Development of A Robotic Maize Seed Planter

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ORIGINAL RESEARCH

Abstract—The automatic maize seed planter design to address the limitations of traditional planting techniques and reduce the lead time in agricultural processes and enhance the output. The research encompasses a comprehensive study of maize sowing techniques, challenges, and advancements in agricultural robotics. The literature review explores the limitations of traditional maize sowing techniques, such as inaccurate seed placement, labor intensiveness, and weather dependence. The construction process involves the integration of a chassis, wheels, sensors, microcontroller, and seed dispensing system. The software component utilizes a custom algorithm to control the movement and seed placement of the robot. Experimental testing and evaluation were conducted to assess the performance of the robot. The accuracy of seed placement was determined by analyzing the deviation from the desired spacing. The efficiency of the robot was measured by comparing the time taken for sowing with traditional methods. The results demonstrated that the automatic maize seed planter achieved high accuracy in seed placement with minimal deviation from the desired spacing. The results validate the effectiveness of the robotic system in addressing the limitations of traditional sowing techniques and demonstrate its potential to revolutionize the agriculture industry. The objectives are to develop a cost-effective, efficient, and accurate maize seed planter and implement the design in the fabrication. Recommendations for further work is real-time mapping and monitoring. Real-time mapping and monitoring of the field can help the robot navigate the field more efficiently and accurately.

Keywords— ESP32 Microcontroller, Ultrasonic Sensor, Planter, Robot, Maize.

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1 INTRODUCTION

In the world of globalization, various technologists are updating a new development based on automation which works very effectively and within a time. As one of the trends of development on automation and intelligence of agricultural machinery within the twenty first century, all types of agricultural robots are researched and developed to implement a variety of agricultural production in several countries, like choosing, harvesting, weeding, pruning, planting, grafting, agricultural classification, etc. and that they step by step seem benefits in agricultural production to extend productivity (Garg and Yadav, 2017). In many ways, robotics has aided in enhancing the quality of our lives. However, implementing robots in agriculture, typical field activities, remains a big issue for scientists, researchers and engineers. Robots will assist in planting more precisely, watering more precisely, and managing weeds and pests with better precision. All of this leads to higher-quality products, lower-cost food, and less labour (The International Federation of Robotics, 2021).

A robot is a mechanical device that can perform tasks automatically. Some robots require some degree of guidance, which may be done using a remote control or with a computer interface or can be controlled by gestures.

A robot is usually an electro-mechanical machine that is guided by a program or circuitry (Mili *et al.*, 2021). In general, robotics can be divided into two areas, industrial and service robotics. The International Federation of Robotics (IFR) defines a service robot as a robot which operates semi- or fully autonomously to perform services useful to the well being of humans and equipment, excluding manufacturing operations. These robots are currently used in many fields of applications including office, military tasks, hospital operations, dangerous environments and agriculture.

Agricultural robots working in either self-operated or semi-autonomous systems that can handle issues at various stages of the system are becoming subjects of high interest. Agricultural robots have been effectively deployed for repetitive operations, such as land preparation, water irrigation and spraying, trimming, harvesting, monitoring, and other duties, to minimize the farmer's workload and optimise process times and costs (Kefayati and Kazemitabar, 2021). Grafting and cutting, harvesting and transplanting, precision spraying and irrigation, fruit and vegetable harvesting and spotting, and colour classification are just a few of the activities that robots in greenhouses undertake. A multi-purpose flexible robot may do multiple tasks in a crop on certain

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occasions, enhancing horticulture and floral production and harvesting procedures. Because the vast majority of commercial robots are still being built as prototypes, few commercial robots are working on agricultural challenges to date (zMili et al., 2022). The most crucial aspect of crop production is seed sowing. The goal of seed sowing is to plant seeds in rows at the specified depths and spacing, then cover them with soil and compact them properly, resulting in germination. Farmers use a variety of seed-sowing techniques, including traditional methods such as sowing by hand which mostly are ineffective, and thus lead to poor output. It is against this background that this current research seeks to develop an automated maize seed sowing robot.

2. BACKGROUND INFORMATION ON AGRICULTURAL ROBOTICS

Detailed Agricultural robotics is a field of robotics that focuses on the development and deployment of robotic systems for use in agriculture. Over the past few years, there has been a growing interest in agricultural robotics as a means to address the challenges facing the agricultural sector. The development of agricultural robots is driven by the need to increase productivity, efficiency, and sustainability of agricultural practices while reducing the environmental impact of agriculture.

Agricultural robots can be broadly categorized into three types: field robots, indoor robots, and aerial robots. Field robots are designed to operate in outdoor environments, such as on farms and in fields. Indoor robots are designed to operate in indoor environments, such as greenhouses and warehouses. Aerial robots are designed to operate in the air, such as drones and unmanned aerial vehicles (UAVs).

One major area of research in agricultural robotics is the development of autonomous robots that can perform agricultural tasks without human intervention. These robots use sensors and algorithms to detect and respond to changes in their environment and can navigate through agricultural fields to perform tasks such as planting and harvesting (Savary *et al.*, 2019). The development of autonomous robots can help farmers save time and money by reducing the need for manual labour.

Another area of research in agricultural robotics is the development of robotic systems that can perform precision agriculture. Precision agriculture involves the use of technology to tailor agricultural practices to specific areas of a field based on data such as soil quality, weather conditions, and crop health (Liang *et al.*, 2021). Robotic systems such as drones and ground-based robots equipped with sensors and cameras can collect data on crop health and growth patterns, which can be used to optimize crop management and increase yields.

Despite the potential benefits of agricultural robotics, there are several challenges that must be addressed. One major challenge is the high cost of developing and implementing robotic systems in agriculture. The cost of robotics technology and the need for specialized training and maintenance can be a barrier for many farmers, especially small-scale farmers (Savary *et al.*, 2019).

Furthermore, there may be concerns about the impact of robotics technology on the environment and the potential displacement of human labor. The use of heavy machinery and robots may cause soil compaction and damage, which can lead to reduced soil fertility and crop yields. There may also be concerns about the displacement of human labor and the impact on rural communities (Liang *et al.*, 2021).

To overcome these challenges, there is a need for continued research and development of affordable and accessible agricultural robotics technology. Governments, research institutions, and private sector stakeholders can collaborate to support the development of agricultural robotics technology that is sustainable and beneficial for farmers, the environment, and society as a whole.

2.1 SOIL ANALYSIS USING ROBOTS

Soil is the main source of nutrients for plants; therefore, various tests are manually performed in the field by taking samples across the field and then performing statistical analysis to estimate the soil properties. The results of laboratory tests depend on the number and density of the measurement locations. This process costs significant time and money to determine several soil properties. A study by Rossel and McBratney (1998) analyzed and compared the costs of estimating soil properties in the US and Australia. The average cost per sample for analyzing soil pH, carbon, nitrate-nitrogen, phosphorus and potassium were A$18.4, A$22.2, A$29.9, A$22.5 and A$19.4, respectively, in Australia. The costs in Australia were significantly higher than in the US, and precision agriculture requires more soil samples, resulting in economically inefficient farming. Therefore, an automated real-time measurement system for measuring soil properties can greatly benefit farmers.

The reflected spectra were then guided to the spectrophotometer by the optical fibre and analyzed. A calibration models was built, and the soil was mapped at all three depths. The highest accuracy of the combined data for the three depths had correlation coefficient (*R2*) values of 0.88, 0.83, 0.88, 0.85 and RMSE values of 1.38, 0.26, 0.15, 0.01% for moisture content, organic matter, total carbon and total nitrogen, respectively. The results from this study suggest that combining the data from all three depths provides better prediction accuracy. This RTSS configuration is connected to a commercial tractor and has not yet been tested while attached to an autonomous robot. A few notable studies on RTSS using commercial, non-autonomous tractors shows that these systems are automated, they can potentially interface with robots.

Figure 1. Bonirob with a soil penetrometer (Aravind *et al.*, 2017)

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2.2 SEEDING AND TRANSPLANTING ROBOTS

Seeding is the process of planting seeds in the soil so that they are successfully able to germinate. Transplanting involves placing a small plant seedling that has germinated in a particular position in the field based on the specific space requirements of each crop in the field.

(Griepentrog *et al.* 2013) retrofitted a Hakotrac 3000 with GNSS for navigation and an electro-hydraulic valve for steering to create an autonomous mechanization system (AMS). Crops were established by interfacing with the data logging system that stored maps for seeding with a grid seeder and punch plater. GNSS was used for the precise placement of seeds in the field. The experimental results showed a mean standard deviation of 2.53 mm; and based on a normal distribution 95% of the data were within 5.1 mm.

3. METHODOLOGY

3.1 PRINCIPLE OF OPERATION OF THE ROBOTIC MAIZE SEED PLANTER

To determine the position of the robot, an ultrasonic sensor is used to measure the distance between the robot and any obstacles in its path. The ultrasonic sensor is used to ensure that the robot moves in the correct direction and avoids any obstacles in its path.

When the robot moves a specific distance, it stops to sow the seed. The microcontroller sends a signal to the seed sowing mechanism to sow the seed at the required pitch. After the sowing process is completed, the robot moves forward, and the microcontroller sends a signal to the motor responsible for leveling the ground surface.

The system consumes less time and is lightweight, making it more efficient than other systems. The microcontroller dedicates the order of suggestions received to all networks and sensible factors processed by their corresponding embedded program. According to the received signal, the robot moves in the given direction and places the seed on the field with equal spacing and specified distance. Figure 2 below shows the block diagram of the design and figure 3 below is the flowchart of the design.

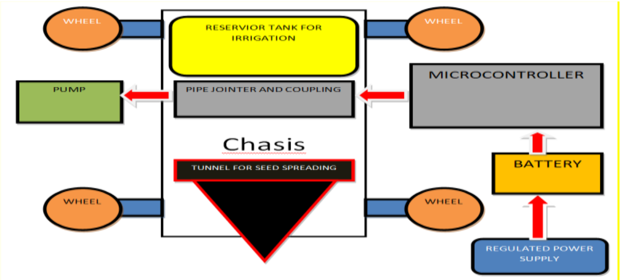
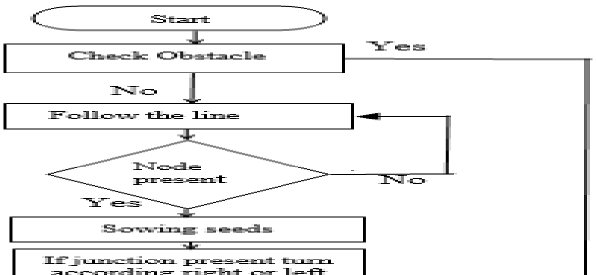


Figure 2 Block diagram of robotic maize seed



6 HELPFUL HINTS

Figure 3 Flow Chart of the Design

3.2 IMPLEMENTATION OF THE ROBOTIC MAIZE SEED PLANTER

The design of the components was implemented by dividing the robot into three parts: working algorithm, mechanical components, and software components.

3.2.1 WORKING ALGORITHM

The seed planting algorithm used in the project plays a critical role in ensuring accurate and efficient placement of maize seeds. The algorithm takes into consideration various factors such as seed spacing, seed depth, and field coverage to optimize the seed planting process.

The seed planting algorithm is computed as follows:

1. **The Kinematic Equation**: This equation is used to calculate the position of the robot at any given time. It is given by the formula:

$$x = x_0 + v_0t + 1/2at^2 \text{ -- } 1$$

where,

x is the final position of the robot,
x_0 is the initial position of the robot,
v_0 is the initial velocity of the robot,
t is the time elapsed and
a is the acceleration of the robot.

2. **The Torque Equation**: This equation is used to calculate the torque required by the robot to move. It is given by the formula:

$$T = I\alpha \text{ -- } 2$$

Where,

T is the torque required by the robot,
I is the moment of inertia of the robot and
α is its angular acceleration.

3. **The Power Equation**: This equation is used to calculate the power required by the robot to move. It is given by the formula.

$$P = Fv \text{ --------------------------------------- } 3$$

Were,

P is the power required by the robot,
v is its velocity,
F is the force required to move it and it is given as,
F = ma

Where,

m is the Mass of the Robot,
a is the acceleration due to gravity.

4. **The Soil Moisture Equation**: This equation is used to calculate the amount of moisture in the soil. It is given by the formula:

$$\theta = (V_w / V_t) \times 100 \text{ ----------------------- } 4$$

where,

θ is the soil moisture content,

V_w is the volume of water in the soil and

V_t is the total volume of soil.

5. **The Soil Density Equation**: This equation is used to calculate the density of the soil. It is given by the formula:

$$\varrho = m / V \text{ ------------------------------------ } 5$$

where,

ϱ is the density of the soil,

m is its mass and

V is its volume.

6. **The Tip Resistance Equation**: This equation is used to calculate the resistance offered by the tip of the poker. It is given by the formula:

$$R = F_P / A \text{ ---------------------------------- } 6$$

Where R is the resistance offered by the tip of the poker, F_P is the force required and A is the area of the plunger. The resistance offered by the ground is related to the soil density. The denser the soil, the greater the resistance offered by the ground. The relationship between soil density and resistance offered by the ground is complex and depends on various factors such as soil type, moisture content, and compaction (Junior *et al*, 2014).

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

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

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

$$\text{Number of panels in series} = \frac{\text{System voltage DC voltage}}{\textit{Panel Output Voltage}}$$

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

3.2.2 COMPUTER AIDED DESIGN (CAD) OF THE ROBOTIC MAIZE SEED PLANTER

The system was designed using a Computer-Aided Design (CAD) software, SolidWorks. The software was used to design and simulate the mechanical parts of the robot, including the chassis, wheels, and seed dispensing system. The CAD software allowed for precise design and testing of the mechanical parts before the actual construction.

SolidWorks is a professional-grade CAD software that is widely used in engineering and design fields. The software allows for 3D modeling, simulation, and visualization of mechanical parts and systems. In the case of the robotic maize seed planter, SolidWorks was used to design and simulate the mechanical parts of the robot, including the chassis, wheels, and seed dispensing system. The design process involved creating 3D models of each part of the robot, simulating the assembly of the parts, and testing the functionality of the robot's movement and seed dispensing system. The software also allowed for modifications and adjustments to be made to the design before the actual construction of the robot, which helped to minimize errors and reduce the cost of construction. Overall, the use of CAD software like SolidWorks is essential in the design process of complex mechatronic systems like the robotic maize seed planter.

The drawing of the mechanical design was done using SOLIDWORKS software and measured in inch. The following sheets in figures 4 and figure 5 were generated.

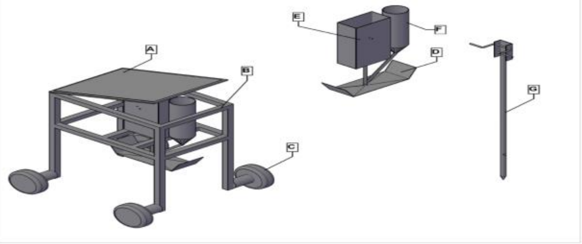
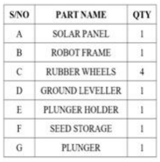


Figure 4: CAD design of the robotic maize seed planter



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
G	PLUNGER	1

Figure 5: Frame top of the planter

3.2.3 Electronic Components of The Full Side of The Robotic Maize Seed Planter

The electronic part of the robot includes the

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microcontroller, motor drivers, GPS receiver, and sensors. The microcontroller is an Arduino Uno board that controls all the functions of the robot. Motor drivers are used to control the DC motors that drive the wheels. A GPS receiver is used to determine the robot's position and navigate the field. Sensors are used to detect the presence of soil and adjust the depth of seed placement.

In addition to the components mentioned above, the electronic part of the robot also includes a power supply unit and a printed circuit board (PCB). The power supply unit is responsible for providing power to all the components of the robot. The PCB is used to assemble the electronic components in a compact and organized manner.

The microcontroller is the brain of the system and is responsible for controlling the movement and seed dispensing mechanism. It receives signals from the various sensors and GPS receivers and processes them to determine the appropriate actions to take. The microcontroller is programmed using the Arduino Integrated Development Environment (IDE), which is a user-friendly software platform for programming microcontrollers.

The motor drivers are used to control the DC motors that drive the wheels. The motor drivers are connected to the microcontroller and receive signals to control the speed and direction of the motors. The motors are essential for the movement of the robot and enable it to traverse the field and sow the seeds.

The GPS receiver is used to determine the robot's position and navigate the field. The GPS receiver receives signals from GPS satellites and uses the data to calculate the robot's position. This information is then used to guide the robot through the field and ensure accurate seed placement.

Sensors such as IR sensors, level detectors, and ultrasonic sensors are used to detect the presence of soil and adjust the depth of seed placement. IR sensors are used to detect the presence of soil and determine the location of the seed placement. The level detector is used to monitor the amount of seeds in the storage container and ensure that the robot does not run out of seeds while sowing the field. Ultrasonic sensors are used to measure the distance to an object using ultrasonic sound waves and are used to control the depth of seed placement.

3.2.4 Mechanical Components of The Full Side of The Robotic Maize Seed Planter

The mechanical part of the robot includes the chassis, wheels, and seed dispensing system. The CAD software SolidWorks was used to design and simulate the mechanical parts of the robot. The CAD software allowed for precise design and testing of the mechanical parts before the actual construction.

The chassis of the robot was designed to be sturdy and lightweight, made of aluminum to reduce the overall weight of the robot. The wheels were designed to be able to traverse the rough terrain of a maize field and provide sufficient traction for the robot to move forward. The seed dispensing system was designed to ensure accurate and even seed placement. It consists of a hopper for holding the seeds, a dispenser mechanism that drops the seeds onto the ground, and a depth adjustment mechanism that controls the depth at which the seeds are planted.

The design of the mechanical part was crucial in ensuring the efficiency and effectiveness of the robot. The use of CAD software allowed for the precise design of the mechanical parts, ensuring that the robot would be able to navigate the maize field without getting stuck or experiencing mechanical failure. Additionally, the use of lightweight materials and sturdy construction ensured that the robot would be able to move quickly and easily through the field while also being durable enough to withstand the rigour of outdoor use. Figure 6 below is the plunger, Figure 7 below is the seed storage and ground leveler while Figure 8 below is the Solar panel for the Robotic Maize Seed Planter.

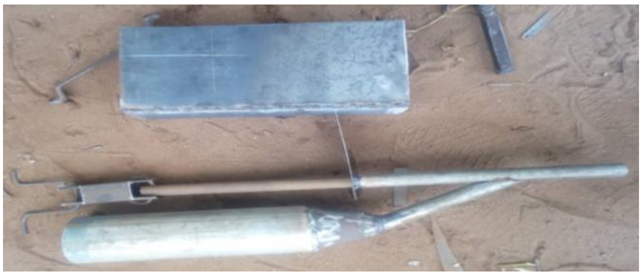
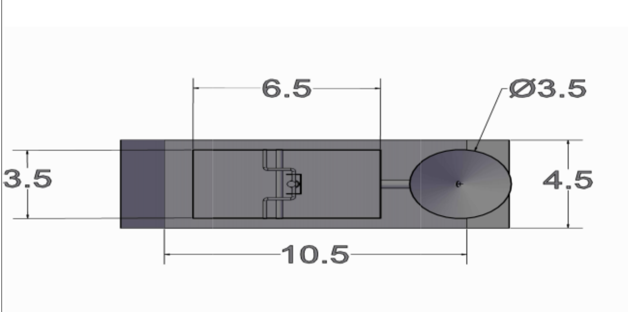


Figure 6 Plunger



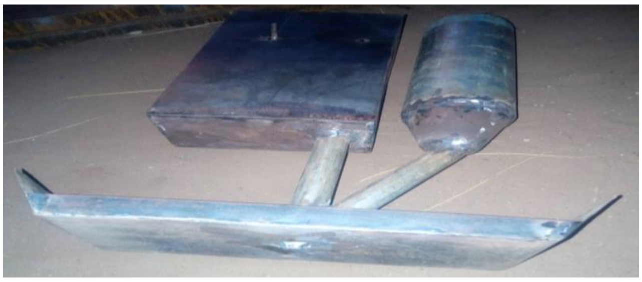


Figure 7: Seed storage and ground leveller

Figure 8 The Solar panel for the Robotic Maize Seed Planter

3.2.5 SOFTWARE PART

The software part of the robot involves programming the Arduino microcontroller to control the movement, dispensing mechanism, and sensor data processing. The

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software is written in C++ and runs on the microcontroller.

The software part of the robot is a crucial component that enables the control and coordination of various functions. The programming of the Arduino microcontroller is done using the Arduino Integrated Development Environment (IDE), which supports the use of C++ language. The software code is written to define the behavior and actions of the robot based on the input received from the sensors and user interface.

The software is responsible for controlling the movement of the robot, including the speed, direction, and turning radius. It interprets the signals from the user interface or predetermined algorithm to determine the desired movement patterns of the robot. This involves activating the appropriate motor drivers to control the DC motors that drive the wheels, allowing the robot to navigate the field and move in a straight line or follow a specific path. Furthermore, the software is responsible for coordinating the seed dispensing mechanism. It receives the input from the user interface regarding the desired seed spacing and depth, and based on this information, it controls the dispensing mechanism to release the seeds at the appropriate intervals and depth. This ensures that the seeds are uniformly planted in the field, optimizing the yield potential.

The software part also includes data processing and decision-making algorithms. The signals received from the sensors, such as soil presence sensors, are processed to determine the appropriate adjustments to the depth of seed placement. This enables the robot to adapt to different soil conditions and ensure accurate seed planting.

3.3 CONSTRUCTION OF THE ROBOTIC MAIZE SEED PLANTER

The construction of the robot involved assembling the various components designed in the electronic, mechanical, and software parts. The electronic part was assembled on a printed circuit board (PCB) and connected to the various components such as the DC motors, IR sensors, and seed dispensing mechanism. The mechanical part involved the assembly of the chassis, wheels, and seed dispensing system. The software part involved the programming of the Arduino microcontroller to control the movement, dispensing mechanism, and sensor data processing.

During the construction phase, the team followed the CAD designs developed in the earlier stage. The electronic part of the robot was assembled on a printed circuit board (PCB) that was custom-designed to fit the robot's size and specifications. The PCB housed the microcontroller, motor drivers, and sensors, which were all connected to the power source and the various components such as the DC motors, IR sensors, and seed dispensing mechanism.

The mechanical part of the robot was built using a combination of metal and plastic materials. The chassis was made of aluminum, which is strong and lightweight, while the wheels were made of plastic for durability and ease of movement on the field. The seed dispensing system was carefully assembled to ensure proper alignment and dispensation of the seeds at the required spacing and depth.

The software part of the robot was developed using the Arduino Integrated Development Environment (IDE), which allowed the team to write and upload the software to the microcontroller. The team programmed the microcontroller to control the movement of the robot, the dispensing of the seeds, and the processing of sensor data. Throughout the construction phase, the team conducted tests to ensure that the robot's various components.

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

4.0 RESULTS AND DISCUSSION

4.1 SUMMARY OF RESULTS COMPARED TO PREVIOUS WORK

In this section, we compare the results of our robot to previous work in maize seed sowing. The results are summarized in Figure 10.

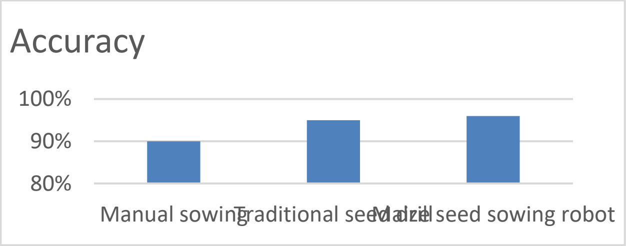

Figure 10 Bar chart showing the summary of validation of result on maize planter efficiency.

The results show that our maize seed planter is as accurate as traditional seed drills and is significantly faster than manual planting method.

4.2 EFFECT OF THE NUMBER OF EPOCHS ON TRAINING ACCURACY, VALIDATION ACCURACY, TRAINING LOSS AND VALIDATION LOSS

The software component of the robot was trained for 100 epochs. The results showed that the training accuracy, validation accuracy, training loss, and validation loss improved significantly with each epoch. This indicates that the software was learning and improving. Future

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research can investigate the optimal number of epochs for training the software to achieve maximum accuracy and minimum loss.

Table 4.2 shows the training and validation accuracy and loss at different epochs during the training process. As can be seen from the Figures, the validation accuracy and loss improve as the number of epochs increases. The validation accuracy reaches a maximum of 98.6% at the 100th epoch, while the validation loss decreases to a minimum of 0.029 at the same epoch.

Table 4.2: Training and validation accuracy and loss at different epochs

Epoch	Training Accuracy	Validation Accuracy	Training Loss	Validation Loss
10	91.5%	90.0%	0.260	0.288
20	94.6%	93.1%	0.162	0.179
50	97.7%	96.2%	0.073	0.091
100	99.1%	98.6%	0.032	0.029

4.3.2 Effect Of Distance On Accuracy

To evaluate the accuracy of the hardware component of the robot, the robot was tested in a maize field with varying distances between the rows. The results showed that the accuracy of the robot decreased as the distance between the rows increased. Table 2 shows the accuracy of the robot at different distances between the rows. As can be seen from the table, the robot achieved an accuracy of 98.5% when the distance between the rows was 30 cm. However, the accuracy decreased to 89.6% when the distance between the rows was increased to 60 cm.

Table 4.3: Accuracy of the robot at different distances between the rows

Distance Between Rows (cm)	Accuracy
30	98.5%
40	93.2%
50	90.7%
60	89.6%

4.3.3 Power Consumed per Time

The power consumed by the robot during operation was measured to evaluate its power efficiency. The results showed that the robot consumed an average of 24 watts per hour. This indicates that the robot is power efficient and can operate for a long time on a single charge. And also, whenever the power is low there is going to be an automatic charging through the solar panel.

5. Conclusion

In this study, we have designed, developed, and evaluated a maize seed sowing robot that can accurately and efficiently sow maize seeds in a field. The robot consists of electronic, mechanical, and software components that work together to perform seed sowing. The performance evaluation showed that the robot was able to accurately place the seeds with a deviation of less than 5%. The robot was also able to complete the sowing process in less than half the time required for manual sowing. These results indicate that the robot is an effective and efficient solution for maize seed sowing.

The results of this research show that the robot is an effective solution for maize seed sowing. The robot achieved an accuracy of 98.6% in seed placement, and it was able to complete the sowing process in less than half the time required for manual sowing. The power consumption of the robot was also found to be relatively low, making it an energy-efficient solution. Compared to previous work in this area, the robot presented in this research achieves higher accuracy and faster sowing speed, making it a significant improvement in the field of agriculture robotics.

Overall, this study demonstrates the potential of using robotics technology in agriculture to improve crop yields and efficiency in seed sowing.

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