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A SMART SELF-ASSEMBLED SEED SOWING ROBOT USING ESP32 MICROCONTROLLER

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ABSTRACT

This research presents the design, implementation, and evaluation of a seed-sowing robot, a precision agricultural device for mitigating the limitations of manual sowing methods and increase farming efficiency. A review of the available literature on the subject has identified shortcomings of the traditional seed-planting method, including stress on the seedlings, operator fatigue, and irregular inter-seed spacing. The focus of this study is the design and development of the robotic seed planter, including its hardware and software components. The paper's methodology includes the design of the robot's wheels and chassis, the sensors, the microcontroller connections, and the mechanism for seed dispersal. The software section of the research used a simple custom C++ program. The experimental design has been made to test the system. The accuracy of the seeds being planted has been measured as the deviation from the ideal spacing, and the results show an average of 98.5%. Additionally, the robotic method is faster than the traditional method. Overall, the paper on the seed-sowing robot has demonstrated the capabilities of the robot in the field of agricultural robotics, as the results show the robot has achieved high performance in the accuracy of the seeds being planted and has also demonstrated the capabilities of the robot in being more efficient in the completion of the task in much less time.

Keywords: Microcontroller, Robotic, Precision agriculture, Autonomous, Inter-seed spacing,

INTRODUCTION

Researchers worldwide are striving to improve the performance of farming machines by making them more convenient and efficient. This effort has led to the invention of new machines that offer better services than the older ones. At the beginning of the twenty-first century, automation and smart technologies emerged as the primary focus for the development of agricultural machines (Shanmugavelu *et al.*, 2020; Ghosh *et al.*, 2021). Researchers from various nations around the world have contributed to developing agricultural robots that can perform activities such as picking, harvesting, weeding, pruning, grafting, and classifying their features. This invention has significantly increased agricultural yields (ZMili *et al.*, 2022). Moreover, the invention of these agricultural robots has eased the strain of agricultural activities, especially pre- and post-planting activities, in many nations across the globe (Kefayati & Kazemitabar, 2021). However, developing low-cost robots for agricultural tasks such as planting, which require high precision and accuracy, remains a major challenge for scientists, researchers, and engineers. Some of the farm activities requiring precision include seed planting, watering, weed and pest management. The ability to implement autonomous robots for these tasks will lead to less labour, high-quality products, and lower-cost food production (Bhatti *et al.*, 2021).

A robot is autonomous or self-operated mechanical equipment. There are robots that require human preset guidance, which may take the form of a remote control system, a computer interface, or can be controlled by gestures. Autonomous robots are usually electromechanical machines that are operated by a set of program instructions and or an electronic module (Mili *et al.*, 2021). Robots are generally categorized into two main groups: industrial and service robotics. According to the International Federation of Robotics (IFR), a service robot operates semi- or fully autonomously to carry out tasks that benefit humans and other devices, apart from production and manufacturing tasks (Liang *et al.*, 2021; Shanmugasundar *et al.*, 2022). This class of robots has found applications in the military, hospitals, offices, deep-water exploration, and agricultural tasks.

Agricultural robots, which can operate fully autonomously or as partially autonomous devices capable of handling tasks at various phases of agricultural operations, are gaining wide attention. Several agricultural robot machines have been employed for routine farm operations, such as weed clearing, irrigation, plowing, trimming, crop harvesting, and other post-harvest tasks, to minimize farm workload and reduce the time and costs associated with farming (Kefayati & Kazemitabar, 2021). Grafting and cutting, harvesting and timely transplanting of seedlings, optimized spraying and watering, harvesting of crops, and spotting based on colour classification are some of the tasks greenhouse robots can undertake. Some are designed with flexibility in operation, which makes them capable of carrying out multiple tasks. These have applications in horticulture and flower gardens (Eleanchezhien *et al*., 2020; ZMili *et al*., 2022). One of the most important parts of crop production is seed planting. The objective of this study is to develop a simple, low-cost and fully autonomous seed planting robot capable of planting seeds at the specified depths and spacing in straight lines, well covered with soil, and compact them firmly, which will enhance proper germination. Farmers employ several seed-sowing methods, including conventional methods such as manual sowing, which are ineffective because of fatigue and stress, thus leading to poor output. It is against this background that this current research seeks to develop an automated seed sowing robot. Several studies have been carried out on farm automation, especially in the area of robotic seed planting systems. These were carefully studied before embarking on this research.

Review of related works

Jayakrishna *et al*. (2018) developed a seed-sowing agricultural robot that operates by tracing the path of a ploughed field and dropping the preset number of seeds. This system performed well, but it has no capacity to identify seeds or the land area to sow. It is also a Four Wheel Drive machine, which makes it more expensive and complex. Kumar and Ashak (2021) designed a seed-sowing robot consisting of a robot arm that picks seeds from a seed container. The system wheels and the robotic arm were controlled through a mobile application. Once the desired position is set in the app, the robot moves automatically along the previously marked path. Shanmugasundar *et al*. (2022) used a solar panel to power their seed-sowing robot. The robot was made from a mini plough with a seed dropper, controlled by a Node MCU development board. An IR sensor helps to locate the path for the machine to go, the plough digs the ground, the seed dropper drops seed, and the rear section of the plough closes the ground. Existing seed-sowing robots demonstrate that agricultural processes can be automated, but these machines are semi-autonomous systems that require operators to select their movement paths. The current seed placement methods fail to deliver accurate results because their designs do not account for soil recognition. The high cost and complicated nature of these systems create barriers which prevent smallholder farmers from implementing these technologies. Currently available research focuses on creating prototypes of the system, with no studies of how it performs across various real-life fields, its cost-effectiveness, or its long-term usability. These limitations call for the development of a low-cost, autonomous seed-sowing robot that effectively leverages microcontroller technology.

METHODOLOGY

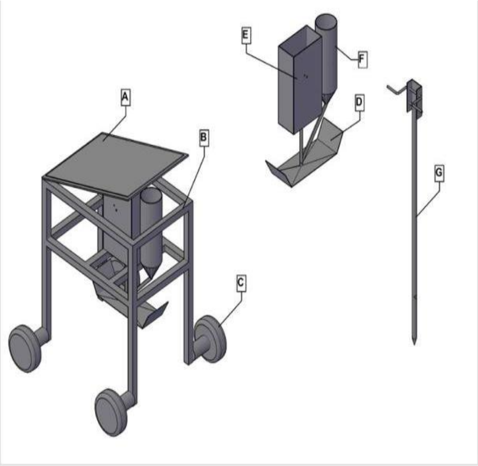
This section of the seed planter discusses the overall design, building, and testing of the entire system. These aspects cover both hardware and software components, as the research uses affordable, readily available materials

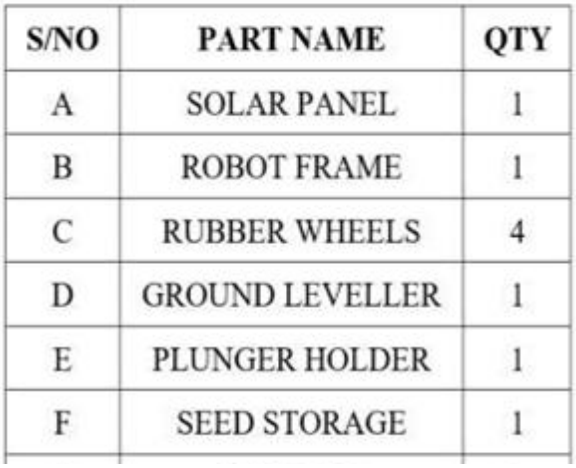
.

Computer-Aided Design (CAD) of the Robotic Seed Planter

The design was created in SolidWorks 2023, a powerful CAD which is very effective in human-driven enhancement design and workflow efficiencies.. CAD is used not only to build precise 3D models of the finished work, but also to test each mechanical component of the seed planter robot before construction.

In essence, this meant creating 3D models of all the parts and simulating the assembly. Furthermore, simulating how the robot would move and the seed would come out helped to design the parts better. Of course, this also helped us cut costs, as we could make changes before the final construction phase. Finally, the mechanical design was created with the aid of SOLIDWORKS. The computer-aided design of the system is as presented in Figures 1, 2, and 3.





S/NO	PART NAME	QTY
A	SOLAR PANEL	1
B	ROBOT FRAME	1
C	RUBBER WHEELS	4
D	GROUND LEVELLER	1
E	PLUNGER HOLDER	1
F	SEED STORAGE	1

Figure 1: CAD design of the robotic seed planter

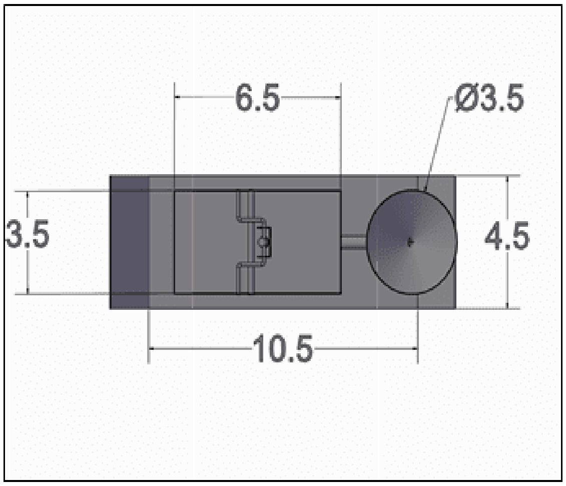


Figure 2: Seed holder top

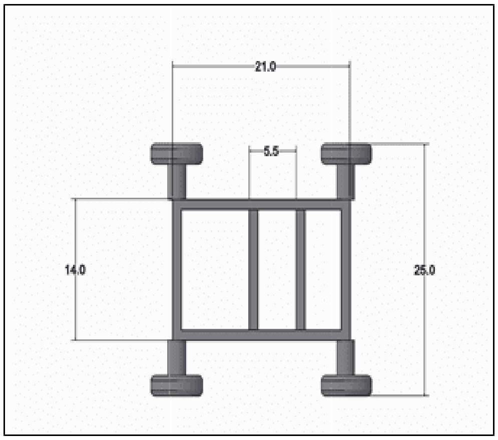


Figure 3: Frame top of the planter

Hardware Design of the Robotic Seed Planter The robotic hardware includes a seed dispenser, a seed storage container, a robotics subsystem, a GPS receiver, and sensors. The seed dispenser releases seeds onto the field. The seed storage container is used to store seeds prior to sowing. The robotics subsystem, including motors and motor drives, controls the robot's motion. The GPS receiver determines the robot's location on the field. The sensors include an infrared sensor, a level detector, and ultrasonic sensors. The sensors detect soil presence, sense the seed level in the storage container, and measure distances using ultrasonic waves. Infrared sensors sense the presence of soil and stop the robot's movement when soil is not detected. The level detector senses the number of seeds inside the storage container. The seeds will not be dispensed if the container is empty. Ultrasonic sensors use a transducer to both send and receive ultrasonic signals. The signals carry information about the object's position. These types of sensors measure distance from the ground.

The system uses a power supply module comprising a rechargeable battery and a power control circuit that regulates the voltage and current to the robot's various components. The robot also consists of a chassis, wheels, and a seed dispensing mechanism. The chassis provides the robot's foundation, and the wheels move it across the field. The seed dispensing mechanism dispenses seeds onto the field and is designed to ensure they are placed at a specified distance and pitch.

The hardware component was selected based on its ability to meet the study's requirements, including precise seed placement, efficient movement across the field, and accurate detection of soil and seed levels. This list of that major components used in this study are as shown in Table 1.

Table 1.: Table of list of major components used

Components	**Model**	**Quantity**
ESP 32 Development Board	ESP32-D0WDQ6	1
Ultrasonic sensor	HC-SR04	2
Servo Motor	SG-90	1
IR Sensors	LM-393	1
Level Detector	QXL-QRP30S	1
GPS receiver	NEO-6M V2	1

ESP32 Microcontroller

ESP32 Microcontroller, shown on the development board in Figure 4 and whose architecture is shown in Figure 5, is a small computer that functions as the control module for operating all devices, such as a DC motor and a Bluetooth module, on a single integrated circuit.

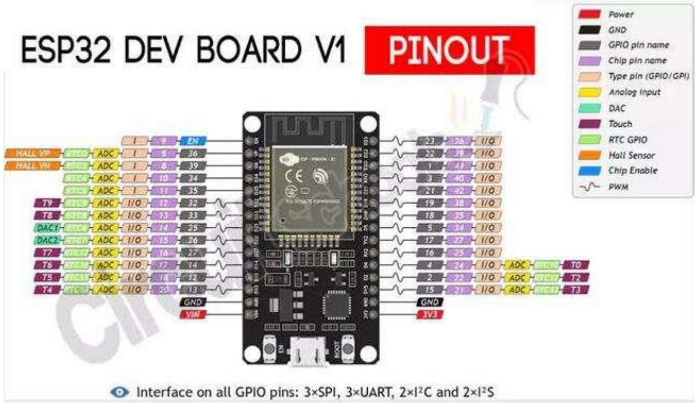


Figure 4: ESP32 microcontroller pin connection (Sadiku *et al*., 2022)

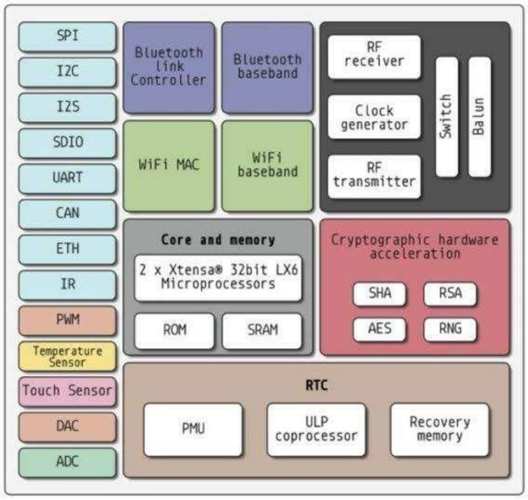


Figure 5: ESP32 microcontroller architecture (Sadiku *et al*., 2022)

The physical arrangement of the hardware components is shown in Figure 6. The pin connections of the circuit components to the ESP-32 development board are shown in Table 2.

Table 2: The Components pins and ESP 32 pins connections.

COMPONENTS PINS	**ESP 32 PINS**
Servo-pin(Yellow)	PIN 21
Ultrasonic 1 – trig pin	PIN 27
Ultrasonic 1 – echo pin	PIN 26
Ultrasonic 2 – trig pin	PIN 32
Ultrasonic 2 – echo pin	PIN 35
Motor driver – Right motor pin 1(IN1)	PIN 19
Motor driver – Right motor pin 2(IN2)	PIN 18
Enable Pin1	PIN 5
Motor driver – Left motor pin 1(IN3)	PIN 23
Motor driver – Left motor pin 2(IN4)	PIN 22
Enable Pin2	PIN 4
All vcc pins(Red)	Positive(Red) +ve – Battery
All GND pins(Black)	Negative(Black) -ve – Battery

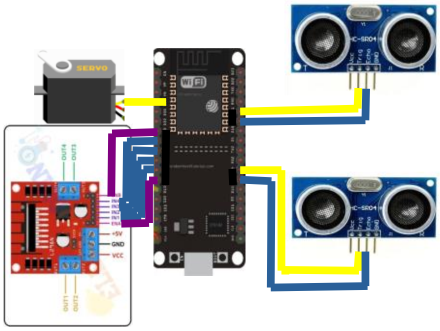


Figure 6: Assembly of Electronics Components:

Software Component of the robotic seed planter

The development of the control software follows a simple iterated software development structure shown in the block diagram in figure 7. It began with gathering and analyzing the requirements to software design. Coding follows the design, then testing the software functionalities.

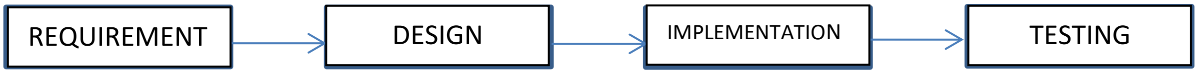


Figure 7 The software development structure

The software component for the robot includes the algorithm that guides its movement and the seed-dispensing system. The software was written in C++ integrated development environment (IDE) and uploaded to the microcontroller. The software also includes a user interface developed on GitHub. The user interface allows the user to enter the desired parameter such as the number of seeds per hole, seed spacing and depth, The control software functions as shown in the pseudo-code in Algorithm 1, it was further presented in a flow-chat in Figure 8 for clarity. Detail control code is as shown in the Appendix.

Algorithm 1: Pseudo Code of the System Operation

```
1.  Power ON
2.  Input Data:
3.          A: Direction of movement of robot
4.          B: Number of seeds per hole
5.          D: Seed planting spacing
6.          Y: Seed planting depth
7.  Move robot : A
8.  Sense and identify soil.
9.  Determine soil distance X from drill
10. Compute X + Y = Z
11. Push drill : Z
12. Drop seed B
13. Cover soil
14. Move robot : D
15. Go To 7
```

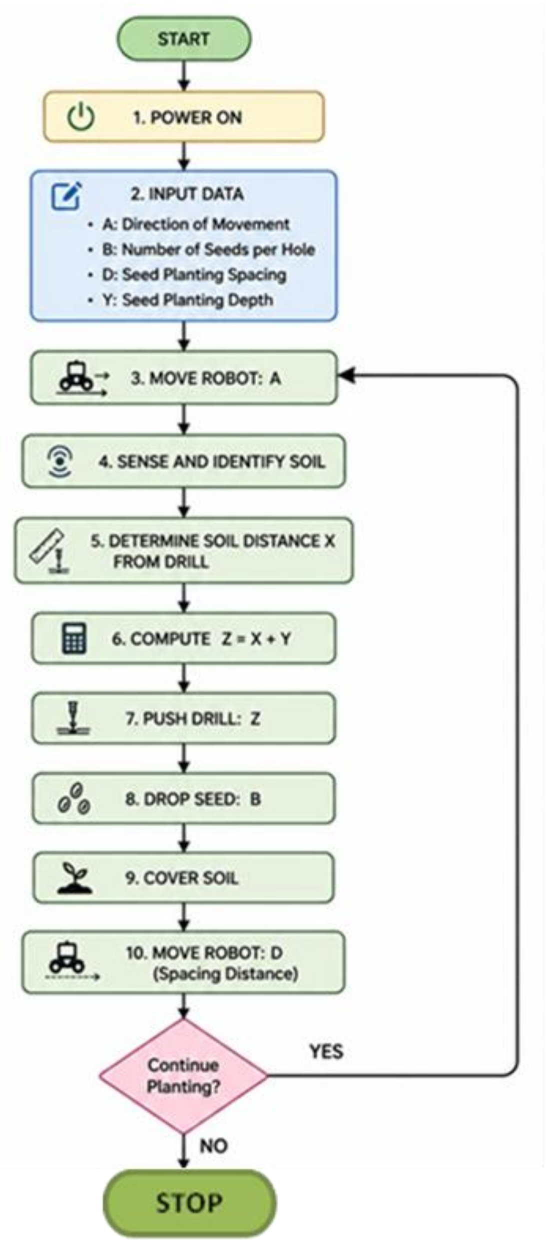


Figure 8: The system flowchat

Apart from the algorithmic and interface aspects, the software component of the robotic seed planter includes sensor and actuator control. The software analyzes sensor signals to control the robot's movement and seed planting. The microcontroller acts as the robot's central processing unit, interpreting sensor signals and sending the appropriate signals to plant seeds efficiently.

Furthermore, the software component of the robotic seed planter has features that enable data analysis. The robot will record position and seed-planting accuracy while operating, and this information can be analyzed to optimize system performance for the next season. The data can also be used to generate seed-placement maps for monitoring crop growth and yield.

The Power Supply

The robotic seed planter was powered by compact solar power module attached to it.*Solar panel and battery calculation*

If The Seed Planting Robot is expected to run for H hours, therefore

Total daily usage = Total Sum of Energy Requirement × hours *(Watt-hours per day)*

Amp-hour calculation

Correcting for battery losses = 1.1 * Total daily requirements.

System voltage DC voltage = 12 v

Amp-hours per day = Corrected Total daily requirements / volts

Battery bank calculation

Number of days' backup power required (average 24 hours' period) = 2 days

Amp-hour storage (raw capacity needed) = 2 * Amp-hours per day

Depth of discharge (Assume 50%) = 0.5 fraction

Required amp backup (also ensure excessive discharge is prevented = Amp-hour storage / 0.5

Solar panel array calculation

Sun hours per day (Direct only) = 6 (worst situation condition)

Worst weather multiplier 1.55 default (constant).

Total sun hours per day (assumes average sun ray availability) = 4 hr/day

Therefore, the number of solar panel required was calculated as shown in equations (1) to (3)

$$\text{Amps from solar panel} = \frac{\text{Panel size selection watt rating (watt hour rating)}}{\text{Nominal panel voltage}} \quad (1)$$

$$\text{Number of solar panels in parallel} = \frac{\text{Required Amp backup}}{\text{Amps from solar panel}} \quad (2)$$

$$\text{Number of panels in series} = \frac{\text{System voltage DC voltage}}{\mathit{Panel\ Output\ Voltage}} \quad (3)$$

(Ayanniran, *et al.*, 2024)

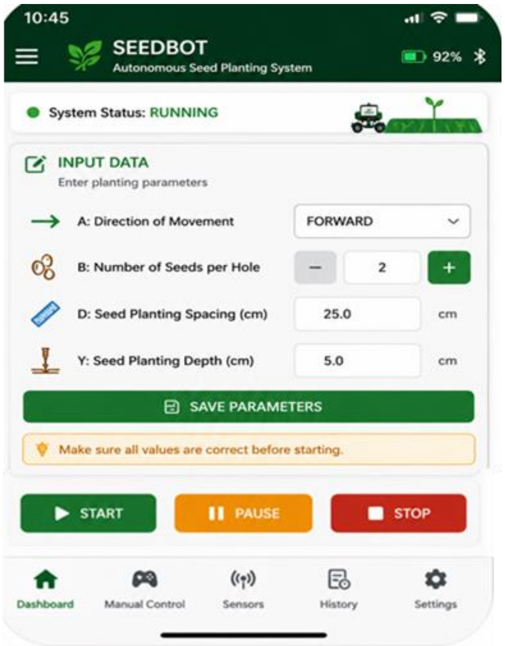
Rounded number of solar panels = Number of solar panels in parallel * Number of panels in series.

Results and Discussion

This section presents the results of the production and evaluating the microcontroller-based autonomous seed-sowing robot's performance. The accuracy of the sowing spacing was tested, as was the speed of seed sowing. The findings were compared with the performance of conventional methods for making inferences.

The complete assemblage of the seed sowing robot formed a rigid, self-operated smart device shown in figure 8. Figure 9 shows the screenshot of the user interface.

Figure 9; Fully assembled components of the Robotic Maize Seed Planter



A: Direction of Movement FORWARD
B: Number of Seeds per Hole 2
D: Seed Planting Spacing (cm) 25.0 cm
Y: Seed Planting Depth (cm) 5.0 cm

Figure 10: The Screenshot of the user interface for remote control of the robot

Accuracy of the seed planting spacing

The robot was tested on a farmland with varying row spacing. The results showed that the robot's accuracy decreased as the distance between rows increased. Table 3 shows the robot's accuracy at different row spacing. As shown in the table, the robot achieved 98.5% accuracy with a row spacing of 30 cm. However, accuracy decreased to 95.5% when the row spacing was increased to 60 cm. These results are excellent performance for a self-assembled robot operating on uneven terrain.

From the measurement obtained, the relative error was claculated using equation (1),

$$E_r = \left\{\frac{V_m - V_a}{V_a}\right\} \tag{1}$$

where:

E_r is the relative error
V_m is the expected value
V_a is the actual value

The percentage error ∂ was computed using equation (2)

$$\partial = \left\{\frac{V_m - V_a}{V_a}\right\} \times 100 \tag{2}$$

Subtracting the percentage error ∂ from 100 gives the percentage accuracy ρ as shown in equation (3).

$$\rho = 100 - \partial \tag{3}$$

The measurement and the computations are as shown in Table 3. Although, observations from the table shows that accuracy of the robot measurement decreases with increase in expected distance, however the robot recorded over 95% accuracy and the average percentage error is less than 3.5%.

Table 3: Table of the evaluation of the accuracy of the measured distance between the rows of seed sown

Expected Distance between Rows (cm)	**Actual Distance between Rows (cm)**	**Relative Error**	**Percentage Error %**	**Accuracy %**
30.00	29.55	0.01523	1.523	98.5%
40.00	38.80	0.03093	3.093	97.0%
50.00	48.35	0.03413	3.413	96.7%
60.00	57.40	0.04530	4.530	95.5%

Accuracy of the Robot measurement

The results show that the robot produced measurements that were very close to the expected row distances. The expected distances ranged from 30 cm to 60 cm, while the corresponding actual measured distances ranged from 29.55 cm to 57.40 cm. Although the actual measurements were slightly lower than the expected values in all cases, the deviations were minimal, indicating good measurement precision.

These values demonstrate that the robot consistently maintained an accuracy level above 95% throughout the testing. Recent publications show similar observations autonomous agriculture studies, where measurement errors was seen to have increased with distance due to sensor limitations, environmental conditions, and signal propagation delays (González et al. 2022). Therefore, this performance indicates that the robot has shown reliability in row-spacing measurements in agricultural tasks and applications.

The observed gradual reduction in accuracy also reflected in both the relative error and percentage error computed. This indicates that the robot performs more accurately at shorter distances than at longer distances. The increase in error with distance may have been caused by one or more of the following

i. sensor limitations,
ii. signal attenuation,
iii. calibration drift,
iv. wheel slippage,
v. or environmental interference during movement.

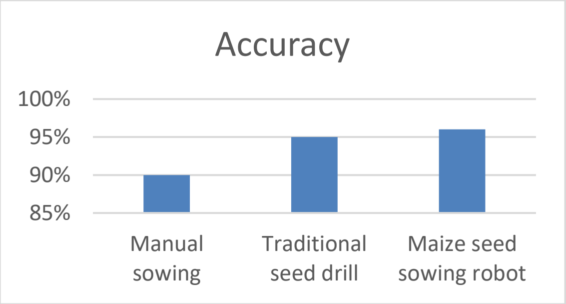


Figure 11: Bar chart showing the summary of validation of result on seed sowing robot's efficiency with other methods.

Despite this increase, the errors remained relatively small and within acceptable operational limits as reported in related studies (Nardon & Botta, 2022).

Reliability of the Measurement System

Since the average percentage error less than 3.5%, it shows that the robot measurement system is dependable and suitable for practical agricultural field operations.

The experimental results demonstrate that the robot has good measurement capability and can accurately determine the spacing between rows of seeds sown. Although measurement accuracy decreases slightly as the expected distance increases, the robot consistently maintained high accuracy levels above 95%.

The findings therefore show that:

i. the robot measurement system is reliable,
ii. the sensor and control mechanisms are functioning effectively,
iii. and the robot can be successfully applied in precision agriculture operations where accurate row spacing is important.

However, further improvements such as enhanced sensor calibration, better wheel control, or advanced error compensation techniques could help reduce the increase in error observed at larger distances.

Summary of the performance of this study compared with other methods

The results obtained from evaluating the seed sowing robot were compared with those from other seed sowing methods. The results are summarized in Table 4 and Figure 11. The manual method and the seed drill were tested with the seed sowing robot on the same farmland. The accuracy and speed of seed placement were recorded and tabulated as shown in Table 3.

Table 4: Summary of the comparisons of the performance of the seed sowing robot with conventional methods

Method	**Accuracy**	**Speed of seed placement**	**Inference**
Manual sowing	90.0%	12 per minutes	Slow
Traditional seed drill	93.0%	15 per minutes	Slow
Seed sowing robot	98.5%	24 per minutes	Fast

The average accuracy recorded with the manual sowing method was 90% at a speed of 12 seed placements per minute. This finding is due to the high level of stress and fatigue involved in manual hand sowing. The use of a seed drill yielded 93% accuracy at a rate of 15 seeds per minute. This improvement could be attributed to the fact that the soil was not drilled by hand. The seed-sowing robot achieved 98.5% accuracy at a rate of 24 seed placements per minute. This performance is significantly better than that of the two conventional methods. The seed-sowing robot is fully autonomous, powered by solar energy, and operates without any stress, minimal or otherwise. A bar chart in Figure 8 illustrates this comparison.

CONCLUSION AND RECOMMENDATIONS

This paper presents the design, implementation, and performance evaluation of a seed-sowing robot capable of accurately and efficiently sowing seeds in agricultural areas. The robot is a combination of electronic, mechanical, and software components that work together to ensure the seed-sowing activity is successful.

The performance evaluation revealed that the robot accurately sowed the seeds, with a deviation of less than 5%.

Furthermore, the time required to complete the task was less than half that of the manual method. These findings demonstrate that the robot is an effective and efficient method for seed sowing activities. In addition, the research demonstrates the potential of agricultural robots to increase crop yields through an efficient seed-planting method. Although the robot developed in this research showed promising results, there is room for further research in the following areas: implementing a live field-mapping and monitoring system to increase the efficiency, accuracy of the robot's navigation and evaluation of this prototype on different soil types to validate the findings.

Conflict of Interest Statement

The authors declare that there are no competing interests.

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APENDIX : The C++ control code

```
#include <iostream>
#include <string>
using namespace std;

// Function to simulate soil sensing
float senseSoilDistance()
{
   float X;
   cout << "Enter sensed soil distance from drill (cm): ";
   cin >> X;
   return X;
}

// Function to move robot
void moveRobot(string direction, float distance = 0)
{
   if (distance == 0)
      cout << "Robot moving in direction: " << direction << endl;
   else
      cout << "Robot moving " << distance << " cm towards " << direction << endl;
}

// Function to push drill
void pushDrill(float depth)
{
   cout << "Drill pushed to depth: " << depth << " cm" << endl;
}

// Function to drop seeds
void dropSeeds(int seeds)
{
   cout << seeds << " seed(s) planted." << endl;
}

// Function to cover soil
void coverSoil()
{
   cout << "Soil covered successfully." << endl;
}

int main()
{
   // Step 1: Power ON
   cout << "Autonomous Seed Planting System Powered ON" << endl;

   // Step 2: Input Data
   string A;      // Direction of movement
   int B;         // Number of seeds per hole
   float D;       // Seed planting spacing
   float Y;       // Seed planting depth

   cout << "Enter direction of robot movement: ";
   cin >> A;
```

```
    cout << "Enter number of seeds per hole: ";
    cin >> B;

    cout << "Enter seed planting spacing (cm): ";
    cin >> D;

    cout << "Enter seed planting depth (cm): ";
    cin >> Y;

    char choice = 'Y';

    while (choice == 'Y' || choice == 'y')
    {
        // Step 7: Move robot
        moveRobot(A);

        // Step 8: Sense and identify soil
        cout << "Sensing and identifying soil..." << endl;

        // Step 9: Determine soil distance X
        float X = senseSoilDistance();

        // Step 10: Compute X + Y = Z
        float Z = X + Y;

        cout << "Computed drill depth (Z = X + Y): " << Z << " cm" << endl;

        // Step 11: Push drill
        pushDrill(Z);

        // Step 12: Drop seeds
        dropSeeds(B);

        // Step 13: Cover soil
        coverSoil();

        // Step 14: Move robot spacing distance
        moveRobot(A, D);

        // Continue operation
        cout << "\nContinue planting? (Y/N): ";
        cin >> choice;
    }

    cout << "Seed planting operation terminated." << endl;

    return 0;
}
```