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Performance Analysis of a Smart Compact Land Plow, Seed Sower and Water Sprinkler Agri-Machinery System

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Abstract

Agricultural robots possess numerous applications that have the potential to decrease the laborious efforts of human beings while increasing efficiency. Given the significant historical context of agriculture in South Asia, and Bangladesh's current sustainable position in terms of farm output, it is evident that agriculture plays a crucial role in the socioeconomic fabric of the country. This research project aims to embark on a transformative journey in agricultural innovation by exploring the multifunctional capabilities of a versatile agricultural robot. Driven by a threefold objective, the project seeks to revolutionize seed sowing, optimize land preparation, and enhance water-spraying methods. Through detailed analyses and rigorous experimentation, the precision and efficiency of robots across various tasks have been highlighted. The robot was meticulously designed using SolidWorks for part assembly, and its validation was ensured through sophisticated 3D printing techniques. The Arduino IDE software was employed to facilitate seamless synchronization of components, thereby enhancing the robot's operational process. A crucial aspect of this project involves the creation and development of a user-friendly app that enables effortless remote control of this technological wonder. This research project envisions a future in which this robotic marvel serves as the catalyst for agricultural transformation.

Keywords
Agricultural Robotics, Automation, Seed Sowing, Precision Agriculture and Smart Farming.

1. Introduction

Agriculture is a basic part of human civilization that has changed a lot over the years. With the ever-growing global population, the demand for food production has increased, requiring innovative approaches to enhance agricultural practices. Traditional farming methods struggle with labor shortages, resource inefficiencies, and environmental concerns. To address these challenges and optimize the farming process, the integration of robotics and automation into agriculture offers a promising solution. Agricultural robots play an important role in advancing precision agriculture, optimizing resource distribution, and significantly reducing environmental impact (Devi et al. 2020; Bhat and Huang 2021).

One of the key agricultural operations where robots demonstrate exceptional suitability is crop seeding. The initial stages of crop cultivation include ploughing the land and sowing seeds, traditionally executed through manual methods that prove inefficient, time-consuming, and physically demanding. Research shows that robot seeders can enhance seeding efficiency up to threefold compared to manual labor, without causing soil structure damage seen with heavy machinery (Azmi et al. 2021).

In the context of Bangladesh, where agriculture is the foundation of the economy, the sector faces challenges due to a declining trend attributed to the lack of mechanization. This research project focuses on developing a cost-effective agricultural robot specifically tailored for crop seeding, land preparation, and water sprinkling. The primary research question guiding this investigation is: How can a multifunctional robotic system be designed and manufactured to effectively perform land preparation, seed sowing, and water sprinkling, optimizing agricultural processes and contributing to sustainable farming practices.

2. Objectives

The specific objectives of this study are:

i) To design and fabricate a cost-effective agricultural robot that can perform land preparation, seed sowing, and water sprinkling tasks autonomously and efficiently.
ii) To evaluate the performance and reliability of the robotic system in various field conditions compared to traditional methods.
iii) To assess the economic impacts of the robotic system regarding labour requirements and cost.

3. Literature Review

Agricultural robotics on a global scale has witnessed a significant surge in interest. According to a report by the World Economic Forum, autonomous farming is transforming agriculture (Bateman 2022). Lenora and Clemens (Ditzler and Driessen 2022) explored the potential for robots to foster an agroecological approach, concluding that a rethinking of automation is necessary for agroecological contexts. Regionally, researchers have attempted to solve these issues. Raut et al. (2013) studied the modernization of agriculture, noting that mechanization reduces unit costs of production. Ikechukwu et al. (2014) designed a manually operated single-row maize planter, finding it worked adequately with a planting capacity of 0.0486 ha/hr.

Recent developments focus on automation and energy efficiency. Swetha and Harsha (2015) experimented on a solar-operated automatic seed-sowing machine to minimize working costs. Sunitha et al. (2017) developed a robot capable of navigating without human intervention, equipped with tentacles for plowing and gears for sowing. Dutta et al. (2019) designed an autonomous seed-sowing robot using machine vision and image processing. More recently, Azmi et al. (2021) developed a low-cost agricultural robot for crop seeding, achieving an accuracy of 92%. Similarly, Pandey et al. (2021) built a multipurpose robot for sowing and irrigation using solar energy. Obialor et al. (2022) fabricated a remote-controlled seed-sowing machine, achieving positive response ranges exceeding 10 meters. Despite these advancements, there remains a gap in creating a fully integrated, cost-effective system capable of simultaneously managing land preparation, sowing, and irrigation for small-scale farmers in developing economies.

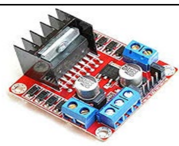
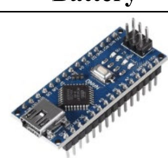
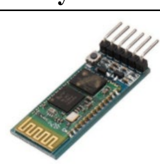
4. Methodology

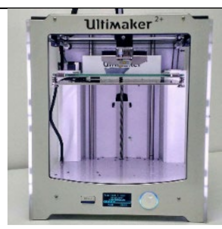
The research methodology followed a sequential process for developing the agricultural robot. This involved material selection based on functional requirements, detailed design using SolidWorks (CAD), fabrication through 3D printing and final assembly, and the development of the control system using the Arduino IDE and a mobile application.

4.1 Materials and Components

The robot utilizes a combination of mechanical and electronic components essential for its multifunctional operation. These materials are cataloged with their specifications and primary purposes in Table 1.

Table 1. Catalogue of the utilized materials and equipment

SL No.	Materials	Manufacturer & Specification	Purposes
01.	 **DC motors**	Model: 25GA Voltage: 12V	Converts electrical energy into mechanical energy to power wheel propulsion and tool actuation.
02.	 **Wheel**	Diameter: 130 mm Set: Four	Facilitates robot mobility, navigation, and maneuverability across varied terrains.
03.	 **Motor driver**	Model: L298N module Logic voltage: 5V Drive voltage: 5V-35V Logic current 0mA-36mA Maximum power: 25W	Regulates and controls the power supply to DC motors to manage speed and direction.
04.	 **BUCK Converter**	Set: Three Input voltage: Adjustable	Regulates and converts higher voltages to lower, stable ones for specific electronic components.
05.	 **Battery**	Capacity: 1800mAh Type: Li-Po	Serves as the primary power source for all robot operations and functionalities.
06.	 **Arduino Nano**	Microcontroller board with 14 digital I/O pins and 16 MHz crystal oscillator	Serves as the robot's brain, executing programmed logic and coordinating all components.
07.	 **Relay Module**	Four-channel module using electromagnetic switches	Controls high-voltage circuits using low-voltage signals to switch power to different components.
08.	 **Bluetooth Module**	Model: HC-05	Provides wireless radio wave communication between the robot and a smartphone or computer for remote control.

SL No.	Materials	Manufacturer & Specification	Purposes
09.	 **Pump**	DC Pump with inlet, outlet, and valve	Responsible for transferring and distributing water from the reservoir to the sprayer nozzle
10.	 **Gear Servo Motor**	Model: MG996 High-torque metal gear 180-degree rotation	Provides precise angular motion for actuating the plow tool and seed dispenser.
11.	 **Servo Driver**	Model: PCA 9685A 16-channel PWM signal controller	Synchronizes and coordinates the simultaneous movements of multiple servo motors.
12.	 **Ultrasonic Sensor**	Contains a transmitter and receiver; Sound wave distance measurement.	Detects obstacles in the robot's path to facilitate safe navigation and collision avoidance.
13.	 **Ultimaker 2+**	Model: Ultimaker 2+ Fused Deposition Modeling (FDM) technique	Used to fabricate intricate robot components such as plow parts and seed Sower elements with precision.

4.2 System Design and Fabrication

The system design followed a structured workflow involving planning, CAD modeling in SolidWorks, 3D printing, and final component assembly.

i) Basement: A 406mm x 305 mm structural frame was constructed to ensure stability and house all primary components. Figure 3 illustrates the SolidWorks schematic and dimensional planning. Figure 4(b) shows the physical basement frame used as the foundation for the robot.

ii) Plow Mechanism: Designed with adjustable blades for various soil types and fabricated via 3D printing using durable ABS plastic. Figure 1 displays the transition from SolidWorks modeling to the 3D printed final assembly of the plow.

iii) Seed Sower: This mechanism features Sower teeth to create furrows, a seed reservoir, and a sliding plate for precise release rate control. Figure 2 details the design and fabrication process of the Sower tooth components and the joint set for seeding operations.

iv) Water Sprinkler: An integrated pump system was developed with a specialized spray range designed to achieve 10–15m of coverage. Figure 4(a) provides the top view of the final assembly, illustrating the integration of the sprayer pipe and reservoirs.

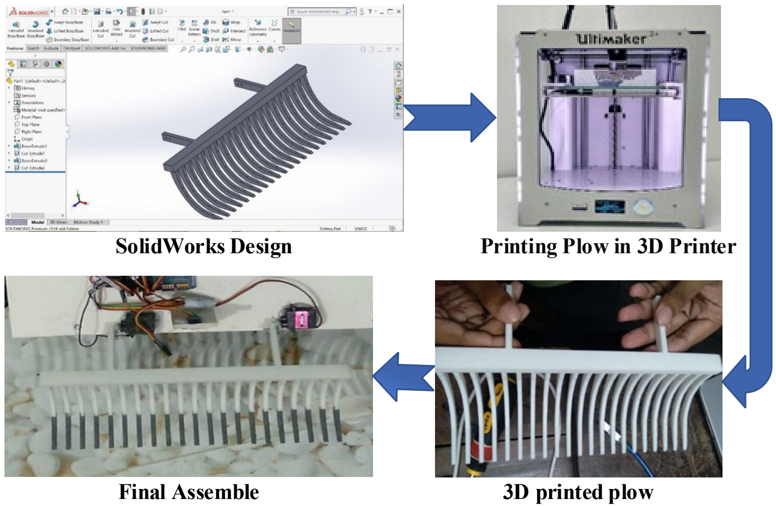


Figure 1. Design and fabrication process of the land plow.

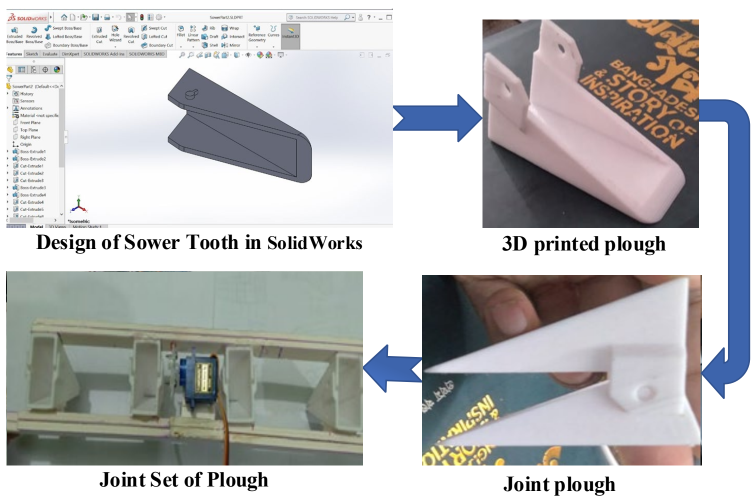


Figure 2. Design and fabrication process of a set of ploughs.

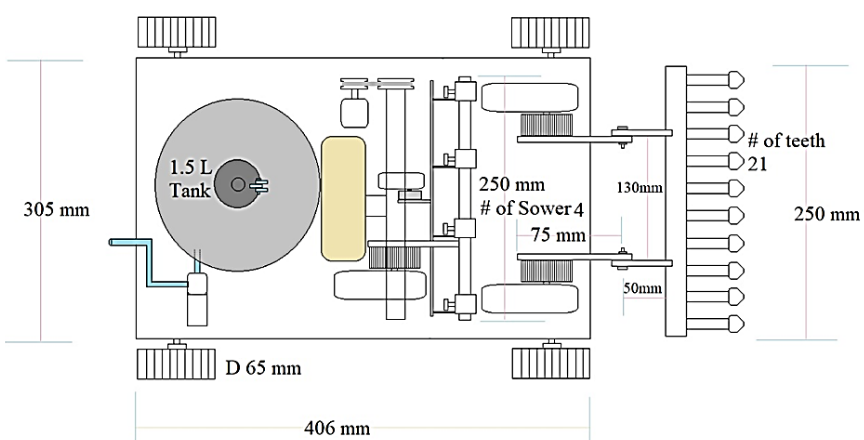


Figure 3. SolidWorks design of the plow and seed sowing mechanism.

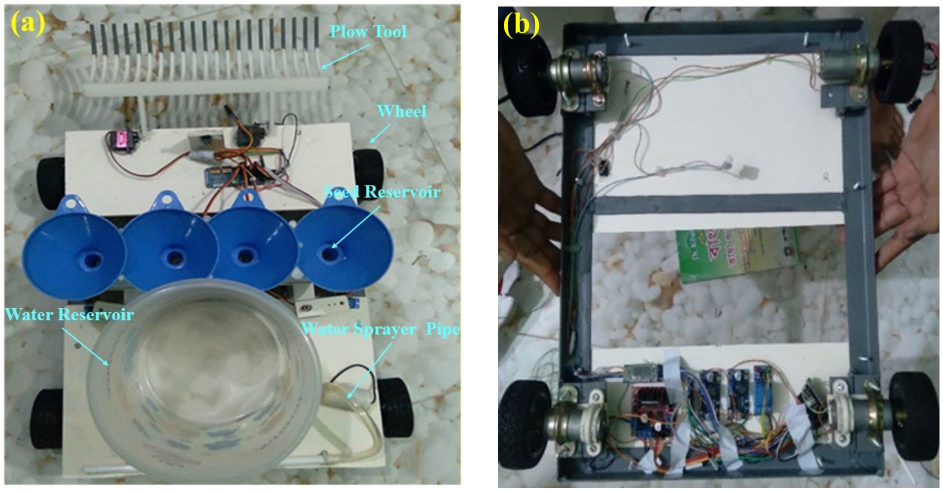


Figure 4. Fabrication smart compact land plow, seed Sower and water sprinkler Agri-machinery system (a) Top view of final assembly of the project, (b) Basement frame.

4.3 Mobile Application and Control

The control system utilizes an MIT App Inventor mobile app communicating via an HC-05 Bluetooth module. Behavioral sequences were developed in the Arduino IDE, as shown in Figure 5(a). Figure 5(b) illustrates the interface for remote management:

i) Navigation: Directional commands for forward, backward, left, and right movement.
ii) Toggling: Controls to activate or deactivate the plow, seed Sower, and water sprinkler.
iii) Speed: Adjustment between slow, medium, and fast modes.

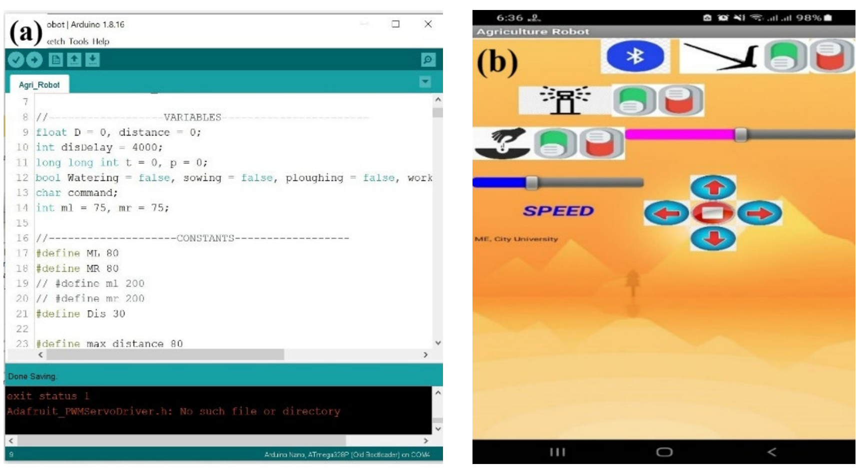


Figure 5. User Interface of (a) Coding environment, (b) Mobile application.

4.4 Equations for Calculations of Plowing Tool, Torque, Seeding and Water Sprinkler

Land Prepared Area, A = Velocity× length of plow (1)

Torque transmitted on the wheel; $T_W = K_w \times W_t \times D_w$ (2)

Were,

K_w= Coefficient of the rolling resistance

W_t= weight of the machine

D_w= Diameter of the ground wheel

$$\text{Seeding Efficiency} = \frac{\text{Actual Seed dropped}}{\text{Theoritical Seed Dropped}} \times 100\% \quad (3)$$

Flow rate of the water, $Q = (\pi /4) \times d^2 \times v$ (4)

5. Performance and Data Analysis

The robot's performance was evaluated based on plowing area, seed sowing accuracy, and water flow rates at various speeds.

5.1 Plowing Performance

Plowing efficiency was tested by varying motor speeds (RPM). The area of land prepared was found to increase proportionally with speed, as shown in Figure 6. Table 2 provides the numerical data detailing the land preparation area achieved at different operating speeds.

Table 2. Land area preparation with respect to different speeds

Speed (rpm)	Speed (m/s)	Land preparing (m^2/min)
20	0.06	1.02
25	0.085	1.27
30	0.10	1.53
35	0.12	1.78
40	0.14	2.04

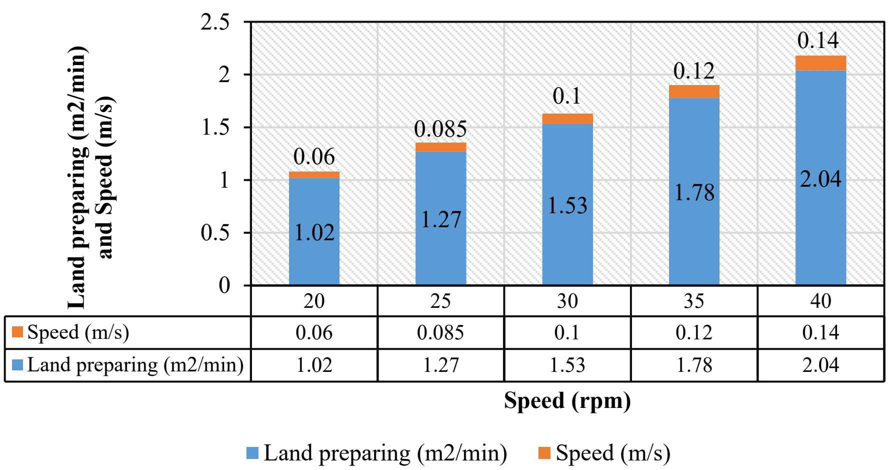


Figure 6. Land area preparation with respect to different speeds.

5.2 Seed Sowing Performance

Seed sowing accuracy was rigorously compared against theoretical values. The mechanism operated at a controlled dropping rate ranging from 1/4 to 1/2 seeds per second. Testing demonstrated high accuracy: at 30 rpm with a 1/4 rate, the robot dropped exactly 10 seeds per meter, matching the theoretical rate. The overall efficiency of seed dropping was calculated to be 95.6%, based on 217 actual seeds dropped versus a theoretical capacity of 227 across 15 trials. Table 3 and Figure 7 detail the comparative seed dropping performance across the trials.

Table 3. Seeding performance per minute

Trial No	Speed (rpm)	Distance Travel (m)	Seed Dropped per Second	Theoretical Seed Dropped per Meter	Actual Seed Dropped per Meter
1.	20	4.08	1/4	15	14
2.		4.08	1/3	20	18
3.		4.08	1/2	29	27
4.	25	5.10	1/4	12	12
5.		5.10	1/3	16	15
6.		5.10	1/2	23	23
7.	30	6.12	1/4	10	10
8.		6.12	1/3	15	15
9.		6.12	1/2	20	18
10.	35	7.15	1/4	8	8
11.		7.15	1/3	11	10
12.		7.15	1/2	17	16
13.	40	8.17	1/4	7	7
14.		8.17	1/3	10	10
15.		8.17	1/2	14	14
Total seed dropped				227	217

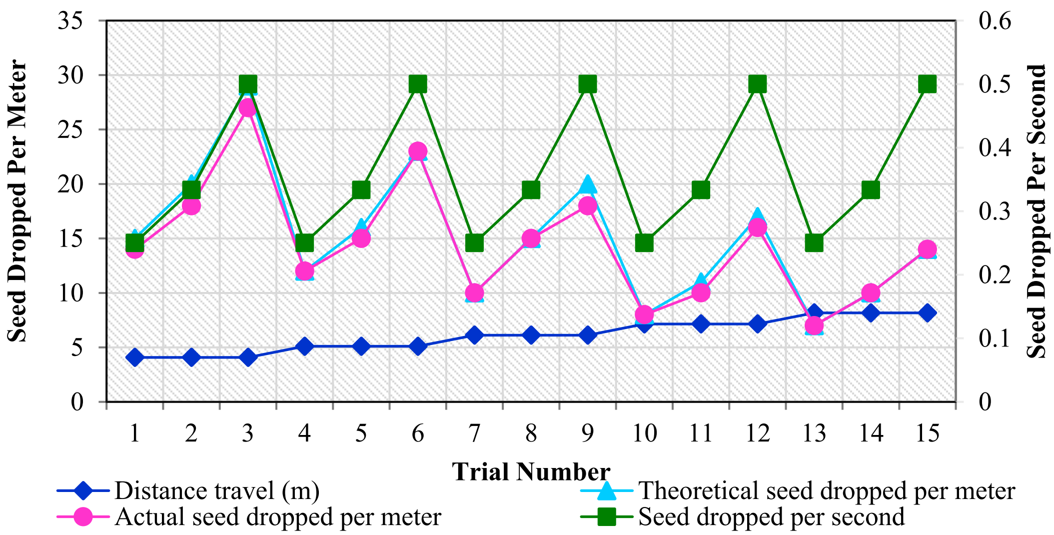


Figure 7. Actual vs Theoretical Seed Dropping Performance.

5.3 Water Sprinkler Performance

The water sprinkler performance analysis confirmed system efficacy by demonstrating a linear increase in flow rate corresponding to the robot's speed. Specifically, the flow rate escalated from approximately 0.139 L/min at 20 rpm to 0.31 L/min at 40 rpm. This relationship is numerically detailed in Table 4 and visually represented in Figure 8, with Table 5 providing the underlying calculation results for the determined flow rates.

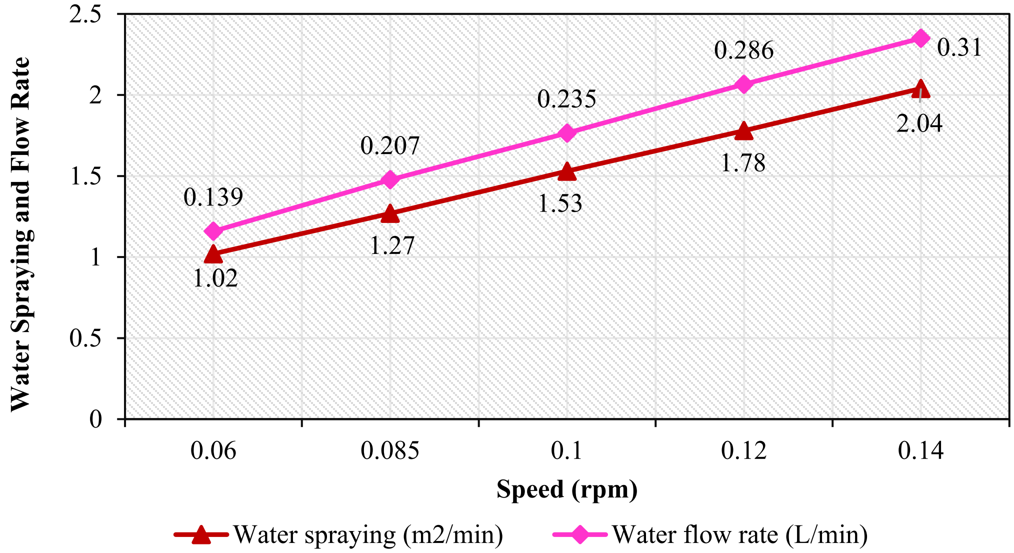


Figure 8. Water spraying with respect to different speeds.

Table 4. Water spraying with respect to different speeds.

Speed (rpm)	Velocity (m/s)	Water spraying (m^2/min)	Water flow rate (L/min)
20	0.06	1.02	0.139
25	0.085	1.27	0.207
30	0.1	1.53	0.235
35	0.12	1.78	0.286
40	0.14	2.04	0.31

Table 5. Flow rate at different speeds.

SL	Speed (rpm)	Time Required (s)	Flow Rate (L/min)	Average Flow Rate (L/min)
1	20	596	0.151	0.139
2		643	0.1399	
3		714	0.126	
1	25	443	0.2031	0.207
2		430	0.2093	
3		431	0.2085	
1	30	378	0.238	0.235
2		394	0.2284	
3		377	0.2384	
1	35	321	0.2803	0.286
2		315	0.2857	
3		308	0.2919	
1	40	279	0.3226	0.31
2		301	0.299	
3		292	0.3084	

5.4 Cost Analysis

A detailed budget analysis was conducted to determine the economic viability of the project, which is given in Table 6. The total cost for fabrication and components was approximately 25,300 BDT (Bangladeshi Taka).

Table 6. Cost of various parts and phases of the project.

SL. No.	Part Name	Cost	Qty	Total Cost (BDT)
01.	Motor	1000	4	4000
02.	Hopper	400	4	1600
03.	Micro controller	2000	1	2000
04.	Battery	6000	1	6000
05.	Pump	500	1	500
06.	Frame	2000	1	2000
07.	Ultrasonic Sensor	200	1	200
08.	Ploughing tool	500	1	500
09.	Flat plate	1000	1	1000
10.	Wheel	500	4	2000
11.	Water tank	500	1	500
12.	Other	2000	-	2000
13.	Assembly	3000	-	3000
Total cost				BDT=25300

6. Results and Discussion

The operational performance of the multifunctional agricultural robot was evaluated through rigorous field experiments focusing on land preparation, seed sowing, and water sprinkling. The results indicate a high level of precision and efficiency across all three primary functions.

6.1 Plowing Performance

Depth of cut = 5 cm

Considering the Speed of the plow as N=20 rpm

So, the velocity, V $= \pi DN$

$= \pi \times 0.065 \times 20$

$= 4.08$ m/min

No. of teeth in plow = 21

Length of the plow = 25 cm

Feed rate = (Speed of plow × Number of teeth in plow × depth of cut)

$= 4.08 \times 21 \times 0.05$

$= 4.28\ m^2/min$

Land Prepared Area, A = velocity × length of plow

$= 4.08 \times 0.25$

$= 1.02 m^2/min$

The plowing mechanism demonstrated a positive correlation between the robot's speed and the area of land prepared. Experimental data showed that as the motor speed increased from 20 rpm to 40 rpm, the land preparation rate increased from 1.02 m^2/min to 2.04 m^2/min. Analytical calculations determined the torque transmitted to the wheels to be approximately 0.797 Nm, which was sufficient for the effective depth of cut required for small-scale farming.

6.2 Seeding Accuracy

Speed = 30 rpm

Row spacing = 7.5 cm

Seed sowing time = 1/2 seed/ sec/per opening

Opening no.= 4

Seed dropping per meter length $= 4 \times (1/2) \times 60 / (\pi \times 0.065 \times 30)$

$= 19.6 \approx 20$ seeds

Hence, if the speed of the wheel is 30rpm, then for a 1-meter distance total of 19 seeds will be dropped.

Calculation of Seeding Efficiency $= \frac{\text{Actual Seed dropped}}{\text{Theoritical Seed Dropped}} \times 100\%$

$= \frac{217}{227} \times 100\ \% = 95.6\%$

The seed sowing mechanism achieved a high overall efficiency of 95.6%. Comparative analysis between theoretical and actual seed drops revealed minimal discrepancy; for instance, at 30 rpm with a 1/4 second drop rate, the actual seed drop was exactly 10 seeds per meter, matching the theoretical value. This confirms the system's capability to maintain consistent seed spacing, which is vital for optimal crop growth.

6.3 Water Sprinkling Efficiency

Velocity of the water, $v = \sqrt{(2gh)}$
$= \sqrt{(2 \times 9.81 \times 0.30)}$
$= 2.43$ m/s
Flow rate of the water, $Q = (\pi /4) \times d^2 \times v$
$= (3.14/4) \times (0.0052) \times 2.43$
$= 5.16 \times 10\text{-}5$ m^3/s
Time for a 5-liter water tank,
5 liters = 0.005 m^3/s
Time for consumption of 0.005 m^3/s is, $T = \frac{0.005}{5.16 \times 10-5}$
T = 96.89 sec
T = 1.61 min
T = 1-2 min

Calculation of actual water flow rate:
For 20 rpm speed,
Trial 1: Water sample volume = 1.5 L
Time required = 596 seconds
Flow rate, $Q_1 = (1.5\times60)/596$
$= 0.151$ L/min
Similarly, Q2 = 0.1399 L/min
Q3 = 0.126 L/min
Average Flow rate, Q = (0.151+ 0.1399+0.126)
= 0.139 L/min

The water sprinkler system effectively managed flow rates relative to velocity. At a speed of 0.06 m/s (20 rpm), the system maintained an average flow rate of 0.139 L/min. The coverage area for water spraying scaled linearly with speed, ensuring uniform moisture distribution.

6.4 Economic Feasibility

A comprehensive cost analysis revealed that the total cost for fabricating the robot, including motors, microcontrollers, battery, and structural materials, was 25,300 BDT. This low production cost validates the project's objective of providing a cost-effective alternative to expensive traditional agricultural machinery.

The research offers profound insight into the operational efficacy of the multifunctional robot. The alignment between theoretical and actual seed drop values (95.6% efficiency) denotes exceptional accuracy. The positive correlation between speed increments and covered area for plowing and watering illustrates the robot's scalability. However, factors such as soil characteristics, robotic calibration, and climatic conditions were identified as variables affecting performance. While the prototype demonstrates high potential, limitations regarding battery life and infrastructure in rural areas must be addressed for large-scale adoption.

7. Conclusion

The design and fabrication of the multifunctional agricultural robot have successfully demonstrated that a compact, low-cost system can effectively automate labor-intensive farming tasks. Through rigorous testing and performance analysis, the study confirms that the robot meets its objectives of reducing human labor while maintaining operational precision. The major findings of this project are summarized below:

i) Operational Efficiency in Plowing: The robot demonstrated a positive correlation between speed and land coverage. At a maximum speed of 40 rpm, the system achieved a plowing rate of 2.04 m^2/min. Analytical calculations confirmed that the torque transmitted to the wheels (0.797 Nm) was sufficient for effective soil penetration and preparation.

ii) High Precision in Seed Sowing: The seed sowing mechanism exhibited exceptional accuracy. Experimental data revealed a seeding efficiency of 95.6%, with the actual number of seeds dropped (217) closely matching the theoretical requirement (227) across varying speeds3. This ensures consistent seed spacing, which is vital for optimal crop growth.
iii) Controlled Water Distribution: The water sprinkler system successfully maintained flow rates proportional to the robot's velocity, ranging from 0.139 L/min at 20 rpm to 0.31 L/min at 40 rpm4. This adaptability ensures uniform moisture distribution and prevents water wastage.
iv) Cost-Effectiveness: A comprehensive budget analysis established the total project cost at 25,300 BDT5. This low production cost validates the system's potential as an affordable alternative to expensive industrial machinery for small-scale farmers.
v) Successful Integration of Control Systems: The system effectively integrated mechanical components designed in SolidWorks (such as the 3D-printed plow and Sower tooth) with an Arduino-based electronic control system. The custom-developed mobile application provided reliable wireless control via Bluetooth, allowing for seamless navigation and task toggling.
vi)

While the prototype has proven functional and efficient, limitations regarding battery endurance and adaptability to extreme soil conditions remain. Future development should focus on integrating AI for autonomous crop detection and incorporating solar power to extend operational field life. Ultimately, this project serves as a foundational step toward accessible and sustainable agricultural automation.

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