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CONTENTS

Design and development of a four-wheel remotely controlled weeding machine

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ABSTRACT: Weed management remains a critical challenge in modern agriculture, adversely affecting crop productivity, input-use efficiency, and profitability. Prolonged dependence on chemical herbicides has resulted in herbicide-resistant weeds, environmental contamination, and regulatory constraints, while labour shortages and rising costs limit the effectiveness of manual and semi-mechanical methods.This study presents the design and development of a four-wheel remotely controlled mechanical weeding machine aimed at reducing labour dependency and chemical herbicide use. The system features a four-wheel-drive configuration powered by four 250 W BLDC motors operated through H-bridge motor driver modules, enabling precise speed and directional control. A 2.4GHz radio-frequency transmitter–receiver system is used for remote operation, while a linear actuator allows controlled engagement of the weeding implement. The overall design emphasizes modularity, operational safety, and ease of field serviceability, providing a scalable and sustainable mechanical weed management solution.

Keywords: Drudgery reduction, mechanical weeding, remote controlled, small farms

Agriculture is increasingly challenged by labour shortages, rising production costs, and environmental concerns. Rapid urban migration and an ageing rural workforce have significantly reduced the availability of farm labour, particularly for labour-intensive operations such as weeding, leading to delayed field operations and reduced crop productivity (FAO STAT, 2022).At the same time, prolonged reliance on chemical herbicides has resulted in herbicide-resistant weed populations, environmental contamination, biodiversity loss, and stricter regulatory constraints, thereby reducing the sustainability and effectiveness of chemical weed control practices (Oerke, 2006). Because weeds compete with crops for nutrients, moisture, light, and space, they continue to cause significant yield losses. As a result, effective and environmentally friendly weed management techniques must be developed. Mechanical weed control is widely regarded as a viable alternative to chemical methods due to its effectiveness, environmental compatibility, and positive effects on soil health and crop growth (Davies *et al.,* 2002). Conventional mechanical tools such as finger weeders, harrows, rotary hoes, and brush weeders have demonstrated effectiveness in row crops (Langsenkamp *et al*., 2014; Melander *et al*., 2015; Pannacci *et al.,* 2020); however, their adoption remains constrained by high labour requirements and operator fatigue.Recent advances in agricultural robotics have enabled the development of vision-based, sensor-guided, laser-assisted, and RTK-GPS-based weed control systems capable of selective inter-row and intra-row weeding (Astrand *et al.,* 2002; Tillett *et al*., 2008; Norremark *et al.,* 2012; Lottes *et al.,* 2017; Xiong *et al.,* 2017). Despite promising performance, the widespread adoption of fully autonomous robotic weeders remains limited due to high capital costs, technical complexity, and maintenance demands, particularly for small and medium-scale farmers.

In this context, remotely controlled mechanical weeding platforms provide a practical and cost-effective transitional solution between manual implements and fully autonomous robots. This study introduces the design and development of a four-wheel remotely controlled mechanical weeding machine emphasizing modularity, operational safety, and adaptability to varying field conditions. Section 2 details the system concept, design methodology, and construction. A discussion emphasizing the importance and potential of the suggested strategy comes next, followed by conclusions with recommendations for the future.

MATERIALS AND METHODS

The weeding platform's design is built on a four-wheel-drive setup that is directed and guided by an Electronic Speed Controller (ESC) connected to a radio transmitter-receiver system. Fig. 1 shows the weeding machine's conceptual layout. The following criteria were taken into consideration when designing the weeder machine:

- The primary objective of this study was to design and develop a lightweight, robust, and remotely controlled four-wheel-drive weeding platform capable of performing effective inter-row weed control under diverse agricultural field conditions. The specific design objectives were as follows:
- To develop a structurally stable yet lightweight chassis capable of withstanding harsh agricultural environments while ensuring operational safety and mechanical reliability. All components were arranged to maintain proper weight distribution and stability during field operation. The machine was designed as a radio-frequency remote-controlled four-wheel-drive vehicle to enhance manoeuvrability and operator safety.
- To ensure smooth and reliable movement on agricultural terrain, the selected drive motors were required to generate sufficient torque to overcome soil resistance and surface irregularities. The operational speed of the machine was designed to be wirelessly adjustable through a remote controller to improve agility and control during field operations.
- To achieve effective mechanical weed control, the working tools were designed to operate just below the soil surface to cut or uproot weeds without soil clogging or jamming. Sweep tines were selected as the primary active weeding elements for efficient weed management in inter-row crop situations. The rear-mounted weeding unit was conventionally designed and adequately insulated to ensure durability and consistent performance during operation.
- To enable reliable performance under varying field and environmental conditions, the machine was designed to operate effectively on farm roads, cultivated fields, grassy surfaces, and mildly sloping terrain. The power supply system was selected to provide stable and continuous operation until battery depletion. Additionally, the platform was designed to function under typical agricultural climatic conditions.

Details of four-wheel drive prime mover

Weeder is a mechanical weeding tool for field crops that can be operated remotely. It is made up of a sweep-style weeding device and a prime mover. Four DC motors, a H bridge high power motor driver module, a 2.4 GHz transmitter receiver module, and other components make up the main mover. Four DC motors and an electronic component are driven by a 24 V, 70 Ah power supply. A 24 V power output was obtained by connecting two 12 V batteries in series. In order to produce adequate torque to propel the car through motor drivers, the four motors were fastened to the wheels. The DC motors can run at 120 rpm, 24 V, and 250 W. Table 1 provided the four-wheel drive prime mover's exact specifications.

Table 1: The four-wheel drive prime mover's detailed specifications

S No.	Particulars	Specification
1.	Structure	Main Frame: 900×400 mmWheels: 4 (380 mm dia) Height: 530 mm (adjustable) Weight: 60 kg (approx..)
2.	Power source	Battery(2) - 24V 70 Ah lead acid
3.	Motor	DC Motor(4)- Voltage: 24V, 120rpm- Rated current: 13.4A- Rated Power: 250 W- Weight : 2.84 kg
4.	Electronic speed controller	Motor driver(4)- Voltage: Input 30 V- Current: 43 A per channel- Weight : 67 g.
5.	Receiver and transmitter	- No of channels: 6- Power supply: DC 4V-14V- Frequency:2.4 GHz- Distance: 400-600 m on ground surface- -Weight -67 g

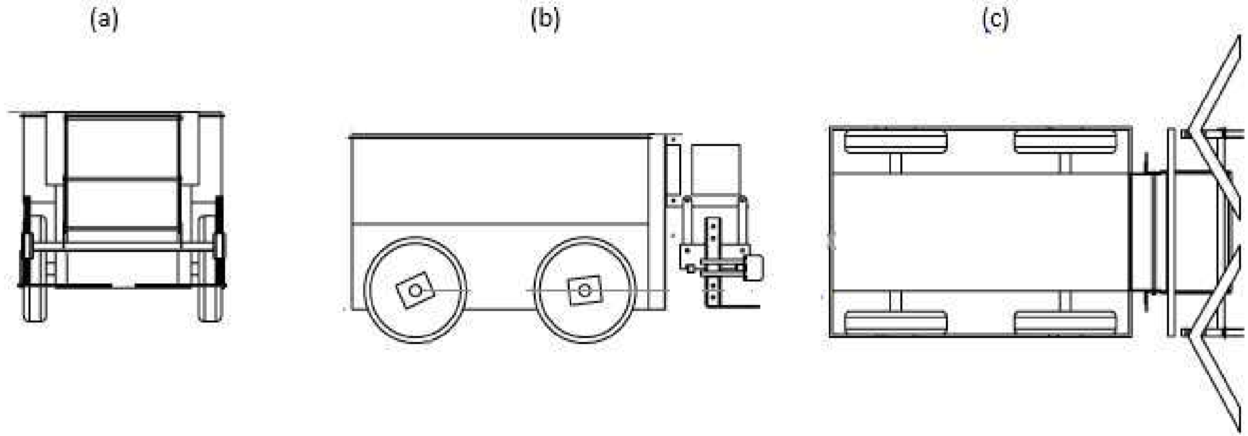

Fig.1:Weeder conceptual diagram (a) front view, (b) side view, and (c) top view

Selection of Drive Motor

Four identical brushed DC motors were used. A simplified vehicle traction model was adopted to estimate the required tractive force, torque, and power (Junyao *et al.,* 2009).

Step 1: Contact Area of Tyre–Soil Interface

A=0.27×b×d (1)

Where:

- b = tyre width = 101.6 mm
- d = tyre diameter = 381 mm
- 0.27 = empirical constant for hard tyre–soft ground givenby Grecenko (1995), Diserens *et al.,* (2011)

A =0.27×101.6×381=10451.59mm^2

Step 2: Gross Traction Force (F)

Gross Traction,F=A×C+WtanØ (2)

Where:

- A=(Contact area of soil)=10,462 mm^2
- C=(Cohesion)=0.002 kg/ (sandy clay loam soil) (Terzaghi *et al.,* 1996; Das, 2016).
- W= (Weight of the machine) =130 kg
- Õ=30°

F=A×C+W tan Ø=(10451.59×0.002)+130×tan (30)=941.35N

Step 3: Rolling Resistance (R)

Rolling resistance, R=×W (3)

Where

- Crr =Coefficient of rolling resistance; 0.02 (Wong, 2009; Wong, 2010; Gillespie, 1992)
- W = Weight of the machine, N

R = Crr × W= 0.02×130 = 25.5 N

Step 4: Net Traction Requirement (T)

Net Traction,T=F-R (4)

T=941.35→25.5=915.85N

Step 5: Traction per Wheel

Since 4 wheels are driven

T_{pw} = 915.85/4 = 228.9 N

Step 6: Wheel Torque Requirement

T=T_{pw} ×r (5)

=228.9×0.1905=43.61 Nm

Step 7: Power Requirement per Motor

P=τ×ω=43.6×2.62=114.23 W (6)

Step 8 Total Power Requirement

P *total* = 4114.22 = 456.92 W

Based on traction and power calculations, each drive wheel requires approximately 44 N·m torque and 115 W power. Considering field losses and safety margin, 250 W DC motors were selected for the four-wheel weeding platform.

Battery backup duration

In fact, power is a crucial component needed to operate the robot. Therefore, a battery pack must be chosen in order to satisfy our energy needs. Here, we used lead acid batteries with a capacity of 70 Ah and a voltage of 12 V. Each of the four DC motors used here is 250 W.

Thus, P = 24V × 70Ah = 1680 Wh is the total power.

The vehicle's power requirement is 457 W.

Consequently, 3 hours(approx.) is the battery run time.

Rover design and development

The four primary factors that influence the design of the robot prime mover are the intended use, load-carrying capacity, stability, structural strength and safety. The structure used in agricultural operations must be robust enough to sustain operational loads while preserving the proper level of stiffness and stability in the field.Because these elements directly affect system cost and performance, the robot's physical size, motor power, and battery capacity must all be optimally matched for an effective design.The developed weeding robot's prime mover, which consists of both mechanical and electronic subsystems, is its fundamental component. The mechanical assembly includes the electronic system mounting frame (1),flanges (2), wheel mounting frame (3),weeding blades (4), actuator mounting unit (5) and related structural components. DC motors, motor driver modules, the battery pack, a transmitter–receiver unit, and the weeding tool actuator control module make up the electrical subsystem. Fig. 2 shows a three-dimensional CAD model of the designed prime mover made with SolidWorks software.

Weeding unit details

The Weeder mechanically weeds field crops using sweep-type blades. The weeder unit's soil engagement and depth adjustment are controlled by a linear actuator. A 12 V, 7 Ah power supply powers it. The weeding device can be operated remotely and moved up and down to change the depth. Two sweep

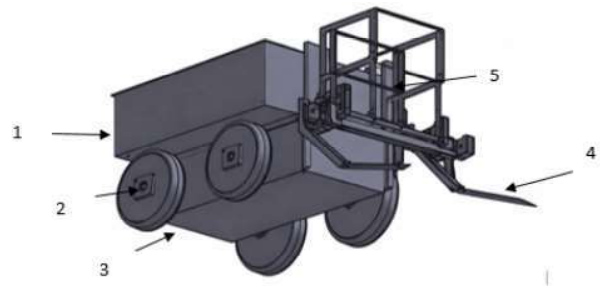

Fig.2. CAD model of the designed prime mover:1) electronic system mounting frame;2) flanges;3) wheel mounting frame 4) weeding blades;5) actuator mounting unit

tynes, which are fixed on the lower back side of the weeder frame with the aid of a tool holder, were utilized as weeding tools.

Principle of Operation

The operational mechanism of the weeder is illustrated in Fig. 3. The machine is designed for remote operation over a distance of approximately 400–600 m. Electrical power is supplied by a 24 V battery system formed by series connection of two 12 V batteries, which drives the DC motors fitted to

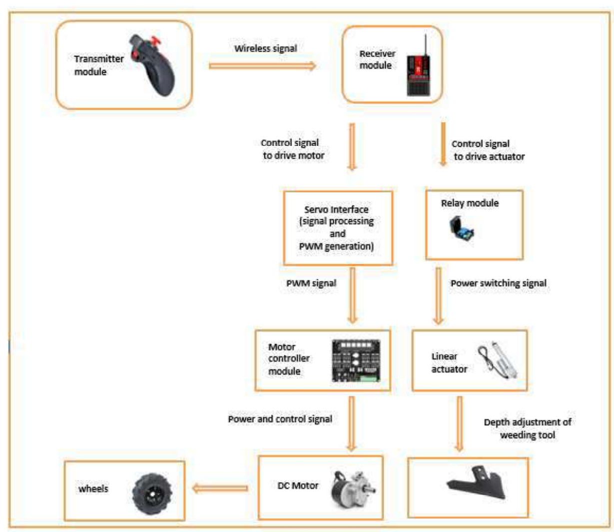

Fig. 3: Overall block diagram of the system

Table 2: Weeding unit specifications in detail.

S No.	Particulars	Specification
1.	Weeding tool	Sweep tynes: 200 mm (2 nos.)Width of cut: 600 mm
2.	Power supply	Battery (1) - 12V 7 Ah lead acid
3.	Soil engaging motor	Linear actuator type- Voltage: 12V, - speed :5mm/sStroke length :500 mm- Rated load: 6000 N- Weight : 2.5 kg

the wheels. Furthermore, a transmitter–relay system is incorporated to allow remote adjustment of the depth of operation of the weeding unit.

CONCLUSION

The present study successfully demonstrated the design and development of a four-wheel remotely controlled weeding machine for small-scale and precision agricultural applications. The system integrates mechanical, electrical, and control subsystems, including a robust chassis, four-wheel drive mechanism, linear actuator–based weeding unit, DC motors, motor controllers, and a battery-powered energy supply. A simplified traction-based analytical model was employed to estimate tractive force, torque, and power requirements, which guided the selection of appropriate drive motors and battery capacity. The developed prototype confirms the feasibility of a compact and modular remotely operated weeding platform.The remotely controlled approach provides a practical and cost-effective alternative to fully autonomous systems, particularly suited to small and medium-scale farms. Maintaining the operator in the control loop reduces system complexity while ensuring safe and flexible operation in unstructured field environments. This approach allows real-time manoeuvring and adaptability to varying crop and weed conditions without the need for complex sensing or computational infrastructure.Overall, the proposed platform contributes to small-scale mechanized weeding by offering a scalable and customizable solution that reduces labour dependency. The design methodology and analytical framework presented in this study can serve as a foundation for developing similar agricultural robotic platforms and for future upgrades toward intelligent and autonomous weed management systems.

FUTURE SCOPE

Although the present study is cantered on the design and development of a four-wheeled remotely controlled weeding machine, several improvements may be considered in future research to enhance its performance and adaptability under practical field conditions. Comprehensive field evaluations under diverse soil types, crop geometries, and weed densities should be conducted to assess key performance indicators such as field capacity, weeding efficiency, energy consumption, wheel slippage, manoeuvrability, and overall operational stability. These experiments would also help validate the theoretical traction and power calculations and identify design limitations during prolonged field operation. The developed system can be upgraded to a semi-autonomous or fully autonomous platform by integrating on board control algorithms. Semi-autonomous operation may include automated speed regulation, straight-line navigation, and tool actuation under operator supervision, while fully autonomous operation may incorporate path planning, obstacle avoidance, and adaptive speed control. Further improvements can be achieved by integrating navigation sensors such as GPS, IMU, wheel encoders, and proximity sensors for accurate positioning and row-following. Additionally, the incorporation of vision-based weed detection using cameras and machine learning techniques would enable selective and site-specific weed control, contributing to improved energy efficiency and sustainable precision agriculture.

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