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Development of 3D-Printed Agricultural Drone (Ardufarmer)

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Abstract. This study addresses the labor crisis that the agriculture industry faces and the need for an alternative planting technology for farmers. Ardufarmer is a seed sowing machine that combines the emerging additive manufacturing technology and quadcopter robotics to form an alternative broadcast farming method that efficiently covers a given land area in the least amount of time through planting toolsets: seed reservoir, dispenser valve, drill, Arduino, and GPS programming. The quadcopter development includes designing the drone fuselage and seed dispenser, three-dimensional printing (3D printing) the parts under different settings, simulation and analysis of 3D-printed parts, and programming the Arduino board and GPS mechanism. The drone was tested in different land areas in terms of time spent. The study shows that the planting rate of the drone is more efficient at 36.41 seconds in 50 square meters than manual planting at 144 seconds in 50 square meters. The Ardufarmer was tested in terms of height, time spent, and spreading diameter in different land areas. The device can effectively sow seeds in 12 seconds per square meter. The study also shows that the minimum percentage relative time saving of the proposed drone technology is 74.72%.

Introduction

About a billion people over the world experience the impacts of food insufficiency. Half of the agricultural sector involves crop production. Thus, farmers are challenged with improving agricultural productivity and planting efficiency despite the high-cost production and low income earning capacity in this sector. It is mainly caused by inevitable problems, including pests, crop diseases, soil infertility, and natural calamities striking planting seasons that severely damage ready-to-harvest, harvested, and newly planted crops [1-2]. Maize (*Zea mays var. indentata*) is one of the most important food staples for resource-poor smallholders in the Philippines, providing food and income to millions [3].

Modern farming in every aspect nowadays is completely technology-driven. There is a clear worldwide demand—a want and a need—for an even cheaper and larger food supply. Mechanization of agriculture increased the area of land that could be planted and produced, owing to the precision and speed with which crop tasks could be completed. Society is on the cusp of the fifth industrial revolution that introduces different revolutionary materials, especially three-dimensional printing (3D printing). Additive manufactured quadcopters have an advantage compared to market-ready drones. Adaptability is one of the advantages of 3D-printed drones because these quadcopters can be customized according to their use [4].

The Unmanned Aerial Vehicle (UAV) is a multirotor aircraft characterized to possess arms and has a small motor with two pairs of fixed pitch propellers installed respectively, that generate torque to help it lift and thrust. Commonly known as a quadcopter, drones are capable of performing autonomous flight operations using GPS navigation and software-controlled flight installed in their flight controller board. Drones can be used in diverse ways, from taking high-altitude pictures and videos to assisting military operations. Since they are quite adaptable once properly programmed, UAVs can perform an excellent deal for the ecological sustainability of the planet [5].

Additive manufacturing (AM) technology builds three-dimensional parts one layer at a time from a material, from polymers, metals, and ceramics to foams, gels, and even biomaterials. Designing the framework through a computer-aided design or CAD usually initializes the process. The method depends on the digital data file sent to a printer that constructs the component layer by layer. It aims to significantly reduce energy usage by using less material, eliminating steps in the production process, and generating less waste than traditional manufacturing methods [6-8]. More popularly known as 3D printing, AM is currently beneficial in a variety of applications like electronics [9], prototyping [10], water filtration and desalination [11-12], health [13], and many others [6],[14]. The use of additive manufacturing technology to Unmanned Aerial Vehicles allows utilizing the full potentials and capabilities of cheap drones in terms of energy consumption, quality, performance, and flight time [15]. Combining the knowledge about additive manufacturing and agriculture could make a significant impact on the agricultural industry.

In developing countries, most farmers experience a greater annual expenditure on farm power inputs than on fertilizer, seeds, or chemicals [16]. Ardufarmer steps off from this approach because it uses a small, agile, lightweight, energy-efficient automated robotic machine that flies to try and do the same job on a plant-by-plant basis that is currently being done by powerful ground equipment that weighs several tons and treats uniformly tens of hectares per hour. This alternative broadcast farming method uses UAVs equipped with detachable implements and reservoirs by what the investigators call the Ardufarmer robot. Ardufarmer uses high-precision GPS to efficiently perform crop dusting, soil drilling, planting, fertilizing, and other field-related farming tasks.
The researchers aim to introduce an alternative aside from the traditional land-based farming equipment and sought to provide an agricultural drone suitable for sowing seeds in fields by optimizing the drone design through Additive Manufacturing for rapid prototyping and low-cost manufacturing of the machine. This study is also concerned with exploring the impact of additive manufacturing on aerodynamics, structures, and materials used for UAVs and providing a cheaper alternative to expensive high-end drones. The project includes two major components: the Ardufarmer robot and the Ardufarmer system that work hand-in-hand in utilizing its four main components such as the 3D-printed seed reservoir or dispenser, seed dispensing wheel, soil distribution plate, and soil drill bit that are all situated on a 3D-printed quadcopter drone equipped with remote-controlled seed dispenser and GPS program that generates coordinates for mission path capable of sowing seeds uniformly, seed dispenser control, and communication. Also, the study is concerned with investigating the use of Ardufarmer in sowing maize (Zea mays var. indentata) grains [17]. Furthermore, this study can add to the existing knowledge on alternative planting and seed sowing practices and techniques and aid the farmers in advancing farming systems and securing the food supply.

Methodology

Phase 1. Construction of Framework

Drone: Design Stage

The quadcopter design was made through the study of the interaction of the different drone components. The agricultural drone was designed in Autodesk Inventor by also considering various factors. Those factors being the distance between motors, which is 16.1 x 16.1 x 5.9 inches, fuselage length, width and height, electrical components, the diameter of the motor rotor, frame weight, location of the ports, the positioning of the boards, the wire routing, the weight of the seeds and the overall structure and durability were considered. Likewise, several constraints were also considered while working on this project. Those constraints are printer volume, extremely light frame design, printing time, 3D modeling skills, battery life, maneuverability, durability, and capability to perform planned missions and tasks [18].

Using the Zortrax M200 printer imposed three primary limitations that had to be considered during the design stage: limited build volume, poor support material quality, the type of filament, acrylonitrile butadiene styrene (ABS), and its tendency to warp and split [19]. Limited build volume was perhaps the foremost apparent and most easily accommodated limitation. The maximum build volume of the ZM200 is 300mm x 200mm x 300mm. It cannot physically print a component with any dimension exceeding this volume. The most straightforward approach was to design parts smaller than the build volume of the printer. However, when this was not an option, the cutting function of Zortrax was used to divide large, unprintable parts into smaller, printable pieces that could be assembled after fabrication.

Before coming up with the open modular design structure, several designs were considered, such as closed-shell design and closed modular design. The chosen design, as shown in Figures 1, Figure 2, and Figure 3, was applied for more simple assembly, better weight minimization, and convenient maintenance. The modular solution of the project ensures sufficient resistance against errors, which may arise during printing. The systems would be pre-configured with compatible modules, thereby giving a wide array of capabilities and choices. The measurements of the drone and the iterated design were taken, and the creation of blind solids based on components and iterations in the CAD software, Autodesk Inventor, was initialized.

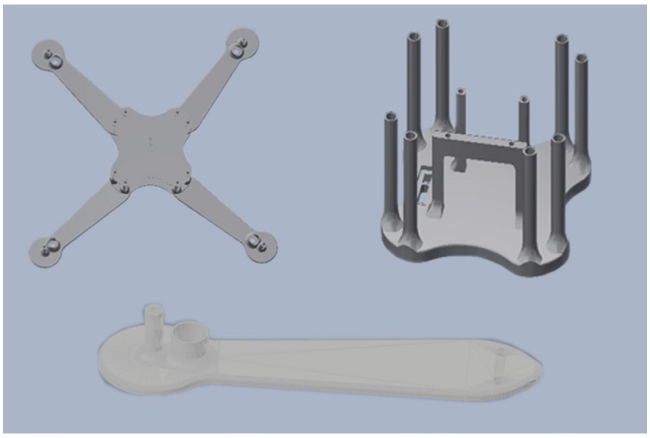

Fig. 1 Computer-aided design of drone parts.

Drone: Simulation Stage

Instead of printing immediately, the finite element analysis of the drone was done in Autodesk Inventor. A stress test was done in order to see how the model would perform given the different requirements and circumstances, such as possible deformation and flight error [20]. Simulating the newly designed unmanned aerial vehicle ensures the safety and reliability of the drone with low cost and low maintenance requirements. The drone must have the control software that is certified for safety, effective communications systems, efficient power management, and the ability to operate in challenging environments.

The analysis sets the requirements that must be surpassed by design to prevent defects from stalling production at the prototyping stage. The simulation stage could avoid problems such as residual stress, print imperfections, build failures, and surface defects. The bases were printability in the 3D printer to be used, Zortrax M200, print volume, and design and material strength. To ensure the printability in Zortrax M200, getting rid of unnecessary curves and complicated design is advised to prevent problems during fabrication. Decreasing the print volume is also essential in minimizing weight as well as lowering the printing time and cost while still taking into account the structural integrity of each part. The material considered for the 3D printing of the drone components is acrylonitrile butadiene styrene (ABS) plastic filament, especially for the parts that are often subjected to heat and friction due to its high heat capacity. The part subjected to finite element analysis was the arm segment that was simulated using ABS plastic material.

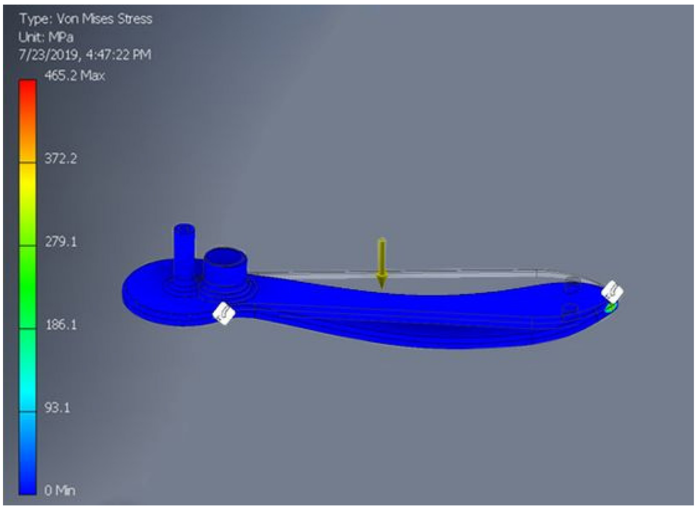

Fig. 2 First design simulated for the arm segment.

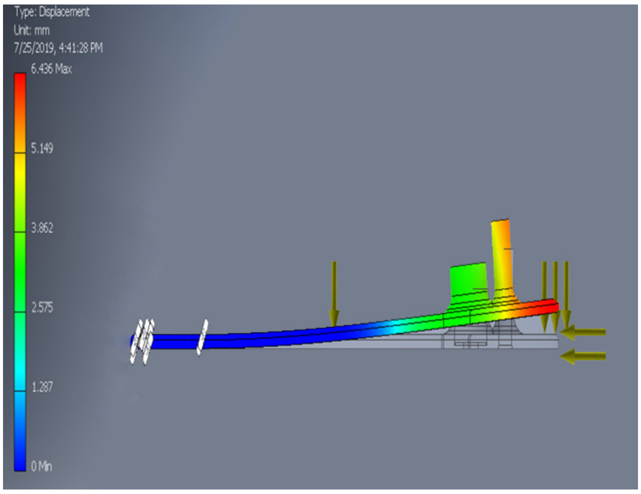

Fig. 3 Second design simulated for the arm segment.

Drone: Prototyping Stage

The created design from Autodesk Inventor was then imported into the Zortrax 3D slicing software, Z-Suite. Since the whole drone frame is larger than the print bed of the 3D printer, it was sliced into smaller segments for printing and assembled using screws. The arm segments and drone fuselage were printed using Zortrax M200 under standard print setting with 0.18-millimeter (0.18-mm) layer height, 80% infill, and auto-support. The printing setting is used and tested during the printing of the initial designs to ensure durability and precise measurements. The test print results using different designs are shown in Figure 6 and Figure 7 using Zortrax M200. Several 3D printing techniques were also considered in the prototyping stage, such as extrusion-based printing, powder bed-based printing, and binder-inkjet. These methodologies can be considered as additive versions of some 2D-printing methods [9].

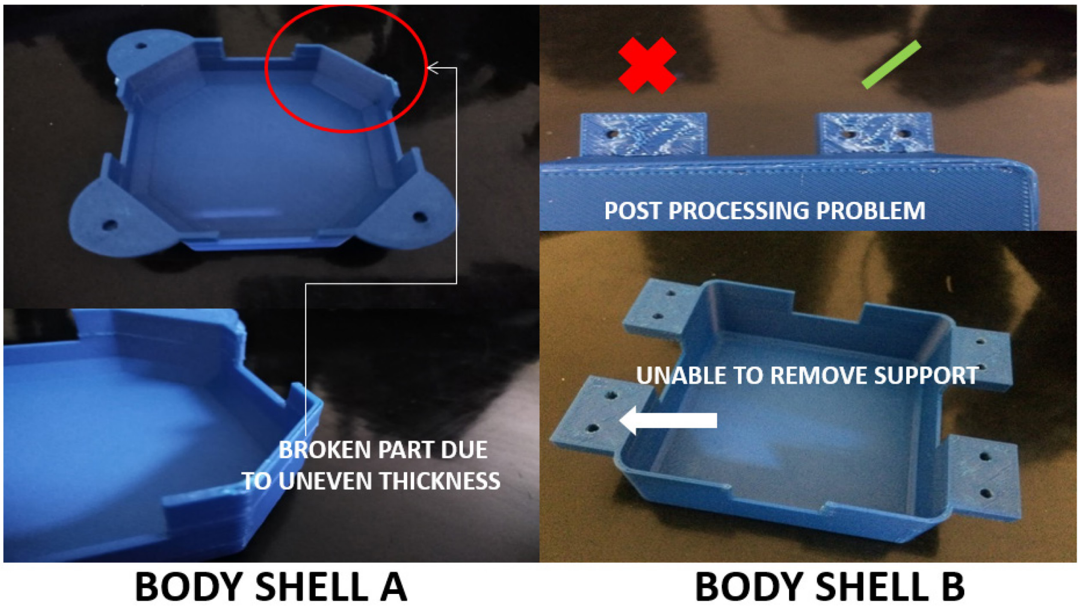

Fig.4 Problems encountered in modular design test print of drone fuselage housing.

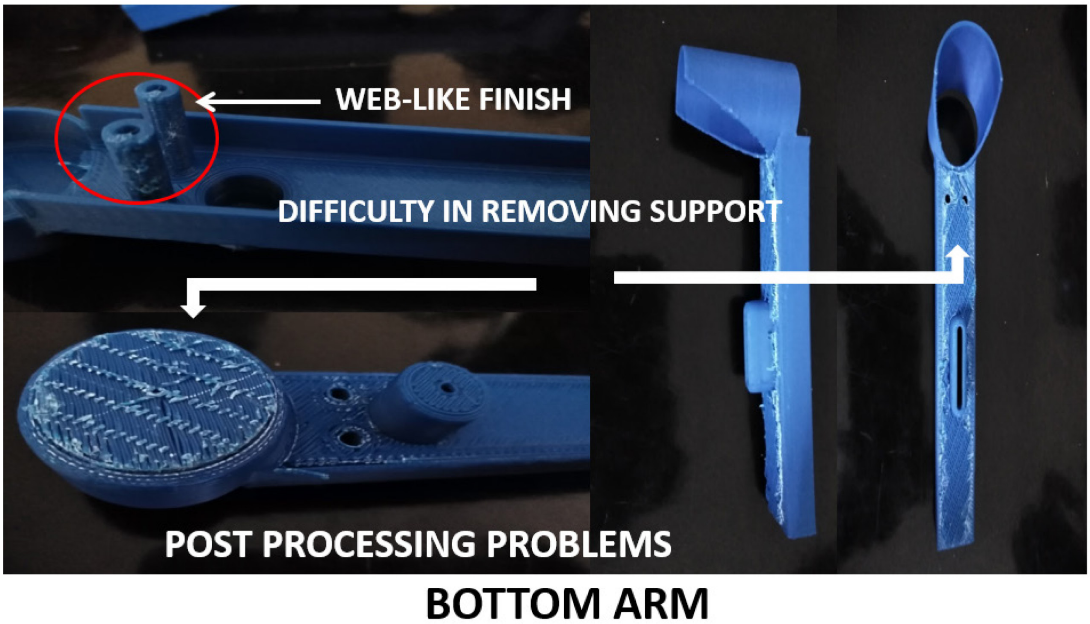

Fig.5 Problems encountered in modular design test print of drone arm segment.

The 3D-printed components, electronic and mechanical parts were then assembled. The purpose of the completed initial prototype was to provide the opportunity to conduct a flight test, the primary objective of which was to determine if the designed structure was capable of stable, controllable flight. Since the current design was optimized for printing instead of a particular mission, there were no specific performance metrics to determine whether the flight test was successful or failed. Instead, the prototype was assessed qualitatively through flight observations and pilot feedback. As configured for the test flight, the ready-to-fly weight was 90g. Figure 8 depicts the flight configuration of the prototype.

Fig. 6 3D-printed drone flight assembly installed with wiring and avionic instruments.

Drone: Iteration and Final Prototype

The quadcopter fuselage, which was initially built to house the different components of the UAV, needed several design modifications in order to accommodate the mounted planting toolsets like the seed reservoir and seed dispenser valve.

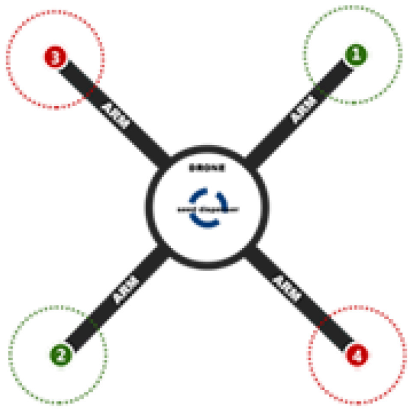

Fig. 7 Schematic diagram of agricultural drone.

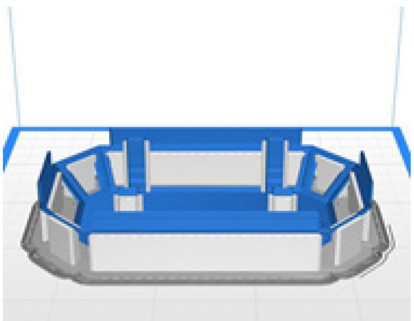

Fig. 8 Stereolithography or .stl format of agricultural drone fuselage.

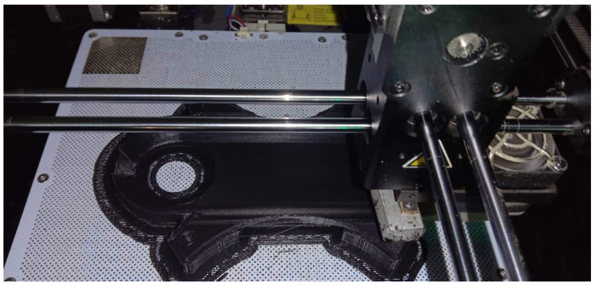

Fig. 9 Printing of agricultural drone fuselage under standard settings.

Fig. 10 Ardufarmer agricultural drone on-standby before mission (left) and in-flight during mission (right).

Seed Dispenser

The researchers used a seed gadget system principle in dropping the seeds on the chosen site [21]. The seed-dropper path is controlled by a gear attached to a servo motor attached to the quadcopter. Seeds are dropped into the holder and then into a rotational administering compartment through the gaps in the base of the holder. An infrared sensor at the base of the compartment can detect the proximity or absence of seeds distributed by the engine distributor. The release mechanism is on the neck of the bottle. The investigators also incorporated additive manufacturing technology to ensure a reduced weight and improved flight performance.

Fig. 11 Stereolithography or .stl format of the seed dispenser components.

Fig. 12 3D-printed seed dispenser components.

Phase 2. Preparation of Seeds

White Corn

The researchers used maize or white corn (Zea mays var. indentata), which is an essential crop in the Philippines, next to rice. It is known as a leading source of livelihood mainly for its versatility since everything in a corn plant is usable.

Fig. 13 Preparation of white corn (*Zea mays)* seeds.

Phase 3. Installation of Electronic Parts

The researcher used an ESC or Electronic Speed Controller that converts the battery voltage down to 7.4V, utilizing which the recipient runs in an 1800 mAh LiPo battery. It also changes over the DC control from the battery to an AC, which the engine requires. A radio channel devoted to a 2.4GHz 4-channel was also used; this has the receiver and the transmitter. The MT 1806 1800 KV brushless motors were also utilized for an efficient battery and flight time.

Phase 4. Programming

The researchers used an Arduino microcontroller that reads and processes data from the GPS (Global Positioning System) module. The microcontroller verifies the read parameters and triggers the actuators to conduct a controlled operation. The actuator, such as the servo motor, will release seeds and be activated by the microcontroller through driver circuits if the read parameters are verified. The sensors used by the researchers are the following:

NEO-6M GPS Module

This is incorporated into the Arduino microcontroller to determine the position, time, and speed essential for seed dispersal and drone navigation.

Infrared Sensor

The sensor is used to determine if the seeds inside the dispenser are already insufficient.

Temperature Sensor

This sensor is used to monitor the temperature of the crop fields and determine if the location in terms of temperature is well suited for *Zea mays var. indentata* seeds.

The actuator used by the researchers is:

Servo Motor

It is used to control the opened diameter, allowing the automatic opening while controlling the number of seeds falling out of the reservoir.

Phase 5. Data Gathering

Height and Seed to Seed Distance

The researchers pilot-tested the drone and measured the hovering height of the drone and the distance among the dropped seeds. Using a measuring tape, the researchers measured the distance between the dropped seeds. An inclinometer was used to measure the hovering height of the drone for visual measuring.

Land Area and Seed Sowing Rate

The investigators conducted the experiment in the three chosen land areas at Bilolo, Orion, Bataan. The length and width of the land were measured using a measuring wheel and calculated by using the formula of the area. The area of the first terrestrial is 50 square meters for the second terrestrial, 100 square meters. Lastly, the area of the third land is 150 square meters. The seed sowing rate was measured using the formula [22]:

$$\text{Seed Sowing Rate} = Ms/T \ \ (gm/s). \qquad (1)$$

where : Ms = Measurement of seeds (Grams) ; T = Time (Seconds).

Theoretical and Practical Seed Sowing Rate

Theoretical value was calculated using the formula of seed sowing rate. A comparison was made between the theoretical and practical values of seed sowing rate.

Time-Saving

The researchers recorded the time of the seed sowing of the drone in three different terrestrials and the time of manual seed sowing. A stopwatch was used to record the time of the seed sowing. Time saved was calculated by using the formula [22]:

$$Time\ saved\ = [\ (T\ human\ -\ T\ drone)/\ T\ human\ ]\ x\ 100. \qquad (2)$$

where: T = Time (seconds)

Statistical Analysis

The sensors and actuators were tested at distances ranging from 50 square meters to 60 square meters.. By collecting data and testing the drone, the time of the drone dispersing the seed in a specific land area was identified. The raw data were subjected.

Results and Discussion

Height and Seed Distance

Table 1 Shows the accuracy of the distance between the height of the drone and the seeds. It was observed from Trial 1 to 3 that the distance of seed sowing and the land increases if the altitude of the drone increases.

Trial	Distance (Meter)	Test I (cm)	Result	Test II (cm)	Result	Test III (cm)	Result
1	1	31.48	Success	32.30	Success	30.759	Success
2	2	33.23	Success	32.35	Success	34.02	Success
3	3	36.56	Success	34.29	Success	33.35	Success

Cost-Benefit Analysis

Table 2 Shows the cost-benefit analysis of the drone, tractor, and carabao that are essential for corn planting. It was evident that in option one, the drone has a 4:39 ratio or 0.1 cost-benefit ratio. The cost-benefit ratio of option 2 is 400:13 or 30.78. The cost-benefit ratio of option 3 is 20:13 or 1.54.

Option	Option 1 (Drone)	Option 2 (Tractor)	Option 3 (Carabao)
Cost	4,000 pesos	1,200,000 pesos	60,000 pesos
Benefit	39,000 pesos	39,000 pesos	39,000 pesos
Cost-Benefit Ratio	4:39	400:13	20:13

The researchers measured the land area and the seed sowing rate. Inland area 1 with the measure of 50 square meters, the seed sowing time is 36.41 seconds having a seed sowing rate of 4.12 gm/s. Inland area 2 with 100 square meters, the seed sowing time is 73.82 seconds having a seed sowing rate of 2.03 gm/s. Inland area 3, with 150 square meters, the sowing time of 110.24 seconds has a seed sowing rate of 1.36 gm/s. It is evident that as the measurement of land area increases, the sowing time increases, and the seed sowing rate decreases.

The amount of the seeds is 100 grams for the three modes. Data shows the relation between the hovering height of the drone and the seeds dropped by the drone. For 1 meter, the distance among the seeds is 31.48 cm with a standard depth of 10 cm. For the 2-meter height, the distance among the seeds is 33.2 cm with a standard depth of 10 cm. Lastly, for the 3-meter height, the distance among the seeds is 34.7 cm in a standard depth of 10 cm.

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Comparison between Theoretical and Practical Seed Sowing Rate

Using the equation for theoretical value, the researchers calculated the theoretical value of the seed sowing rate compared with the automated planting value. Experimental results show that the practical value of the seed sowing rate is somewhat lower than the theoretical value, which is defined as the loss factor.

Time-Saving

Table 3 Summarizes the seeds sowing rate for different land areas.

Land Area	Amount of Seeds (gm)	Sowing Time (s)	Seed Sowing Rate (gm/s)
1	100	36.41	4.12
2	100	73.82	2.03
3	100	110.24	1.36

The researchers sowed the seeds from different heights and spreading diameters. The researchers calculated the time required to cover 150 square meters of land. It requires 30 minutes to sow seeds using the agricultural drone. While in manual technology, it requires 210 minutes to sow seeds in 150 square meters of land. The investigators found that the minimum percentage relative time saving by the proposed drone technology is 74.72%

Conclusion

The present study develops an agricultural drone capable of planting seeds in fields at a rate of 12 seconds per square meter as an alternative to traditional land-based farming equipment. The seed dissemination procedure will be quick and efficient in terms of seed placement. After some tests and observation, the researchers made a larger seed-releasing compartment and propellers for more precise and smooth rotations. The researchers tested the efficiency of the seed-dispersing of the drone. The program Arduino IDE is developed to manipulate the servo motor. The seed dispensing is delegated by the GPS coordinates or by manual control using the infrared remote. Also, the temperature of the environment is monitored in planting the drone to determine if the environment is compatible with the seeds. The study shows that the seed sowing using a drone has a faster time at 36.41 seconds in 50 square meters compared to the traditional or manual planting at 144 seconds in 50 square meters. Moreover, the minimum percentage relative time saving by the proposed drone technology is 74.72%. Improvements in the electronic components are recommended. It is also recommended to utilize a lighter battery and motors to reduce the overall weight of the agricultural drone.

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