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DESIGN AND IMPLEMENTATION OF AN UNMANNED AERIAL VEHICLE (UAV) FOR IMAGE CAPTURE IN ENTERPRISE FARMING

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Abstract
Unmanned aerial vehicle (UAV), also known as drone is one of the most interesting emerging technologies with a wide range of applications including agriculture, surveillance, security, search and rescue, mapping, farmland surveying, and wildlife conservation, among others. In Nigeria, UAV is gaining popularity in applications such as in social functions for taking both moving and static pictures, military and security, mapping and agriculture. In this work, an UAV was designed, some components produced by 3D printing, coupled and tested with certain level of local content in view. The UAV is a quadcopter equipped with a camera for real-time image capture of farmlands and it can perform autonomous missions by using global positioning system (GPS) waypoints. The weight of the quadcopter was approximately calculated and hence the electrical and mechanical components selected using a standard empirical design table. The thrust to weight ratio was set at 2:1. Autodesk Maya and Inventor software were used to design the frame in two parts: the frame arms on which the propellers are mounted and the central connecting part that links the four arms. The arms are made up of aluminum square pipes while the central connecting part for the arms was printed with a 3D printer (200 x 200 x 200 Wanhao duplicator i3) using PolyEthylene Terephthalate Glycol (PETG) Filament material of 1.75mm standard gauge. Material selection was based on material strength, cost and availability. NCH Debut video and image capture software was used to record live feeds from the UAV onboard camera. Functionality tests for lift, stability, yaw, roll, pitch, loiter, auto landing, return to launch, flight time, altitude/signal, auto mission using GPS waypoints were carried out with the completed UAV on a less windy day to avoid the influence of wind. It was generally observed that the UAV successfully took off the ground, gained stability, flew to over 100m height, captured aerial photographs of the land below it while on flight at the required height and landed safely. Cost saving advantage of 45.28% was achieved when compared to imported equivalent types.

1.0 INTRODUCTION
The Massachusetts Institute of Technology (MIT) predicts that UAV technology will offer the Agriculture business a high-tech makeover, with planning and strategy based on real-time data collection and processing [1]. Due to the rise in global population and the resulting pressure on agricultural consumption, the deployment of UAV technology in agriculture has become increasingly vital [2]. The ever-increasing global population is not proportionately matched by agricultural production; hence, food sustainability is a significant challenge [3]. In order to meet this challenge, farmers around the world have

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used sophisticated and automated technologies to keep up with the ever-changing agricultural needs of the world population. UAVs are one such technologies that could aid in agriculture productivity enhancement. UAVs can be used to monitor extremely hazardous and perilous situations/missions for humans. UAVs were developed initially for military applications, but gradually they became successfully deployed in a variety of civil applications, including agriculture, law enforcement, surveillance and recreation [4].

In a related study [5], a computer vision-based citrus tree detection using UAV imagery study was carried out to detect, count and monitor citrus plant in a cultivated environment. In this work, a connected component labelling (CCL) algorithm and unmanned area vehicle (UAV) with a high-resolution multispectral imagery was adopted. Their results shows that they were able to detect citrus plant precisely using a small dataset with their methods. To ensure high precision in an UAV imagery, a study [6] was carried out to determine the best type of multispectral camera between wideband and narrow band camera that can be used for detection and monitoring of crop in farm. The camera investigated are narrowband Mini-MCA6 multispectral camera and a sunshine-sensor-equipped broadband Sequoia multispectral camera. PixelWrench software was used in the calibration of Mini-MCA6 camera to generates a six-band georeferenced orthomosaic (GOM) imagery while ASD spectrometer was used in processing of image capture by Sequoia camera from the four standard diffuse reflectance panels.

It was shown that with proper calibration, narrow band camera was more accurate than the wideband. The result also shows that the broadband camera performs more accurately in reNDVI than Mini-MCA6. In a review study [7] related to this work, a systematic literature review was conducted to determine the use of machine learning and UAV application in remote sensing for agricultural application. A meta statistical analysis was used while 163 peer-review papers were analyzed within 13 remote sensing journals that span for over 20 years. The results show that 62% of the paper used regression model while 38% used classification model. Linear regression and random forest are the most prominent method used by most researchers in processing of the captured imagery. It also shows that the common sensor technology used in UAV imagery detection is camera. In another related work [8], mapping of cynodon dactylon infesting a cover crop was carried out using UAV and machine learning.

The study used a combined decision tree (DT) and object-based image analysis (OBIA) in conjunction with UAV to map Cynodon dactylon infestation on cover crop in a vineyard. The spectral similarity problem that arises from study of this nature was solved by output of well-mapped vineyard using their method while the time limit of processing was also improved upon. This work is limited to design, rapid prototyping/manufacture of some UAV components, coupling and implementation/testing of a UAV for image capture in farms.

2.0 MATERIALS AND METHODS

A quadcopter drone, also known as a quadrotor-helicopter or quadrotor, is the type of drone developed in this project. It is built as a simple flying mechanical vehicle with four arms and four motors, with a propeller attached to each arm. The propellers produce lift for this UAV as in Figure 1 which shows the quadcopter motor configuration, with motor number 2 and 4 rotating in counterclockwise (CCW motors) direction while motor number 1 and 3 are rotating clockwise (CW motors) direction.

Figure 1: Motors directions of the quadcopter [Source: https://www.dronezon.com/learn-about-drones-quadcopters/how-a-quadcopter-works-with-propellers-and-motors-direction-design-explained/]

2.1 Design of Mechanical Structure and Electrical Circuit

2.1.1 Autodesk maya

Autodesk Maya, a CAD program, was used to create the initial conceptual design. This program was utilized to create the models (Figures 2 and 3), after careful examination of several other designs in literature.

2.1.2 Autodesk inventor

Figure 4 shows a CAD application built with Autodesk for 3D mechanical design, simulation, visualization, and documentation. This application was used to design 3D-printable components.

Figure 2: Autodesk maya application

Figure 3: Initial CAD design of the drone made in Autodesk maya software before actual construction of the UAV

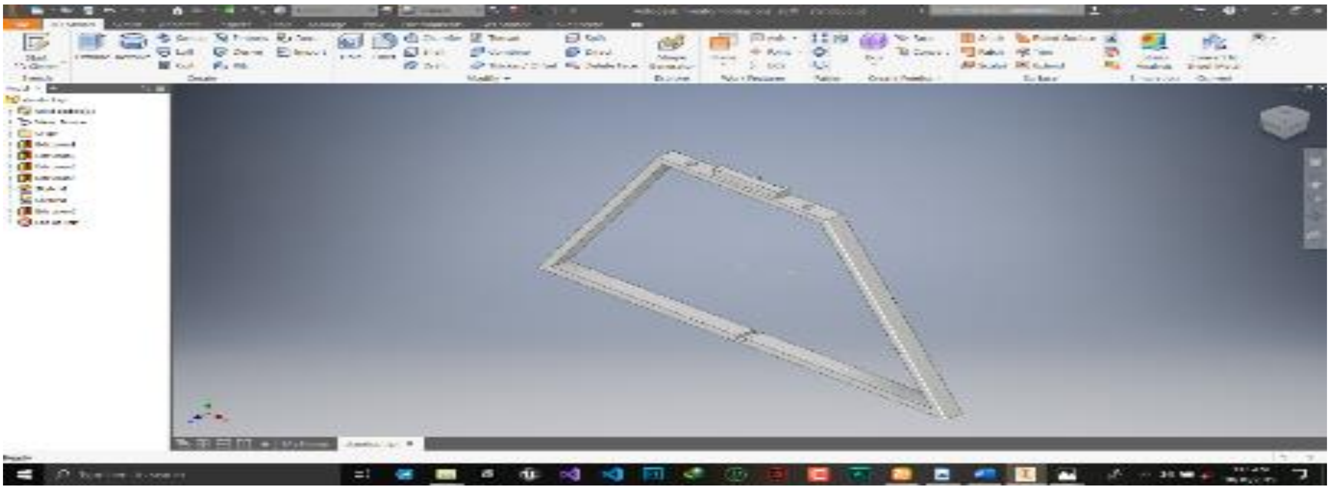

Figure 4: Autodesk Inventor application as used to design the landing gear

2.1.3 Mechanical structure

In accordance with the initial calculations and hypotheses, CAD designs were made to aid in the manufacturing of the quadcopter drone. Autodesk Maya was used to create the initial design before Autodesk Inventor was used to create part-by-part models for the purpose of 3D printing of these parts. Figure 5 shows the 3D-printed components, which include the upper and lower components of the deck compartment (i.e. the central connector linking the four arms) and the landing gears.

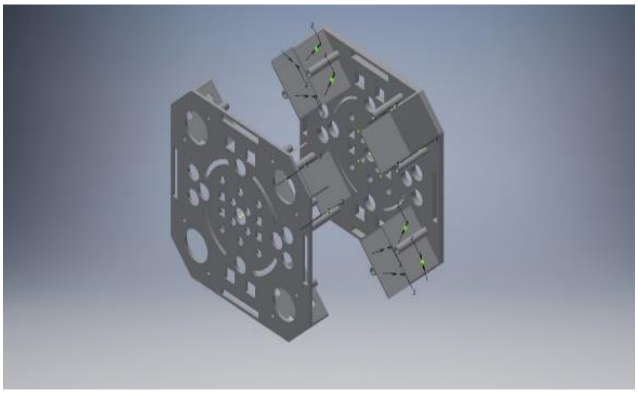

Figure 5: The upper and lower deck parts CAD design for 3D printing in Autodesk Inventor

2.1.4 Electrical components circuit design

Prior to the actual construction of the project, the components of the drone are connected as shown in Figure 6.

2.2 Design Analysis/ Calculations

Before and during construction, these calculations are performed to determine the estimated weight of the quadcopter in order to select the appropriate materials. As references for these analyses and calculations, specific parameters and components were required. Experiments conducted on various components and characteristics yielded a table of design values based on the available literature standards. Table 1 demonstrates the optimal frame, motor, propeller, and battery relationships for flying.

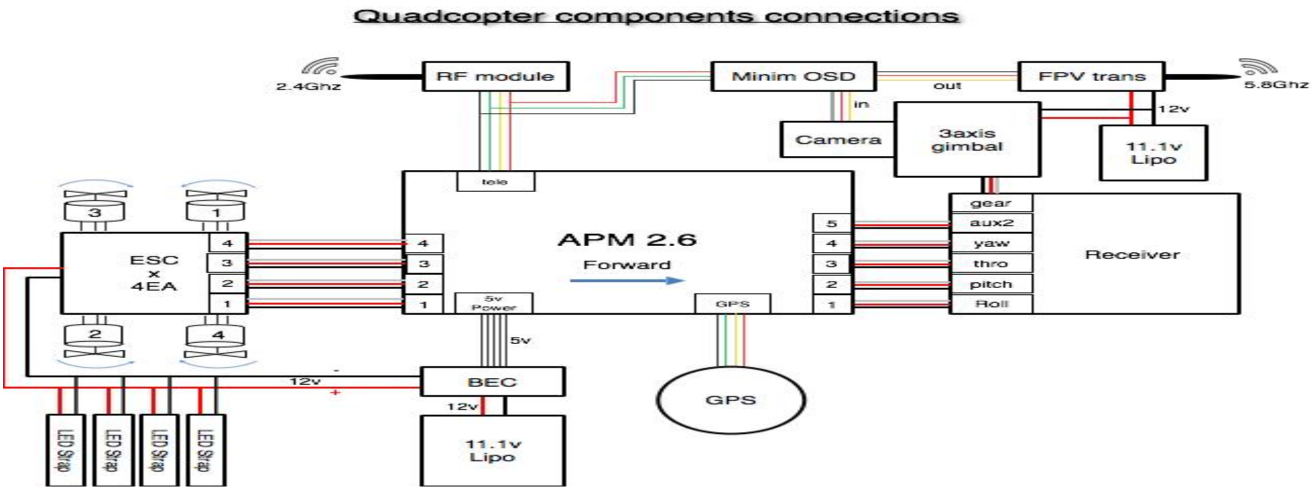

Figure 6: Block diagram of components connection

Table 1: Standards for frame, propeller, motor and battery relationship for a quadcopter

Frame Size/mm	Prop Size/In	Motor Size	Motor Speed/KV	Li-Po Size/mAh
120/smaller	3	1104-1105	4000+	80-800 1S/2S
150-160	3-4	1306-1407	3000+	600-900 2S/3S
180	4	1806-2204	2600+	1000-1300 3S/4S
210	5	2204-2206	2300-2700	1000-1300 3S/4S
250	6	2204-2208	2000-2300	1300-1800 3S/4S
330-350	7-8	2208-2212	1500-1600	2200-3200 3S/4S
450-500	9-12	2212-2216	800-1000	3000+ 3S/5S

[Source: https://www.genstattu.com/blog/how-to-choose-quadcopter-frame]

The UAV components were designed and or selected following a UAV standard design table (Table 1) as follows.

Frame type and size

The X-shaped frame was chosen for this project since it is the simplest Quadcopter frame design for stability. The frame size of a quadcopter is the distance between its diagonal motors. The 450mm frame size was chosen to fit the requirements of this project.

Propeller size

The size of the propeller was determined to be 10 inches to correspond with the numbers in Table 1 and to withstand the potential weight (the longer the propeller the higher the thrust).

Motors size and VA rating

The selected motor size was 2212 from Table 1, that is, a motor of 22mm height and 12mm diameter with a KV rating of 920 KV, or 920 revolutions per minute.

Battery size and capacity

A 3S (3 cell) 3300mAh lithium polymer battery was selected from Table 1.

2.2.1 Weight and thrust calculation

This calculation depends on the thrust of the motors to establish the optimal target weight of the UAV. Using the reference parameters selected from the Table, particular values and ratings were assigned to certain components. These are the base materials and their respective data sheet parameters required for this calculation:

Battery:

$weight = 275g$

$Capacity = 3300mAh$

$Discharge\ value = 30c$

Brushless motors (4):

$$Weight\ of\ each = 48g\text{ , }total\ weight\ of\ the\ 4\ motors = 48g \times 4 = 192g$$

$$Thrust\ of\ each = 900g, total\ thrust\ of\ the\ 4\ motors = 900g \times 4 = 3600g$$

$$Motor\ Size\ Rating = 2212\ (from\ the\ Table\ 1)$$

Therefore, the corresponding KV of motor rated 2212 from Table 1 is given as

$KV\ Rating = 920KV$

$$Amp\ draw = 9A, Total\ amp\ draw\ of\ the\ 4\ motors = 9A \times 4 = 36A$$

Flight controller (APM 2.8):

$Weight = 37g$

2.2.2 Total target weight of the UAV

To determine the theoretical weight of the UAV for optimal working efficiency, thrust-to-weight ratio was used as defined in Equation (1).

$$Total\ thrust\ of\ the\ motors = Total\ weight\ of\ UAV \times 2 \tag{1}$$

The total weight of the UAV, W is defined in Equation (2) since the thrust is given by 3600g.

$$W = \frac{3600g}{2} = 1800g \tag{2}$$

This implies that the total target weight $\leq 1800g$.

Target weight of frame and other accessories:

To determine the total weight of the UAV, the component weights were added to the undetermined weight of the frame and various accessories. Therefore, the overall weight of the UAV is equal to the sum of the weights of the battery, motors, and flight controller, plus x, as described in Equation (3).

$$Total\ weight = 275g + 192g + 37g + x \tag{3}$$

where x is the weight of frame and other accessories.

To determine the target weight of frame and other accessories x for 100% efficiency, we equated Equation (2) to Equation (3) and make x the subject as defined by Equation (4).

$$x = 1800g - 504g = 1296g \tag{4}$$

This implies that the target weight of the frame and other accessories $\leq 1296g$

2.2.3 Estimated power consumption / flight time calculation

These calculations are based on the values of the battery and the current or Amp draw of the motors.

Power Calculation:

$$Battery\ Size = 3s\ (3\ cells), each\ cell\ has\ 3.7v\ as\ nominal\ voltage,$$

$$Total\ Nominal\ voltage = 3.7v \times 3 = 11.1v$$

The nominal voltage is specified to prevent the battery from being entirely discharged, which could be harmful. Each cell has a maximum voltage capacity of 4.2v. Consequently, the power consumption of the UAV is specified in Equation (5). The cells are connected in series and the total maximum voltage, V_t is equal to 3 times the maximum voltage rating of the battery which is given as

$$V_t = 3 \times V_m = 3 \times 4.2 = 12.6v$$

where V_m is the maximum voltage of each battery cell.

The battery capacity is giving in ampere-hour and the value for each cell, C_c is 3.7Ah.

$$Power = V_t \times C_c = 12.6 \times 3.3 = 41.58W \tag{5}$$

where total voltage of battery, V_t = 12.6v and battery Capacity, C_c = 3.3Ah.

Flight time calculation:

To calculate the flight time at full throttle efficiency, 80% of the battery capacity was used in order not to allow the battery to drain completely to 0% as defined in (6).

$$Flight\ time = \frac{Battery\ capacity \times 80}{Average\ Amp\ draw \times 100} \times 60 \tag{6}$$

$$Flight\ time = \frac{3.3 \times 0.8}{36} \times 60 = 4.4mins$$

2.3 Material Selection for the Drone

The materials utilized for the project are classified into three categories:

Mechanical tools and materials: Alin key, Aluminum rod, Plastic material, 3D printer, Nuts, Bolts, Washers, Saw, Filing machine, Drilling machine, Bench vice, Screw drivers, and Hammer.

Electrical/Electronic tools and materials: ArduPilot Mega (APM), Camera, GPS module, Electronic Speed Controller (ESC), Telemetry, Wires, Brushless Motors, Battery, Multimeter, and Soldering iron.

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Software Used: Autodesk Maya and Inventor, NCH Debut Video Capture Software and Mission Planner.

2.4 Construction

2.4.1 Sketching

After selecting the frame size, motor size, propeller size, and battery type, a conceptual sketch of the system was made. The sketch included information regarding the frame and electrical unit compartment measurements. The height and width of the frame were 363mm and 450mm respectively. The electrical compartment deck consists of a square shape, a height of 120mm, a length of 120mm, and design to accommodate the drone arms.

2.4.2 Components and specification

During a market survey, components were selected according to their specifications. The market research conducted in Nsukka, Enugu, and Abuja revealed that the majority of the components required for this project were not widely available in Nigeria. This is because drone technology is still emerging in Nigeria. As a result, certain components were categorized for sale on online marketplaces such as AliExpress and Jumia. The characteristics of the components obtained from various online buying platforms are showed in Table 2 and Figure 7.

Table 2: Specification of materials and cost

S/N	Components	Unit	Specifications	Amount (Dollars $)
1	Brushless motors	4	920KV, 2CW and 2CCW	26.64
2	ESCs	4	30A with 5v BEC	25.90
5	Camera Vtx and Rtx	1		95.90
3	flight controller	1	APM2.6	
4	Radio transmitter and receiver	1	6 channels	
6	Telemetry	1	433Mhz, 2.4Ghz	
7	GPS with Compass	1	Ublox, 7M	
11	Power module	1	5v	
7	Battery	1	3s Lipobattery, 3300mah	18.52
9	Propellers	4	2CW and 2CCW	6.60
10	Battery voltage beeper	1	1-8s voltage checker	19.00
11	Mechanical frame		PETG material + Aluminum Square Tubing 4Pcs 25mm x 25mm x 200mm Long Wall Thickness 1.5mm	48.35
			Total Amount	**240.91**

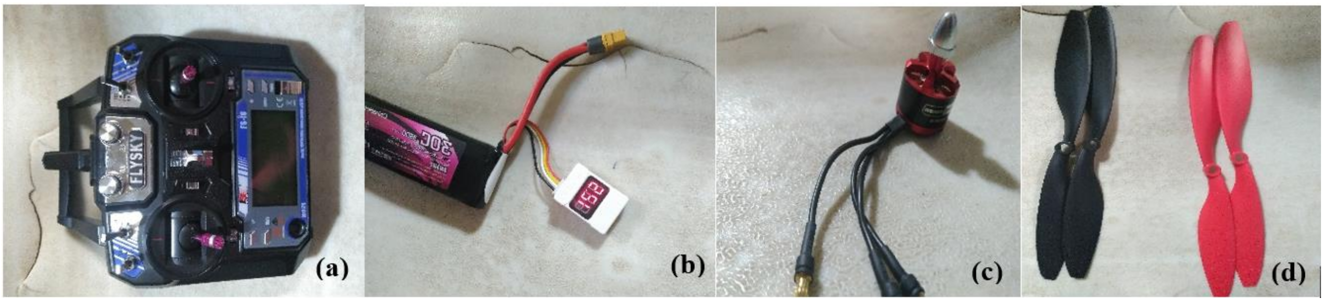

Figure 7: (a) Radio transmitter, (b) LiPo battery, (c) Brushless motor, (d) Propellers

Equivalent UAV price at Amazon: Speedy FPV Q450 450mm Quadcopter Drone kit + Camera + Delivery = $440.24.

In contrast to procuring an off-the-shelf drone, this research demonstrates a remarkable cost-saving advantage of up to 45.28% achieved through the localized construction of the drone, employing the meticulously curated materials outlined in the accompanying Table 2. This substantial financial benefit underscores the efficacy of the do-it-yourself approach, offering not only a customizable and tailored solution but also a significant reduction in overall expenditure when compared to acquiring an equivalent commercially available drone.

Other components or materials were purchased through a company affiliate. Centre for Basic Space Science (CBSS), which is the company in question in Nsukka, assisted with the completion of these projects by granting access to their laboratories and use of certain supplies.

2.4.3 Construction of the frame

The aluminum arm was divided into four pieces, each 200mm in length, for the four arms. The upper and lower halves of the central connector for the four arms that make up the frame were printed with a 3D printer (200x200x200 Wanhao duplicator i3) using PolyEthylene Terephthalate Glycol (PETG) filament material of 1.75mm standard gauge.

The printing was done at a 4mm offset to allow the arm to properly fit into the central connector. Each arm was positioned as a brace on the lower deck, and the 4mm offsets of the arms into the lower deck were covered with the upper deck and secured with screws, as illustrated in Figures 8 and 9.

Figure 8(a): Before installion of the arms

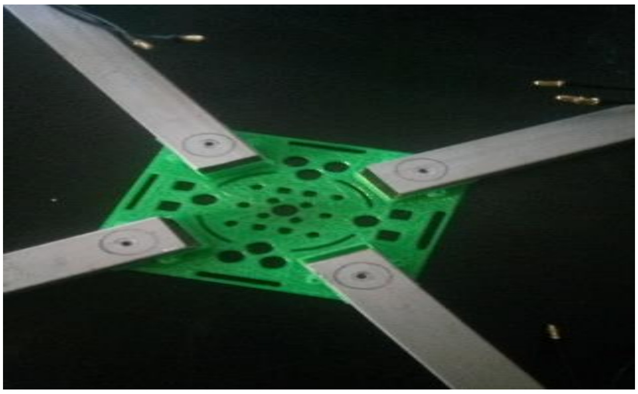

Figure 8(b): During installation of the arm

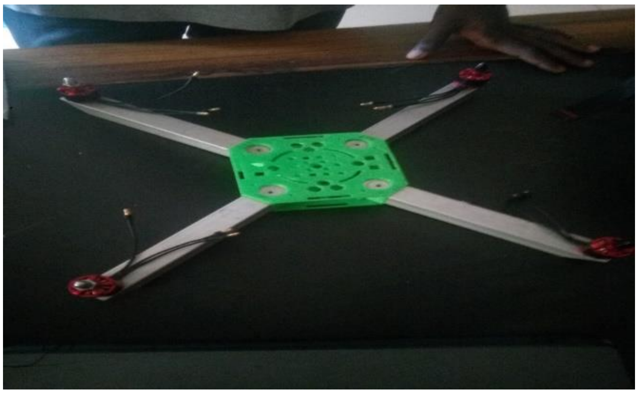

Figure 9: Finished installation of arms into the central frame connector

2.4.4 Connection of electrical components

Block diagram of the electrical connection for the system is as shown in Figure 6 while the final electrical set up is as shown in Figure 10. Each arm was equipped with its own ESC, which was connected to the APM output pins. The radio transmitter receiver and the camera receiver were linked to the input pins. The telemetry receiver was connected to the telemetry port board. A power distribution board was created to power the motors via the ESCs, APM board, and camera. After the connections were made, a multimeter was utilized to detect any improper wiring.

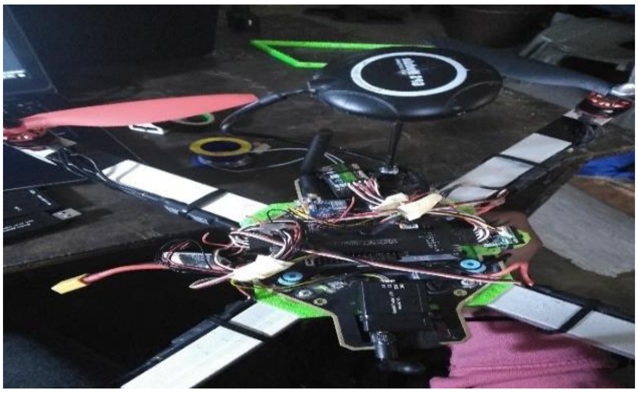

Figure 10: Connections of the electronic components

3.0 RESULTS AND DISCUSSIONS

3.1 Implementing the Firmware and Programming the Flight Controller

After the components were assembled, the APM2.8 flight controller was programmed using the mission planner application. Due to the alleged age of the APM series, its firmware was unavailable in this application. To resolve this issue, the quadcopter firmware for the APM series, version 3.1.2, was downloaded and loaded via USB into the APM board. The various sensors were calibrated, which included: calibration of the compass, calibration of the radio, calibration of the ESCs.

All of these calibrations were performed to obtain the precise orientation of the APM board and UAV, as well as the tuning of the various sticks and switches of the radio transmitter for improved control over the motor-controlling ESCs. After calibration, the UAV was prepared to be tested and adjusted for optimal flight.

3.2 UAV Testing

On completion of the construction of the UAV, a test was undertaken on a less windy day to avoid the negative impact of wind on UAV stability and flight performance. These tests were undertaken to guarantee that the UAV was operational and that the predetermined goals were met. Lift test, Stability test, Yaw test, Roll test, Pitch test, Loiter mode, Auto land mode, Return to launch mode, Flight time test, Altitude test/signal testing, and Auto mission planning with GPS waypoints tests were all performed (Figures 11 and 12). The images in Figure 13 were captured with a modified version of the UAV built in our lab.

The images were captured at a height of about three meters for the purpose of developing a deep learning algorithm for plant detection; towards weed control through selective precise herbicide spraying, as reported in [11].

Figure 11: First successful flight test

Figure 12: Auto mission test

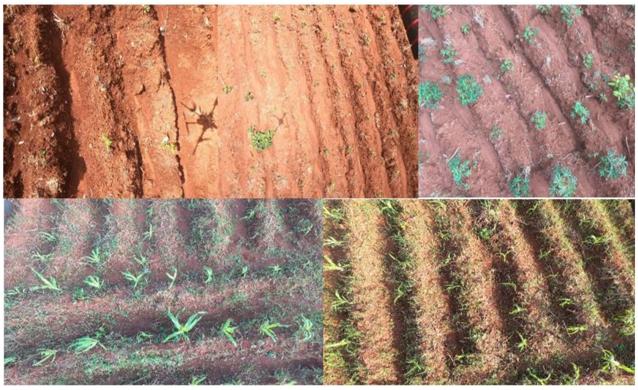

Figure 13: Plant and farm images captured with the UAV at a height of 3m

3.2.1 Performance variables tested

Table 3 shows the results of the various tests carried out on the UAV.

Table 3: Test results and discussion

S/N	Tests	Discussions
1	Lift test	The test for lift was a success as the UAV leaves the ground a little above half throttle of the throttle stick.
2	Yaw	The yaw tests were successful as the UAV seemed to response to rotation about its axis in the direction intended.
3	Roll	The roll tests were completed after recalibrating the transmitter as the drone's responses to the roll command were opposite in direction.
4	Pitch	The pitch tests were successful as they were seen to pitch and move forward and backwards without the quadcopter losing its stability.
5	Loiter mode	This mode, when initiated with the switch on channel 5 of the transmitter was found to make the drone hover except directed otherwise. This means the test was a success.
6	Auto-land	This was successful as the UAV automatically lands slowly when the command is initiated with a switch.
7	Return to Launch	Return to launch mode which uses GPS coordinate of the point of launch to automatically land on the said point was successful at first trial.
8	Flight time	The flight time was noted with a stopwatch for two modes such as loiter and manual flight mode. The flight time was estimated to be 4.5minutes with an onboard camera and 5 minutes without the camera
9	Altitude/signal test	The test for the maximum height was recorded till it loses signal using flight logs from the mission planner software. The software recorded a height of 1.2km before the transmitter loses signal. This means with a transmitter with longer signal range may allow an altitude flight of more than 1.2km
10	Auto mission planning using GPS waypoints	This was implemented using GPS waypoints for complete automatic flight. The drone completed the mission flight successful.

Based on the foregoing tests and findings, it can be concluded that the drone is capable of achieving the predetermined objectives with both manual and autonomous flight operations. The designed throttle efficiency of 81% of the quadcopter was sufficient to achieve the objectives of this work. It is important to note that if the drone is subjected to additional weight, its performance will deteriorate.

4.0 CONCLUSION

A quadcopter UAV was designed, developed, coupled and tested. Autodesk Maya and Inventor were used in the design. Thrust-to-weight ratio of 2:1 was adopted in the design and selection of components. Some components were purchased while some were either constructed through standard workshop methods or produced using rapid prototyping by a 3D printer. The UAV was assembled and subjected to functionality test for lift, stability, yaw, roll, pitch, loiter, auto landing, return to launch, flight time, altitude/signal, auto mission using GPS waypoints on a less windy day to avoid the influence of wind. It was generally observed that the UAV successfully took off the ground, gained stability, flew to over 100m height, captured aerial photographs of the land below it while on flight at the required height and landed safely. Cost saving advantage of 45.28% was achieved when compared to imported equivalent types. This work is a step forward in advancing precision agriculture in

Nigeria, through indigenous technology, especially for UAV farmland mapping as well as crop monitoring and weed management.

5.0 FUTURE WORK

Future work will focus on continuous improvement of local design and manufacture capacity, material development, design optimization, enhancing payload capacity, extending flight time and actual experiments on image detection and analysis for weed and disease detection and control. Also, application of UAV for mapping and crop monitoring will be explored in the future.

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