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Design and Development of Multi-Utility Battery Operated Self-Driven Cultivation Tool for Small Farmers

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Abstract: Small and marginal farmers face challenges such as high labor costs, fuel dependency, and lack of affordable mechanization. This paper presents the design and development of a multi-utility battery-operated self-driven cultivation tool tailored for small-scale farming. The system utilizes a 48V BLDC motor powered by a $LiFePO_4$ battery, ensuring efficient, eco-friendly, and low-noise operation. A modular chassis architecture allows rapid interchange of implements such as rotavator, cultivator, plough, sprayer, trolley, and ride-on seat, enabling diverse operations including soil preparation, sowing, spraying, and light transport within a single platform. Comprehensive design calculations validate adequate tractive effort and energy efficiency for uneven terrains, while prototype testing demonstrates reduced operator fatigue, lower chemical consumption, and improved productivity. The compact form factor, ergonomic design, and silent drive system make the tool especially suitable for women and elderly farmers, enhancing inclusivity in agricultural mechanization.Beyond immediate utility, the innovation establishes a foundation for future advancements such as smart power management, regenerative braking, autonomous navigation, and expanded attachment ecosystems. By integrating sustainability with affordability, the project exemplifies how modern engineering can empower smallholders, reduce reliance on fuel-based equipment, and promote scalable rural technology solutions.

Keywords: Battery-operated agriculture tool, BLDC motor, small farmers, cultivation machine, sustainable farming, modular design.

I. INTRODUCTION

Agriculture remains the backbone of India's rural economy, with the majority of farmers being small and marginal. However, they face challenges such as labour shortage, high fuel costs, and lack of access to mechanized tools. In India, more than 80% of farmers belong to the small and marginal category, owning less than 2 hectares of land. These farmers often cannot afford tractors or mechanized equipment due to high costs and limited field sizes. The need is to design a compact, battery-powered, self-driven, and multi-functional cultivation machine that can assist them in daily farming operations with minimal physical effort and operational cost.

II. PROBLEM STATEMENT

The majority of available farm mechanization solutions are either too expensive, large, or fueldependent. Small engine operated tools incurred a fuel cost, maintenance, issues like vibrations, pollution, etc.

Small farmers face the following key challenges:

- High labour dependency and cost.
- Lack of affordable mechanization.
- Difficulty in working on narrow field rows.
- Unavailability of multi-functional tools in a single platform.

III. OBJECTIVES

- •To design and develop a compact, battery-operated, self-propelled cultivation tool tailored for small and marginal farmers.

- To integrate multiple farming functionalities such as inter-cultivation, spraying, weeding, seed sowing, and fertilizer application in a modular format.
- To ensure ease of operation, especially for women and elderly farmers.
- To promote low-carbon, noise-free farming operations through clean energy technology.

IV. MARKET SURVEY

A. *Existing Technologies*

Various mechanization solutions are available for small-scale farming; however, each has limitations. Fuel-based power tillers are widely used due to their versatility but suffer from high fuel consumption, noise, and maintenance requirements. Mini-weeders are lightweight and affordable but are limited to basic operations and cause operator fatigue due to continuous vibration. Electric weeders offer a low-cost alternative; however, they lack sufficient torque, battery endurance, and modularity. Sprayers are effective for chemical application but cannot perform soil preparation tasks, forcing farmers to rely on multiple tools.

B. *Global Trends*

Recent global developments indicate a shift toward sustainable and compact agricultural mechanization. Electrification of farm tools is rapidly increasing in regions such as China, Israel, and Europe due to environmental concerns and rising fuel costs. BLDC motor-based systems are replacing internal combustion engines owing to their higher efficiency and low maintenance. Additionally, modular robotic platforms such as FarmDroid and Naïo Robotics demonstrate the potential of lightweight, autonomous machines for precision farming. Advances in battery technology are also enabling longer runtimes and faster charging.

C. *Research Gap*

Despite technological advancements, several gaps persist in the Indian context. Existing systems lack a compact, multi-functional electric platform capable of handling diverse farming operations. Limited torque and battery capacity restrict performance in challenging soil conditions. Furthermore, the absence of modular attachments, poor ergonomic design, and dependence on imported battery systems increase costs and reduce accessibility for small farmers.

D. *Scope for Development*

The identified gaps present opportunities for innovation in agricultural mechanization. A self-driven, battery-operated modular cultivation tool can address these challenges by providing high torque, extended runtime, and multi-functional capability. Incorporating ergonomic design will enhance usability for diverse users, including women and elderly farmers. Moreover, the development of indigenous components and integration of smart technologies such as IoT can improve efficiency, reduce costs, and support sustainable farmingpractices.

V. LITERATURE REVIEW

[1] Prasad Reddy *et al.*(2021) developed a solar-powered multi-purpose agricultural vehicle that reduces fuel dependency and supports sustainable farming.
[2] Chandraker*et al.*(2022) reviewed battery-powered sowing machines, improving seed placement accuracy and reducing manual labor.
[3] Saini and Masih (2020) designed a battery-assisted multi-crop reaper to reduce physical effort and improve harvesting efficiency.
[4] Bharath *et al.*(2022) proposed a solar-based multi-functional farming machine focusing on sustainability and cost reduction.
[5] Prem Kumar *et al.*(2024) reviewed battery-powered tillers, highlighting ergonomics, efficiency, and usability.
[6] IRJET authors (2022) developed a battery-operated weeder to enhance productivity and crop health.
[7] Chimote *et al.*(2016) introduced a solar-powered cultivator with interchangeable blades for versatile farming operations.
[8] Wamborikar*et al.*(2013) demonstrated the feasibility of solar-powered agricultural vehicles for mechanization.
[9] Prem Kumar *et al.* (2022) designed an automatic water tank cleaner showcasing automation for rural applications.

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VI. METHODOLOGY

1) *Phase I: Design and Analysis*

- User Requirement Analysis: Surveys and interviews were conducted with small farmers to identify key challenges such as labor shortage, high fuel costs, and difficulty in operating heavy machinery, leading to the definition of functional requirements like tilling, sowing, spraying, weeding, and light towing.
- Conceptual Design: 2D sketches and 3D CAD models were developed using tools like SolidWorks/AutoCAD, focusing on compactness and ergonomic design for ease of use.
- Design Calculations: Essential parameters such as torque requirement, battery capacity (2–4 hours runtime), attachment dimensions, and center of gravity were calculated to ensure performance and stability.

2) *Phase II: Manufacturing Drawings*

- Detailed manufacturing drawings were prepared from CAD models, including dimensions, tolerances, and material specifications.
- Sub-assemblies such as chassis, motor-transmission system, battery enclosure, and modular attachments were designed.
- Safety and usability features like welding details, ergonomic handles, and cut-off switches were incorporated.

3) *Phase III: Manufacturing and Assembly*

- Fabrication: The frame was constructed using mild steel, and components such as BLDC motor, battery, transmission system, and attachments were fabricated and assembled.
- Assembly: All subsystems were integrated, including motor, transmission, wheels, and control systems with user-friendly controls.
- Initial Testing: Basic testing was conducted to verify torque output, battery performance, and overall system functionality.

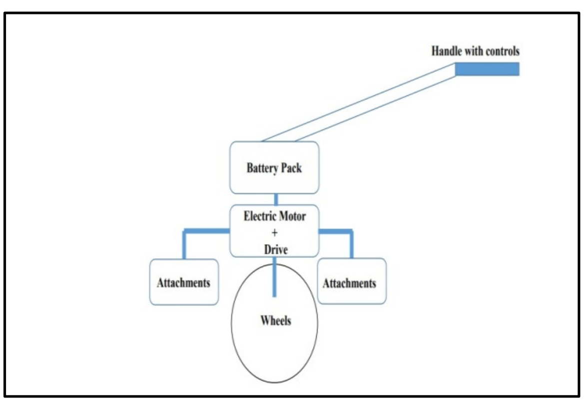
4) *Phase IV: Field Testing and Evaluation*

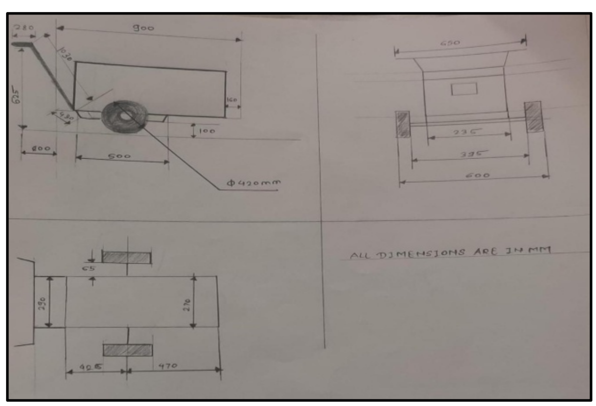
- Attachment Testing: Performance of tilling, sowing, spraying, and weeding operations was evaluated under real field conditions.
- Performance Analysis: Parameters such as battery endurance, work rate, and ergonomic comfort were measured along with farmer feedback.
- Comparative Study: The system was compared with manual tools and fuel-based machines to assess improvements in efficiency, cost, and environmental impact.

5) *Phase V: Documentation and Reporting*

- Technical documentation including CAD models, BOM, calculations, and test results was compiled.
- Feedback-based improvements were recorded, and scalability for mass production was analyzed.
- The final report was prepared following IEEE standards.

a) *Concept Design*





(a)ProposedLayoutOfMultiUtilityAgriTool(b)DrawingOfCultivation *b) Material Selection*

- Structural Frame & Base: Mild steel (IS 2062) is used for the chassis due to its high strength, weldability, and cost-effectiveness, ensuring durability under field conditions.
- Compression/Press Plates: Mild steel or tool steel (H13) is selected to provide rigidity, wear resistance, and fatigue strength under repeated loading.
- Rotary Tiller Blades: Boron steel or hardened alloy steel is used for its high hardness and abrasion resistance, enabling effective soil cutting and longer service life.
- Seed/Fertilizer Hopper: HDPE or aluminum alloy (6061) is preferred due to its lightweight nature, corrosion resistance, and ease of handling.
- Wheels: Rubber tires with cast iron or steel hubs are used to provide traction, shock absorption, and load-bearing capacity on uneven terrain.
- Handlebar & Control Panel: Aluminum with ABS plastic is used for lightweight construction, corrosion resistance, and ergonomic operation.
- Fasteners & Joints: Stainless steel or zinc-coated fasteners are used to prevent corrosion and allow repeated assembly in modular design.
- Battery Housing: Polycarbonate or aluminum casing is selected for impact resistance, heat dissipation, and protection against dust and moisture.
- Gearbox & Transmission: Case-hardened steel gears and bronze bushings are used for high wear resistance, strength, and smooth power transmission.
- Electrical Wiring: Copper conductors with PVC insulation are used for efficient electrical conductivity and protection against environmental conditions.

c) Design Parameters and Strategy

- Vehicle Mass: The total system mass of 250 kg (including operator and attachments) is considered to ensure the frame can withstand static and dynamic loads without excessive deformation.
- Wheel Diameter: A wheel diameter of 0.58 m is selected to improve rolling efficiency and reduce soil sinkage while maintaining maneuverability in narrow farm rows.
- Operating Speed: The operating speed of 2.0 m/s (≈ 8 km/h) is optimized for safe and efficient field operations, requiring a low-speed, high-torque transmission system.
- Motor Specification: A 1200 W, 48 V BLDC motor is used due to its high efficiency, low maintenance, and capability to deliver sufficient torque for cultivation tasks.
- Battery Specification: A 48 V, 48 Ah $LiFePO_4$ battery is selected for its safety, long life, and stable performance, providing approximately 2.3 kWh energy for extended operation.
- Ground Clearance: A clearance of 0.55 m is maintained to ensure smooth operation over uneven terrain and to prevent crop damage.
- Wheel Track: A track width of 0.762 m is chosen to enable inter-row operations while maintaining lateral stability during motion.

d) Overall Design Strategy

- Structural Design: The frame is designed using mild steel to achieve an optimal balance between strength, weight, and cost.
- Powertrain Design: The BLDC motor and gearbox are matched to provide high torque at low speeds for effective soil interaction.
- Energy System: The battery system is designed for reliable operation with adequate backup and safe enclosure.
- Ergonomics: The handle and control system are designed for user comfort, reducing fatigue and ensuring ease of operation for all users.

VII. COMPONENTS

1) Electric Motor (BLDC)

The 48V BLDC motor is the main power source of the machine. It converts electrical energy from the battery into mechanical motion to drive the wheels and attachments. The motor provides smooth torque at low speeds, making it suitable for farming operations. It is efficient, lightweight, and requires very low maintenance.

Fig. 1ElectricMotorA48VbrushlessDCmotor

2) Battery Pack

The LiFePO₄ battery pack stores and supplies electrical energy to the motor and control system. It provides stable power output and includes a Battery Management System (BMS) for protection against overcharging and overheating. The battery is safe, long-lasting, eco-friendly, and can also support solar charging.

Fig.2 LiFePO₄battery

3) Transmission System

The transmission system transfers power from the motor to the wheels using a gear reduction and chain drive mechanism. It reduces speed and increases torque for better traction in soil operations. The system is durable, efficient, and easy to maintain under field conditions.

4) Chassis and Frame

The chassis and frame provide structural support to all machine components and attachments. Made from IS 2062 mild steel, the frame is strong enough to withstand field loads, vibrations, and rough terrain. Its modular and corrosion-resistant design improves durability and customization.

Fig.4ChassisandFrame

5) Wheels

The pneumatic agricultural wheels help the machine move smoothly across different terrains. Their deep lug tread pattern provides better grip and traction in wet or loose soil. The wheels are durable, shock-absorbing, and capable of carrying heavy loads without excessive sinkage.

Fig. 5 Wheels

6) Control Handlebar

The control handlebar allows the operator to steer the machine, control speed, and operate attachments. It includes throttle and control switches mounted on an ergonomic aluminum frame. The lightweight and user-friendly design makes the machine easy to maneuver in farming fields.

Fig.6ControlHandlebar

VIII. DESIGN CONSIDERATION

1) OperatingConditions:

- VehicleMass:250kg(machine+man+riding/attachments)
- Total OperatingMass:250 kg
- WheelDiameter:0.58m(12″rim)
- Speed:2.0m/s(≈8km/h)
- Motor:1200W(48VBLDC)
- Battery:48V,48Ah($LiFePO_4$)
- GroundClearance:0.55m
- WheelTrack:0.762m(2.5ft)

2) Assumptions:

- RollingResistance(Crr):0.06(soil)
- DrivetrainEfficiency(η):0.85
- Gradient:10%
- Gravity(g):9.81m/s²
- MotorRPM:3000

Table.1DesignConsideration

Parameter	Value
Rolling Resistance Force	147 N
Grade Resistance	245 N

Total Tractive Force	392 N
Power at Wheels	784 W
Required Motor Power	923W
Wheel Torque	114 N.m
Wheel Speed	66 rpm
Approx. Gear Ratio	45:1
Required Motor Torque	3 N.m

Table8.2.1BatteryEnergy

Avg Power	**Runtime**
500 W	3.7 h
400 W	4.6 h
300 W	6.1 h

Interpretation:One1200Wmotorissufficientforlevel/medium-gradeoperations.
Batteryenergy&Runtime
Packenergy:
E_pack=V×Ah=48V×48Ah=2304Wh=2.304kWh

$LiFePO_4$usableDoD(safe)≈80%→usableenergy:
E_usable=0.8×2304=1843.2Wh=1.8432kWh

Ifaverageelectricalpowerdraw P_avg=500W(typicalmixeddutyweeding+small attachments), runtime:
t=E_usable/P_avg
t=1843.2/500=3.6864h≈3.7h

IfP_avg=400W→
t=1843.2/400=4.608h≈4.6h

IfP_avg=300W→
t=1843.2/300=6.144h≈6.1h
UsableEnergy≈1840Wh(80%)
EstimatedFieldRuntime:4–6hoursundermixedduty.

Sizing Summary

Table.3SizingSummaryTable

Parameter	Vehicle Only
Total Mass (kg)	250
Tractive Force (N)	392
Wheel Torque (N.m)	114
Motor Power (W)	923
Motor Torque (N.m)	3
Gear Ratio	45:1
Speed	8 km/h

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ComponentSpecification

Table.4 ComponentSpecifications

Motor	1200 Watt BLDC
Battery	48 Ah Li-Ion
Backup	3 to 6 hours
Tyre	4.00*10.00
Dimensions	830x850x550(mm)
Weight	120kg Inc. 48Ah Li-Po4 Battery
Wheel Track	23” to 31” Inches (interchangeable)

IX. ATTACHMENTS

Design Considerations for Attachments

1) Plough Tool

The plough tool is used for soil loosening, turning, clump breaking, aeration, and mixing nutrients into the soil. It helps prepare a fine seedbed for cultivation. The tool is designed to operate within the machine’s draft force capacity for both level ground and sloped conditions.

2) Three-Tyne Tool

The three-tyne cultivator is used for soil preparation, weed removal, aeration, and moisture regulation. It breaks compact soil and creates a proper seedbed for sowing. The draft force for all three tynes is maintained within the machine’s operating limit.

3) Cutting Blade

The cutting blade is used for harvesting crops and removing weeds. It provides clean cutting action with low power consumption. The attachment is designed to work efficiently within the motor’s available power capacity.

a) Rotavator

The rotavator is a modular soil tilling attachment powered by an electric motor and chain drive system. It is used for seedbed preparation, weed control, and shallow to medium soil cultivation. The attachment provides smooth operation with low vibration, low noise, and reduced operator fatigue.

b) Ride On

The ride-on attachment allows the farmer to sit comfortably while operating the machine. It improves ease of operation during tilling, spraying, and cultivation tasks. Different tools can be mounted at the rear side for efficient field work.

c) Trolley

The machine includes two trolley options: a small ride-on crate for carrying fertilizers, crops, and tools, and a big trolley capable of carrying up to 500 kg load. The larger trolley also includes a separate braking system for safe transportation.

d) Sprayer

- 100 L Boom Sprayer

The 100 L boom sprayer is designed for low-height crops such as soybean, onion, and vegetables. It uses an electric motor and diaphragm pump to provide uniform spraying with low chemical and water consumption.

- 200 L Air-Assisted Sprayer

The 200 L air-assisted sprayer is specially designed for orchards and grape farming. It uses air-assisted technology for deeper canopy penetration, uniform chemical distribution, and reduced pesticide wastage.

- Sprayer Summary

The 100 L boom sprayer is suitable for small crops and provides economical operation, while the 200 L air-assisted sprayer is better for orchard applications with higher coverage and spray penetration.

X. FIELD TESTING OF CULTIVATION TOOL

A. Objective of Field Testing

The field testing was conducted to evaluate the performance, reliability, safety, and ease of operation of the cultivation tool under real farming conditions. The aim was to verify soil preparation, weed control, durability, and farmer comfort.

B. Testing Methodology

1) Site Selection

Field trials were carried out on loamy and clay-rich agricultural lands to test the machine in different soil conditions.

2) Test Setup

The tool was tested on plots of 100–500 m² with multiple operating passes. GPS tracking, photos, videos, and manual observations were used for recording results.

3) Parameters Evaluated

The testing evaluated:

- Soil loosening efficiency
- Weed removal capability
- Maneuverability
- Battery performance
- Structural strength
- Operator comfort
- Safety during operation

C. Observations and Results

1) Soil Interaction

The tool loosened soil effectively up to 8–12 cm depth with good soil mixing and low clumping in dry and wet conditions.

2) Weed Management

The machine achieved around 75–85% weed removal efficiency, especially effective for surface weeds.

3) Battery Performance

The battery provided continuous operation for about 2.5–3 hours under moderate load without overheating.

4) User Feedback

Farmers found the machine compact, easy to handle, and less physically tiring. Suggestions included adjustable handle height and better blade visibility.

Image’sTakenWhileTestingTheCultivationTool

Fig.7CultivationTool

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Fig.8 TestingTheCultivation Tool

XI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

- The battery-operated cultivation tool is a compact and efficient solution for small farmers.
- It helps reduce labor cost, farming effort, and equipment expenses through a multi-utility design.
- The machine can perform tillage, weeding, spraying, and seedbed preparation using a single platform.
- The electric drive system provides low operating cost, low noise, and eco-friendly operation.
- Prototype testing proved reliable performance, good traction, and user-friendly operation in field conditions.
- The project demonstrates sustainable and affordable small-scale farmmechanization.

B. Future Scope

- Integration of smart power management and regenerative braking systems.
- Development of advanced modular battery packs with fast charging/swapping.
- Addition of sensors, obstacle detection, and semi-autonomous navigation features.
- Expansion of attachments such as seed drill, fertilizer applicator, and reversible plough.
- Improvement in frame design, adjustable handle system, and better weight distribution for different soil conditions.

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