) M2 x 15 mm bolt, 15) M4 bolt x 80 mm,

16) Bolt M2 x 80 mm, 17) Electrical Insulation 3m, 18) Spacer Pcb 20 mm, 19) Voltage regulator/rectifier unit (commonly known as *kiprok* in Honda motorcycles), 20) M6 nut, 21) M8 nut, 22) Gas strap, 23) Rear hand brake cable, 24) 16 mm terminal, 25) 10 mm terminal, 26) Heat shrink 1 cm, 27) Heat shrink 3 cm, 28) Heat shrink 5 cm, 29) Door hinge, 30) Bumper clip, 31) Box x3, and 32) Box x6.

Only core components such as the FS-i6 transmitter and receiver, DC motors, servo motors, solenoids, relays, and Kiprok Honda (as the voltage regulator) were included in the final hardware wiring diagram to simplify the control layout.

2.2 Research procedures

This research begins with preparing research tools and materials. The next stage is the design of the control device, where components such as receivers, transmitters, and DC motors are integrated to convert remote signals into mechanical movements [28]. The control system is designed with two DC motors that independently control the left and right brake handles using pulleys and ropes to pull the steering lever, enabling the tractor to turn.

The throttle lever system was modified to adjust the speed with one DC motor that pulls or stretches the throttle rope based on remote commands. Three-speed levels were set, namely 3 cm (slow), 6 cm (medium), and 9 cm (fast) from the stop point, with a neutral function (A, B, C) to return the lever to the starting position. The steering modification is consistent with this configuration, using the same two DC motors controlling the brake handles as part of the turning mechanism rather than a separate motor.

Next, the control system assembly was carried out using a 12V battery downgraded to 6V through a DC buck converter to power the Fly Sky FS-i6 receiver and drive the control motor. The remote control regulates the servo power to pull the throttle lever and activates the clutch solenoid's transmission relay. The entire system was tested to ensure motor responsiveness, lever position accuracy, and signal stability before field tests were conducted to evaluate the overall performance of the prototype.

2.3 Equipment and land preparation

Preparation includes land observation, provision and checking of tools and materials, technical consultation, and briefing on the method of operating the two-wheel hand tractor. Hand tractor performance tests were carried out in the field with the observation of indicators to be measured: Theoretical capacity, adequate capacity, tractor working speed, tractor working efficiency, tractor wheel slip, ploughing depth, and fuel requirement.

2.4 Response speed

Measurement of response speed on hand tractors can be modified [28]. The first step in measuring the response speed of the solenoid is to prepare a stopwatch as the measuring instrument. This stopwatch calculates the time it takes for the solenoid to pull the sling rope connected to the tractor brake handle. Once the measuring instrument is ready, the measurement is carried out by timing how long the solenoid takes to activate the brake handle through the pulling motion of the sling rope. The measurement is repeated three times for each tested angle to ensure accuracy and reduce random errors. The time recorded from these three repetitions is systematically documented for every measured angle. After all the data is collected, an analysis is conducted to determine the solenoid's average response time and assess whether there are any significant differences in response time at the various measured angles. This analysis is crucial for evaluating the solenoid's performance consistency and understanding the angle's influence on its operational speed.

2.5 Tractor working speed

Tractor working speed is used as a variable for each predetermined treatment. The tractor speed was measured by activating the stopwatch when the tractor began operating to cultivate the soil using two transmission gear positions. The first gear position was used for starting, while the third and fourth gear

positions were used for road operation [29]. To calculate the working speed of the tractor, use Eq. (1) where v is speed (m/s), s is distance travelled (m), and t is time required (s).

$$v = \frac{s}{t} \quad (1)$$

2.6 Tractor wheel slip

The Amount of wheel slip is the difference between the tractor mileage during tillage and the theoretical tractor mileage in the same traction wheel rotation [30]. To calculate the wheel slip of the tractor, use Eq. (2) where S is the tractor wheel slip (%), S_b is the distance travelled by the tractor during tillage in wheel rotation (m), and S_0 is the mileage of the tractor without tillage in wheel rotation (m).

$$S = \left(1 - \frac{S_0}{S_b}\right) \times 100\% \quad (2)$$

2.7 Tool stability

The tool's stability on the hand tractor can be measured in the following way. The first step is to prepare the hand tractor to be tested and ensure it is in good condition. Testing is carried out on the servo motor for gas lever control. Stability testing is carried out by pulling the gas lever at a position of 8 cm, which is used as the deviation threshold for stable operation. Measurements of the stability of the gas lever are taken at distances of 30, 60, 90, 120, 150, 180, 210, 240, 270, and 300 meters. The treatment is repeated 3 times on the stability of the gas lever. The test is stopped if the movement becomes unstable, and the gas lever or clutch control mechanism is inspected to determine the cause of the issue.

2.8 Straight motion

Measurement of straight motion on a hand tractor can be done in the following way [28]. The measuring instrument is prepared with a measuring tape (meter) and a 20-meter track with sufficient width so that the hand tractor can run smoothly. The initial position of the hand tractor is in the middle of the test track axis, so make sure the hand tractor runs straight. Marks are prepared every 2 meters along the track. The tractor is run and measured. Each tractor travels 2 meters. The measurement results are recorded on each stake or mark provided.

2.9 Action provision

Measuring the action of the gas lever on a hand tractor can be done in several stages. First, prepare a measuring tool in the form of a ruler that is in good condition and has a high level of accuracy. Ensure the hand tractor throttle is off and the gas sling rope is installed correctly. Measurements start from an angle of 22.5°, which can be seen through the curve display on the remote control. Next, hold the ruler at the end and place it on the gas sling rope attached to the tractor. The measurement results are recorded in a notebook. This step is repeated for measurements at angles of 45°, 67.5°, and 90° to obtain complete data.

2.10 Fuel requirement

Fuel requirements can be calculated by Eq. (3), where Q_f is the amount of fuel used (litres/hour), V is the volume of fuel used (litres), and t is the working time (hours).

$$Q_f = \frac{V}{t} \quad (3)$$

3 Results and discussion

3.1 Control system design

The system design begins with a drive circuit that controls the car's starter solenoid, which pulls the left and right clutch levers. In the control box circuit, the receiver unit receives command signals from the transmitter and sends them to the components and servo motors that pull the gas lever [31]. The entire central power control system is protected and regulated by an 80-ampere relay, functioning as a high-capacity electronic switch to ensure current stability and

safety during operation. To ensure consistency in performance, all servo motors used for the braking and throttle systems were calibrated using a standardized PWM signal tester before testing. This calibration process minimized variations in motor strength that could affect response time.

Fig. 1 shows the Control Box circuit schematic, designed to control motors and actuators wirelessly. Where the description in Fig. 1 is: 1. 40 Ampere battery, 2. X3 type switch box measuring 10.1 cm x 7.7 cm x 3.3 cm, 3. Control box circuit, 4. Gas lever control servo motor, 5. Car starter solenoid clutch lever control, 6. Car starter solenoid indicator LED light, and 7. 80 Ampere relay. The circuit starts from a 40-amp battery (1), the system's primary electrical power source. The current from the battery flows to the X3-type switch box (2), which functions as a manual control panel measuring 10.1 cm x 7.7 cm x 3.3 cm. It is designed to accommodate the switches and other control components. From the switch box, the electric current is distributed to the control box circuit (3), which regulates the control signals for the actuator components based on user commands. One of the actuator components that is controlled is the servo motor (4), which functions to move or adjust the gas lever precisely. In addition, the control box also regulates the car's starter solenoid (5), which functions as an automatic clutch lever driver in the mechanical system. To provide a visual indication of when the solenoid is active, an LED indicator light (6) is installed, which lights up as a sign that the solenoid is working. The entire central power control system is protected and regulated by an 80 Ampere relay (7), which functions as a high-capacity electronic switch to ensure the stability and safety of large electric currents while the system operates.

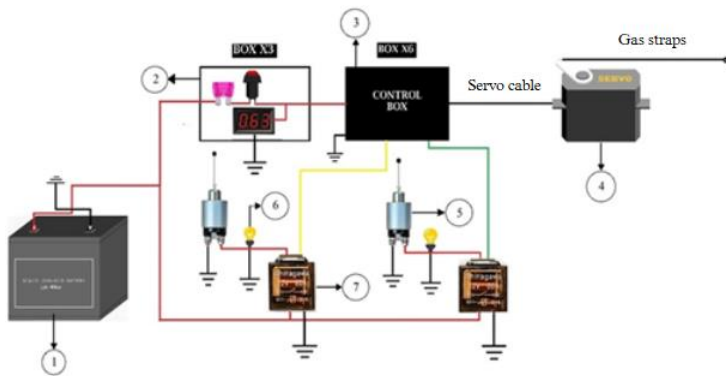


Fig. 1. Schematic of the drive circuit

In designing the control system, a control box circuit diagram is also created, which is presented in Fig. 2, where the description in Fig. 2 is: 1. DC Buck Converter, 2. Receiver FS – iA6B, 3. Motor servo, 4. ESC, and 5. Relay switch 6 volt. Fig. 2 explains the control box circuit diagram starting from the DC Buck Converter (1). This tool reduces the voltage from the primary power source to suit the needs of the electronic devices in the system.

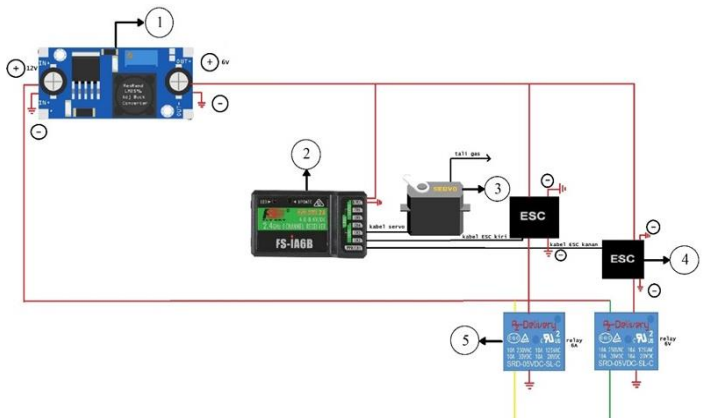


Fig. 2. Control box circuit schematic

This regulated voltage is then used to turn on the FS-iA6B receiver (2), which receives control signals from the transmitter or remote

control. According to user instructions, this receiver then sends a signal to the servo motor (3) to regulate mechanical movement, such as opening or closing the lever. In addition, the receiver also sends a signal to the Electronic Speed Controller (ESC) (4), which regulates the speed and direction of the motor based on the PWM signal received. To control additional devices such as lights or other actuator systems, a 6-volt relay switch (5) is used, which functions as an automatic electronic switch controlled by signals from the receiver. This circuit forms an efficient and integrated remote-control system between control components, actuators, and power regulator systems.

3.2 Response speed

The response speed test is carried out to determine the time lag in the control system and to ensure that the control system is functioning correctly and is responsive to commands given by the operator via the Fly Sky FS-i6 remote control. The average delay for brake activation was 0.47 seconds (right brake) and 0.59 seconds (left brake), while the throttle system had an average delay of 1.23 seconds. These values confirm that the system operates with an overall average delay of less than 1.5 seconds across all functions, consistent with the statement in the abstract.

Fig. 3 now includes the throttle response time, and the legend has been corrected for clarity. The left brake handle has a longer response time (0.59 seconds) than the proper brake handle (0.47 seconds). This asymmetry is primarily attributed to hardware differences in servo motor torque. The calibration process, as described in the design section, helped reduce but did not fully eliminate these differences.

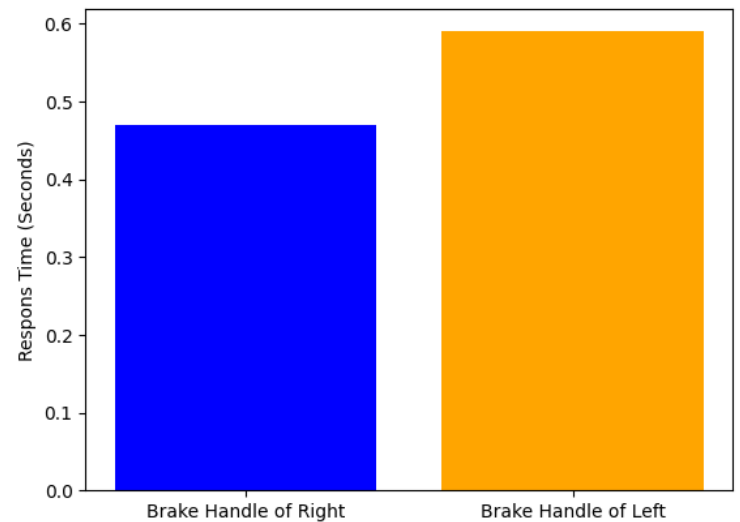


Fig. 3. Response times for two different brake handles on a remote-controlled hand tractor

3.3 Tractor working speed

Speed is a quantity that measures the change in position or distance of an object per unit of time. Speed in physics is a vector quantity, which means it has a direction or magnitude. The time it takes an object to move from one location to another is called velocity. The Average distance an object travels during a period is its average speed. The unit of speed used in the international system of units is meters per second (m/s) or (km/h). The results of the average working speed of a two-wheeled tractor using a sky FS-I6 type remote control are presented in Fig. 4.

Fig. 4 explains that the position of the gas lever, 3 cm from the stop position, is 1.872 km/h, at a position of 6 cm from the stop position is 2.628 km/h, and at a position of 9 cm from the stop position is 3.096 km/h. Theoretical and practical field capacities derived from these speeds were 0.11 ha/hour and 0.09 ha/hour, respectively, with a calculated working efficiency of 82%. These values fall within the typical range for two-wheeled tractors operating under smallholder farm conditions.

The average value is an increase in the speed of the tractor's travel distance. The faster the tractor, the shorter the time required to

plough the land. Factors that affect the speed of a two-wheeled tractor during field testing are land conditions, loads carried, tractor power, wheel size, speed settings, and operators when operated using the remote control.

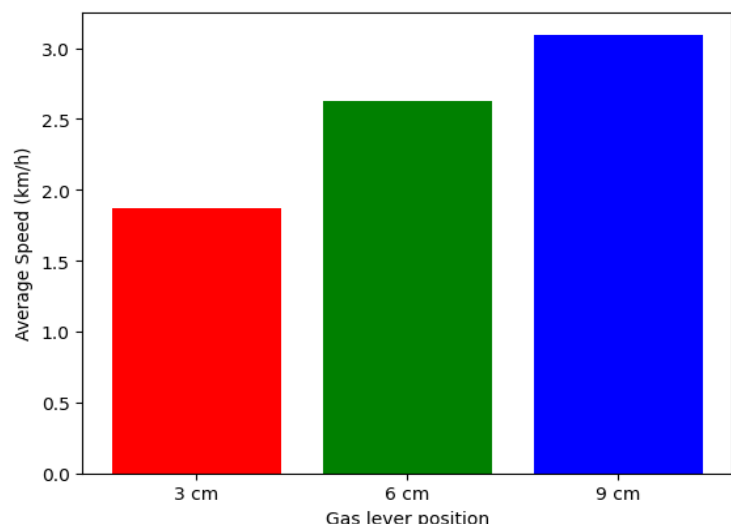


Fig. 4. Working speed of a two-wheeled tractor using a Fly Sky FS-i6 type remote control

Land conditions that are not level, many tree stumps, and land that is not clean will decrease because of the difficulty of the two-wheeled tractor in passing through obstacles in the land, while the two-wheeled tractor will be smoother on flat land without obstacles [28]. Excessive loads will affect the tractor's ability to accelerate and stabilize speed when moving forward or turning the tractor. The size of the two-wheeled tractor plays an important role in speed. Larger wheels can provide higher speeds because they have a longer distance per wheel rotation. Two-wheel tractors using remote controls are equipped with speed settings that allow the operator to have the desired speed according to the task being performed. Speed settings can limit or increase the maximum speed of the two-wheel tractor using the remote control [30].

3.4 Tool stability

The stability of the remote hand tractor gas lever control is measured based on the output from the servo motor. The servo motor is automatically controlled using a remote control to be controlled at a certain distance. Testing is done by observing the gas lever control on the servo motor, as shown in Fig. 5.

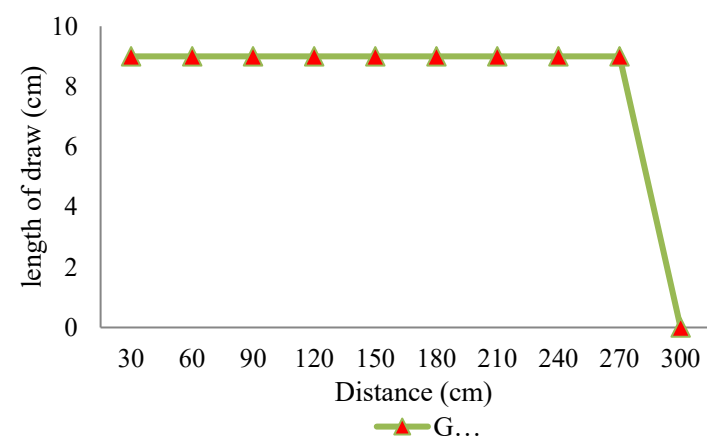


Fig. 5. Gas lever servo stability test results

Fig. 5 describes the stability test of the throttle lever servo that can pull a 9 cm throttle lever load. The abscissa in Fig. 5 has been corrected to clearly represent distance (m), and the legend differentiates between stable and unstable operation. The test was successful when the throttle lever servo pulled a 9 cm load at a 30–270 meter distance. At a distance of 300 meters, the device stopped because the servomotor and dynamo could not be connected. This shows that the communication and power systems from the

controller to the servo are still effective up to a distance of 270 meters. Using wireless communication (e.g., signal or Wi-Fi) indicates that the signal range is still stable up to that distance, the servo and dynamo work optimally in this range. At a distance of 300 m, it failed because the signal weakened exponentially based on the distance, causing a disconnect between the transmitter and receiver. ESP8266/ESP32 with Wi-Fi is also limited to around 200–300 meters in open spaces. In addition, due to the long cable system or weak battery, there may be a voltage drop, so the servo does not receive enough power to work. A dynamo load that is too large at long distances can also cause system overload [28].

3.5 Straight motion

Straight motion testing is conducted to measure the difference in the deviation value of the hand tractor wheels from the initial condition (baseline) when driven via a remote control operated by the operator. The test consists of three stages, which include (1) testing on a straight road with the gas lever placed 3 cm from the stop position, (2) placing the gas lever at a position of 6 cm from the stop position, and (3) placing the gas lever at a position of 9 cm from the stop position. The position of the gas lever that is further away from the stop position indicates an increase in the hand tractor's speed, as seen in Fig. 6.

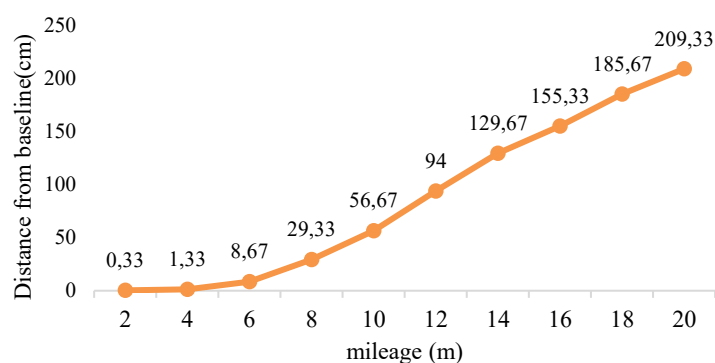


Fig. 6. Straight motion test of the hand tractor

Fig. 6 shows the straight motion test of the hand tractor carried out at three different speed levels. In the test results in straight motion tests I, II, and III, the hand tractor moved normally following the baseline according to the standard speed. When it reached the middle of the track, the hand tractor moved away from the standard speed used as a benchmark. This condition occurs because the ground surface is uneven due to initial processing, which causes the auxiliary wheels to be unable to follow the baseline. Several factors that affect the straight motion speed of the hand tractor include: 1) tractor conditions, 2) soil conditions, 3) soil processing patterns, 4) topography of the area, 5) size and shape of the plot, 6) vegetation conditions on the ground surface, and 7) operator skill level [29]. The hand tractor can move to deviate to the right of the baseline since the beginning of the straight motion test II. The three straight motion tests of the hand tractor showed a change in forward direction in the middle of the track. The most significant deviation value in the straight motion test of the two-wheeled tractor controlled by the remote control was recorded at 240 cm to the left of the baseline in the straight motion of test I. The deviation from the baseline in the hand tractor when moving forward is caused by the slip on the right wheel, which is higher than the left wheel [32]. The results of the larger percentage of slip on the left wheel cause the hand tractor to deviate to the right. The accuracy calculation in straight motion is measured based on the movement of the hand tractor from a straight position, controlled using a remote control system [33]. The accuracy of straight motion is measured using a meter [17].

3.6 Action provision

Action is carried out to determine whether a tool can produce movements by the command, and is focused on the control carried out via the buttons on the remote control, so that the desired speed can be set [12]. Speed regulation is carried out through the control of

the gas lever at angles of 22.5°, 45°, 67.5°, and 90°. The use of control on the remote control makes it easier for users to operate the tool, as seen in Fig. 7.

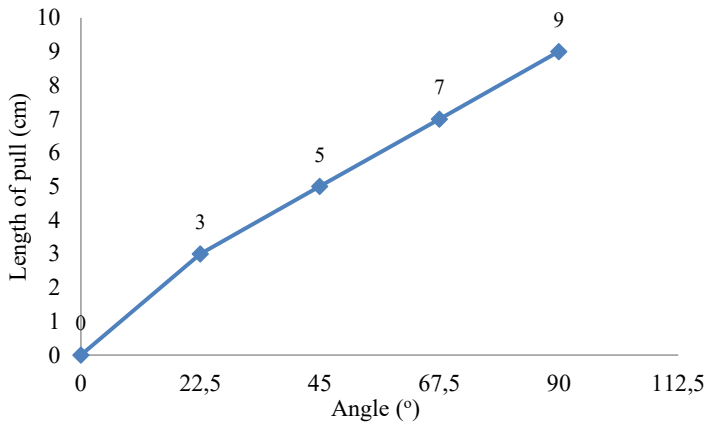


Fig. 7. Speed regulation was through the control of the gas lever at angles of 22.5°, 45°, 67.5°, and 90°

The action test was conducted at angles of 22.5°, 45°, 67.5°, and 90°. The results obtained from the action test at angles of 22.5°, 45°, 67.5°, and 90° were 3 cm, 5 cm, 7 cm, and 9 cm, so the increasing angle of degrees caused the pull length of the gas lever servo motor to be higher on the two-wheeled tractor. This can be seen in the linear relationship between the rotation angle and the pull length. In addition, there is a servo rotation motion conversion system into translational motion on the gas lever, running efficiently and proportionally. The larger the servo angle, the greater the linear displacement from the lever's end because the circle's arc is getting longer [34].

3.7 Wheel slip

Wheel slip is the loss of forward speed caused by operational loads in the field. The reduced speed of the tractor when working with a load compared to the potential speed of the tractor indicates wheel slip in tractor traction. Wheel slip can occur in dry or wet soil conditions, depending on the tractor load and soil conditions. The wheel slip is affected by vegetation conditions, which can inhibit or delay the tractor's speed because the rotating fins are covered by bushes or reeds [35].

Based on Fig. 8, it can be seen that the wheel slippage in the first repetition of soil processing was 11.25%, the wheel slippage in the second repetition was 12.14%, and the wheel slippage in the third repetition was 10.85%. The wheel slippage obtained from each repetition is included in the SNI standard, which is $\leq 25\%$. Factors that affect wheel slippage, such as land surface conditions (smooth, rough, and moist), can affect the ability of the tractor wheels to maintain traction.

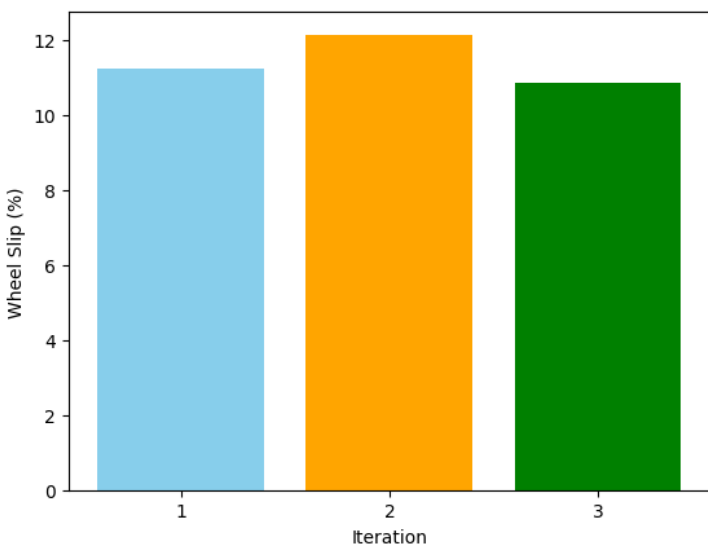


Fig. 8. Iteration of treatment on wheel slippage (%)

Slippery or muddy surfaces can increase the risk of wheel slippage. The load carried by a two-wheeled tractor plays a role in wheel slippage because excessive or uneven loads can cause slippage due to excessive pressure on the wheels, which reduces traction. The tread pattern of the two-wheeled tractor tyres and their conditions affect traction and slip resistance; tyres with a sharp tread pattern can provide better traction on uneven or slippery surfaces [36]. Excessive speed can increase the risk of slippage, especially on unstable or muddy surfaces. The operator's skill in managing the vehicle and applying proper driving techniques can affect the level of wheel slip; techniques such as smooth throttle, proper braking, or appropriate gear changes can help reduce wheel slip. The performance that can be produced by a tractor is influenced by the condition of the traction equipment, soil conditions, soil surface conditions, and the interaction of the traction equipment with the soil [29].

3.8 Fuel requirements

Visualization of fuel requirement measurements using a measuring cup to measure fuel requirements on a two-wheeled tractor when using the Fly Sky FS-i6 type remote control. Before operating a two-wheeled tractor, the gas tank must be filled. The two-wheeled tractor runs for 10 minutes on a 240 m² plot. After the two-wheeled tractor has finished running, the gas in the tank will be replaced using a measuring cup to calculate the fuel consumption value. Fuel measurements are carried out every time they are repeated. To calculate fuel consumption during tractor operation, look at the initial fuel height in the tank and the final fuel height after soil processing is complete, then subtract the added value. From the added value [37]. The longer it takes to cultivate the land, the more gasoline the two-wheeled tractor consumes.

Fig. 9 explained that the results of the average fuel requirement with three repetitions are 0.33 liters/hour, with each test of 0.24 liters/hour, 0.36 liters/hour, and 0.39 liters/hour. Differences between repetitions were primarily due to variations in turning time and ploughing depth, as plots with more irregular edges required more manoeuvring and thus consumed more fuel.

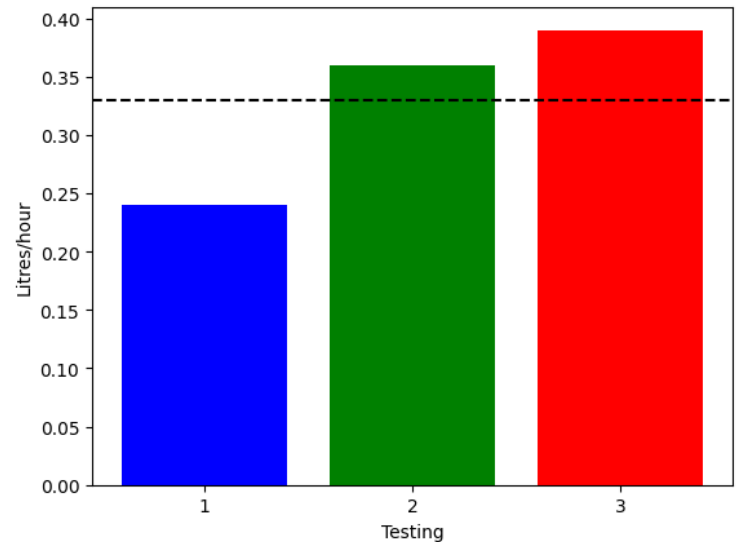


Fig. 9. Testing of the testing fuel requirement

The previously unfounded statements related to tank refill location and general fuel efficiency have been removed. One of the factors that causes the fuel measurement to vary is the position of the tractor. If the land where the tractor stops is uneven (sloping), then the gasoline measurement seems full because of the sloping land. The location of the tractor refill on flat land shows that the tank is not yet full [38]. The repetitions carried out are another factor that makes a difference in fuel consumption results. The effect of differences in fuel consumption in each repetition depends on the time to process, the depth of the ploughing results, and the turning time. These factors influence fuel consumption because the Amount of fuel that enters the cylinder to drive the gear lever to implement (puddler) and the operation time require a lot of fuel consumption. This is supported

by research that shows that land processing activities are related to the time spent due to rotation during agricultural land processing. Land cultivation must consider using a tractor to be more effective and efficient in saving on fuel purchasing costs [17].

3.9 Affordability analysis

Beyond performance, the developed remote-control system demonstrates significant cost advantages compared to existing agricultural automation systems. The total cost of components used in this research was approximately USD 210 (equivalent to IDR 3.4 million), compared to commercial IoT- or GPS-based tractor automation systems that can cost USD 600–1,000 per unit [23, 24]. This cost differential underscores the affordability of the proposed system and aligns with the design objective of ensuring accessibility and ease of adoption for farmers with limited capital resources.

4 Conclusions

This research successfully designed and implemented a remote-control system for two-wheel hand tractors using the Fly Sky FS-i6 transmitter. The system demonstrated reliable performance in remotely controlling throttle, clutch, and brake functions by integrating DC motors, servo motors, and solenoids. Field tests showed that the system responded effectively with minimal delay (≤ 1.5 seconds) and enabled the tractor to operate at variable speeds of 1.872 km/h, 2.628 km/h, and 3.096 km/h, depending on throttle positions.

The developed system maintained acceptable levels of wheel slip ($\leq 12\%$) and achieved a consistent ploughing depth of 14–16 cm across different field conditions, meeting standard soil preparation requirements. Fuel consumption averaged 0.33 litres per hour, indicating efficient energy use during operation. Stability tests confirmed the servo's ability to respond up to a 270-meter range, with minor signal loss occurring at 300 meters.

Straight-line movement and directional control remained accurate, with deviations caused primarily by uneven terrain and wheel traction imbalance. The modular design allows easy integration into existing hand tractors without replacing the main engine, making the system economically feasible for smallholder farmers due to its use of accessible components and upgradeable structure. In addition, the remote-control capability reduces operators' exposure to vibration and physical exertion, improving operator comfort and reducing fatigue compared to conventional manual operation. This system offers a promising transitional solution toward affordable precision agriculture for smallholder farmers, enhancing field efficiency and reducing reliance on intensive manual labour.

Future research should investigate the incorporation of obstacle detection systems and enhanced signal processing capabilities to further optimize autonomous functionality across diverse agricultural environments. In addition, further development is recommended to evaluate critical parameters such as control system responsiveness, straight-line accuracy, throttle, clutch and brake modulation, terrain adaptability, energy efficiency, user interface and safety, scalability and modularity, as well as data logging and analytics. These improvements will ensure the system can be scaled and adapted for wider agricultural applications.

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