UIQuad I: A Low-cost and Modular Surveillance Quadcopter

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***Abstract*—The paper presents the development of an Unmanned Aerial Vehicle (UAV) quadcopter, capable of both manual and autonomous flight modes, fitted with a camera to provide pictorial and video footage of any selected environment. The prototype of the quadcopter was built with an Ardupilot (APM) 2.8 flight controller which in-corporates a microcontroller in addition to an Inertial Measurement Unit (IMU). In its autonomous mode, an open source Ardupilot Mission Planner software was used for the control of the quadcopter. Flight missions with a specified paths, altitudes and speeds were tested and stable flight operations with no human input were achieved. This surveillance quadcopter can be used as it is or scaled up or down to suit agricultural, humanitarian, government, and industrial applications.**

***Keywords*—product design, surveillance, quadcopter, radio control, autonomous**

I. INTRODUCTION

In contrast with the past when Unmanned Aerial Vehicles (UAVs) were limited to military applications, the quadcopter system has proven to be an open platform for achieving breakthroughs in numerous areas. With the present state of this world, security is a priority resource every nation and community needs. Surveillance can be defined as the focused, systematic, and routine attention given to details of activities in an environment for the intent of influence, management, protection, and/or direction [1]. It is used by various institutions to understand and manage complex environments and populations, such as traffic patterns, consumer habits, and even weather systems. Surveillance is advantageous to populations and communities, helping them better understand themselves and their environment, and to call to order those who are negatively affecting that environment [2]. A quadcopter, also known as a drone, is a type of UAV that has Vertical Take Off and Land (VTOL) capabilities [3–5]. As the name implies, the quadcopter has four motors, and propellers are mounted on the motors which provide lift for the quadcopter when they rotate. In recent times the astounding growth of quadcopter technology has resulted in affordable equipment fitted with advanced sensors and versatile motion abilities [6–8]. This has made the quadcopter to be a beneficial tool in the field of video surveillance and is now viewed as the future face of surveillance [7]. The quadcopter is not a new technological development, the Israeli, United States and other military have since utilized the advantage of Unmanned Aerial Vehicles (UAVs) in gathering military intelligence and stopping security threats [6]. With the increase of interest in drones for both commercial and military purposes nowadays, many commercial complete packaged quadcopter solutions have been developed and are available for purchase today [5].

Quadcopters come in all shapes and sizes, from sizes that can fit into your palm to those big enough to lift serious equipment like chemical sprays and filming equipment [6–9]. Control of the quadcopter can either be manually remote-controlled by a radio controller, computer or phone, or it can autonomously fly by executing specific lines of code uploaded to its onboard flight controller. Due to the build of the quadcopter, it can easily function in almost every environment and can maneuver in tight spaces [10]. In application to surveillance, a camera can be attached to the bottom of the center plate of a quadcopter's frame as a payload for live video feed during flight. With a camera mounted on a quadcopter, video surveillance now becomes mobile, and,

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in a moment, the aerial video feed of an environment can be given from an eagle-eye point of view. Nigeria is a country that has for a long time been subject to the onslaught of security, confronted by multiple security challenges, notably the Boko Haram terrorist group in the northeast, the long-running Niger Delta tension, increasing violent confrontations between herders and farming communities, and the separatist Biafra agitation. These catastrophes have displaced more than two million Nigerians thus creating a massive humanitarian crisis [11–13]. Quadcopter surveillance is versatile, having the advantage of going to places that are too dangerous, physically challenging, or impossible for humans to go to while giving a visual representation of the events or environment to person miles away. They can survey hostile military areas, monitor large farmland, obscure natural locations, or far places in need of instant relief or attention and this can be very useful for Nigeria. With the introduction of aerial surveillance, the fight against security threats can be positively accelerated. An aerial Surveillance System can be used to easily get jobs done without causing any harm to human life [14]. Also, such a system boosts the speed of surveillance operations as drones can fly faster and can continue to fly unhindered for a long period. Asides from security, drones can be utilized to collect data for research, deliver food and medicine, and also for conservation of natural resources [15]. This study is novel and laudable due to its ability to travel while unmanned. This finds great usefulness especially in regions with high security threats like the northern part of Nigeria.

A. Literature Study

UAVs were first developed for war with the earliest record being 1849 when the Austrian military tried to use hot air balloons to deliver bombs to Italian territory, although the brilliant idea quickly backfired when the wind blew some back into Austria [14]. Over fifty years later, in 1907, two French brothers, Louis and Jacques Bréguet, under the tutelage of Professor Charles Richet built and tested the first documented quadcopter and it was called the Bréguet Richet Gyroplane No 1 [15]. Its first successful demonstration was the 29 September 1907. Later on, two other improved designs were developed with Étienne Oehmichen making history in 1924 after he was able to successfully build and test a quadcopter that could travel a record distance of 360 m (1,181 ft). Étienne was later in that year able to achieve the first kilometre long flight of a quadcopter in seven minutes and forty seconds [17]. During that period, a few years before or after, Dr. George de Bothezat and Ivan Jerome designed a quadcopter for the United States (US) army with an X-frame structure that had a six-bladed rotor placed at each end of the structure [15]. Then in 1956, Dr. George de Bothezat and Ivan Jerome developed the Convertawings Model A Quadcopter which was one of the first quadcopter designs to control its roll, pitch, and yaw by varying the thrusts of the propellers, although it proved difficult to fly due to the heavy load on the pilot to control the thrust of all the four propellers at once [18] and it was able to complete several experimental tests before the US army scrapped the program [19].

B. Quadcopter Motions

By altering the driving forces on the quadcopter, five different types of motions can be achieved. These five motions are: quadcopter take-off/landing, hovering, yawing, pitching, and rolling. Fig. 1 shows the motions of the quadcopter.

Fig. 1. Motions of the quadcopter.

C. Components of the Quadcopter

1) Mechanical, electrical and electronics

1. Frame: The frame, also known as the chassis, can be described as the skeleton of the quadcopter that gives it structure and provides support and housing for all other quadcopter components.

2. Battery: The battery is the powering unit of the entire quadcopter assembly. It provides electrical power to all necessary electrical components from the motors to the flight controllers and the various sensors of the quadcopter.

3. Motors: Motors are the driving force of the quadcopter. It is the motors that cause the propellers to spin hence providing the aircraft with enough thrust to overcome lift and drag forces to fly.

4. Propellers: The propellers are the components responsible for the quadcopter carriage. Mounted on the motors, they spin in their respective directions to lift the aircraft.

5. Electric Speed Controllers: Electronic Speed Controllers (ESCs) are electric circuits that have the chief function of translating throttle signals from the flight controller into electric pulses that control the speed of the motors.

6. Flight Controller: Every machine/robot needs a processing unit and that is what the FC is. The FC is popularly referred to as the “brain” of the quadcopter and this is because, as the name implies, it is the controller of all the quadcopter’s operations.

7. Gyroscope: The gyroscope is a simple sensor chip that measures the angular velocity of the quadcopter [20]. This means that it can help detect the quadcopter’s rotational speed in the roll, pitch, and yaw axis and thus any change in its attitude.

8. Accelerometer: The accelerometer works concurrently with the gyroscope in a system termed the Inertial Measurement Unit (IMU) of a machine [21, 22]. The accelerometer simply measures linear acceleration forces in the roll, yaw, and pitch axis.

9. Barometer: The barometer is a pressure sensor that measures the air pressure it is exposed to. This implies the barometer can effectively report to the flight controller, the altitude quadcopter at any point in time.

10. Magnetometer: The magnetometer, also known as the compass, simply measures the position of an object in space [23–25].

11. GPS: The GPS is a device that can calculate the position of a body on the earth's surface or in the atmosphere through satellite communication. By interfacing with the satellites orbiting the earth, the GPS can determine the distance the quadcopter is from the satellites and so its position on earth.

12. Telemetry Module: For autonomous flight, since there is no communication with the quadcopter via a radio remote controller, another tool is needed for the pilot at the ground station to be able to monitor the flight, health, media feed of the quadcopter, and also give it instructions [26–28].

13. Camera: The camera is the final piece of a quadcopter that gives its purpose definition. The camera is a well-known device used to capture photos and videos of the environment and its inhabitants. The camera can communicate with the pilot at the ground station either through a Video Transmitter (VT) or with the newer and more sophisticated ones, via wireless connection (WiFi).

2) Software

The Mission Planner Software: this plays an important role in the operation of the quadcopter. It is majorly used to create waypoints that help to guide the quadcopter through the predefined path of the pilot. The mission planner also works with the radio transmitter and receiver. Interfacing the RC transmitter and receiver for manual control of the drone importantly helps to make the quadcopter autonomous when need be [29, 30].

II. Methodology

The first step taken was to conduct an in-depth study broadly into quadcopter technology and specifically in the area of aerial surveillance. From accumulating useful information, it was made clear what was demanded in the design and construction of the quadcopter. A primary focus for our design was that the thrust-to-weight ratio of the quadcopter should not fall below 2:1. That is, the total weight of the drone aggregated by the components should not be more than half of the total thrust to be produced by the brushless motors. A 3D CAD model of the quadcopter was generated using Autodesk Inventor and a stress analysis of the model was conducted. Figs. 2 and 3 show the conceptual design and algorithm of surveillance Quadcopter respectively.

The work commenced with the installation and calibration of the flight controllers to be employed for the development of the quadcopter. A 3D computer aided design model was thereafter developed (Fig. 2) to guide and as well give the Quadcopter developers hint on the end picture. The materials to be used for various parts of the fabrication were selected carefully after due considerations of specific requirements. This was followed with a motor programming for the Quadcopter and the coding of the Adruio system before the installation of and calibration of the flight controllers. The final phase of the work was to test flight, which was carried out to assess the success rate of the Quadcopter.

Fig. 2. Conceptual design of surveillance quadcopter.

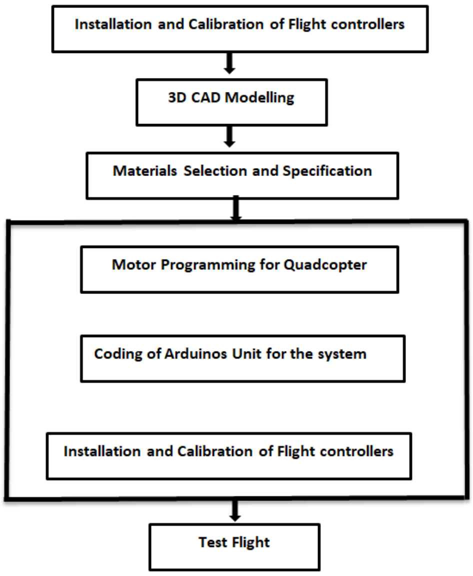

Fig. 3. Design algorithm of surveillance quadcopter.

III. Results and Discussions

Following the conceptual design, the components needed for the quadcopter operation were chosen. The first component to be selected is the F450 frame with a 450 millimeters motor to motor length. Then from standard tables, we were guided to select the correct motor with electric speed controllers' specification and propeller size needed. Using the thrust datasheet from the brushless motors we were able to calculate the battery size needed to achieve a thrust to weight ratio of 2:1, assuming the weight is at a maximum of 1,700 g. Table I shows the Mechanical, Electrical and Electronics components used and their specifications.

TABLE I. List of Mechanical Electrical and Electronics Components and Their Specifications

Component	Specification
Frame	450 mm
Propellers	8-inch, 4.5 pitch
Brushless Motor	2212 920KV
LIPO Battery	4S 5000 mAH
ESCs	Simonk 30 A

A. *Research Phases*

The research was subdivided into three phases. These three phases differ majorly by the flight controller used in each phase.

1) *Phase one*

In the initial phase, a Bluetooth module in conjunction with a smartphone application was used to control the motors of the quadcopter. By writing a simple program for the motors to increase and lower their speed in response to signals from the Bluetooth module, we were able to practically see the fundamental operations of the quadcopter. It also helped us to confirm that the clockwise and anticlockwise motors were spinning in the proper directions [12, 20]. It was discovered that the two counterclockwise motors were instead spinning in the clockwise directions, so their poles were switched and reconnected to the ESCs. The result of this phase was a successful take-off but unsuccessful flight. The motors spun correctly at the same time but due to the lack of attitude measuring sensors, the quadcopter was very unstable in the air. Fig. 4 shows smartphone application for the Bluetooth control.

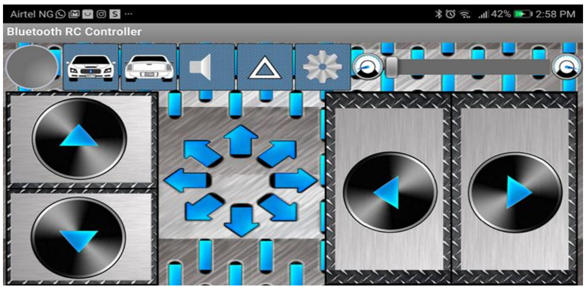

Fig. 4. Smartphone application for bluetooth control.

2) *Phase two*

In this second phase, an Arduino Uno was selected instead to be used as the flight controller [30]. The major aim of this phase was to again get the design team acquainted with the working of the quadcopter and also be involved with the rudiments of the electronics and programming of the quadcopter. An open-source code known as MultiWii was used as the flight code. This open-source code was adapted to the quadcopter specifically, by altering the PID values and also assigning motions to the different radio channels of the receiver. The Arduino Uno board was supported by a gyroscope and accelerometer module, a Global Positioning System (GPS) module, a barometer, and a radio receiver. Fig. 5 shows the Arduino Flight Controller.

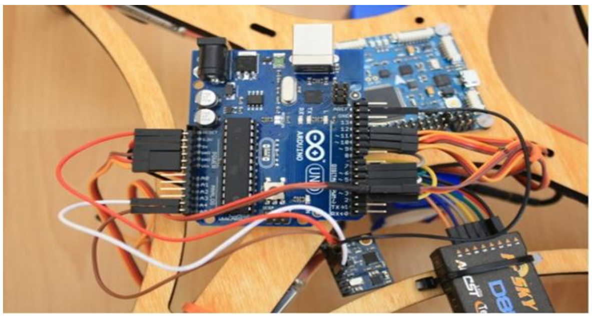

Fig. 5. Arduino flight controller.

This phase was more successful than the first, but the drone still experienced some significant instability while flying.

3) *Phase three*

This final stage utilized the APM 2.8 as the flight controller. This flight controller is a well-packaged board that has an IMU integrated with it. After proper installation and calibration of all sensors including an off-board GPS module and a telemetry module using the ArduPilot Mission Planner, the quadcopter underwent numerous tests. Fig. 6 shows the ArduPilot Mission Planner. Table II shows the component of the items and their specifications.

Fig. 6. ArduPilot mission planner.

TABLE II. LIST OF COMPONENTS B AND THEIR SPECIFICATION

Component	Specification
Flight Controller	APM 2.8
GPS	N/A
Telemetry Module	N/A
Power Module	N/A
Camera	N/A
Radio Transmitter and Receiver	FLYSKY FS-i6X 10CH 2.4GHz AFHDS RC Transmitter w/ FS-iA6B Receiver

The first tests were done to establish the proper manual mode of control with the radio remote control. The remote control uses Radio Transmitter and Receiver with six channels, four channels (1–4) were used for throttle, yaw, pitch, and roll, respectively, while the other two channels (5 and 6) were used selecting the automatic flight modes. Three flight modes: Stabilize, Loiter, and Land modes were selected on channel 5, while Altitude Hold (AltHold), Return to Lunch (RTL) and Auto modes were selected on Channel 6. The Stabilize mode is used for normal operation of the quadcopter. In loiter mode, the flight controller takes over after take-off and keeps the quadcopter at a set hovering point to avoid it drifting due to winds or imbalance.

Land mode simply allows the quadcopter to land without input from the human controller. In AltHold the throttle is automatically controlled to maintain the current altitude. In this mode the roll, pitch and yaw operate the same as in Stabilize mode meaning that the pilot directly controls the roll and pitch lean angles and the heading. When RTL mode is selected, the copter will return to the home location. The copter will first rise to return to launch altitude (RTL_ALT) before returning home or maintain the current altitude if the current altitude is higher than RTL_ALT. The default value for RTL_ALT is 15 m. The autonomous mode was tested as well, for this mode, the land mode on the radio controller was switched to Auto mode. Using the mission planner, waypoints on the map were selected as well as the hover speed, travel speed, travel radius and a return to home command for the end of the trip. With the mode of the quadcopter switched to auto mode using the radio remotely, the throttle was raised for the trip to begin. After successful tests of both modes, the camera was fitted to the bottom of the quadcopter, and surveillance footage was tested. Using the XDV mobile application, live streaming from the camera was established via WiFi while the quadcopter was in flight. Fig. 7 shows the flight plan for autonomous flight or Auto mode. The prototype of the proposed UIQuad I is shown in Fig. 8, while Fig. 9 shows the prototype air-bound during autonomous flight test.

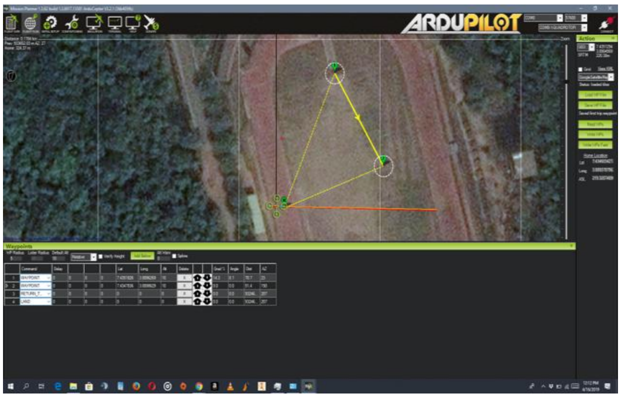

Fig. 7. ArduPilot mission planner.

Fig. 8. The prototype of the proposed UIQuad I.

Fig. 9. UIQuad I air-bound during autonomous flight test.

B. Cost Estimate for the Construction of the Prototype

The cost estimate for the construction of the prototype is shown in Table III. The major parts used for the construction were a frame, landing gear, battery, motors, propellers, speed controllers, a telemetry module camera, a radio controller and receiver and a power module. The frame used for this work was a usmile F450 Quadcopter Frame Kit with Integrated PCB Wiring which cost $42.03. A single quantity of a landing gear bracket support was also acquired at $45.50 to help facilitate the landing capabilities of the Quadcopter. To facilitate the powering of the system, 4 pieces of brushless motors (A2212 2200KV) was acquired each at $11.55 batteries making a total of $46.20 for the four motors. A pair of propellers were purchased at $2.30 each to facilitate the airlift of the designed Quadcopter. Summarily, a total of $845.27 was expended to acquire the various parts.

TABLE III. COST ESTIMATION FOR CONSTRUCTION OF THE MODEL

Item	Specification	Quantity	Unit Cost ($)	Amount ($)
Frame	usmile F450 Quadcopter Frame Kit with Integrated PCB Wiring	1	42.03	42.03
Landing gear	Landing Gear Bracket Support	1	45.50	45.50
Battery	11.1V 3S 35C 5200mah Lipo battery	1	69.28	69.28
Motors	Brushless motor A2212 2200KV	4	11.55	46.20
Propellers	1045 Propeller	2 pairs	2.31	4.62
Electric Speed Controller (ESC)	Simonk ESC 30A	4	12.70	50.80
Flight Controller with internal Gyroscope, Accelerometer, Barometer and Magnetometer	APM 2.8 Flight Controller with Barometer	1	80.83	80.83

Global Positioning System (GPS)	M8N GPS module with compass for APM	1	48.50	48.50
Telemetry Module	Telemetry 433MHz 500mW	1	138.57	138.57
Camera	Actman v3 waterproof Wi-Fi camera	1	58.89	58.89
Gimbal	2 Axis Gimbal	1	69.28	69.28
Radio controller and Receiver	Flysky FS-i6 6 channel drone remote with iA6 receiver	1	92.38	92.38
Power module	Power module	1	25.41	25.41
Power socket	XT60 pair	1	0.92	0.92
Assembly tool kit	Household Electric Tool Kit	1	72.05	72.05
Total				**845.27**

IV. Conclusion

A surveillance quadcopter was successfully built and seeded. The quadcopter's vibrations barely affected the surveillance stream, and it maintains steady flight while seamlessly executing ground pilot orders.

Conflict of Interest

Authors declared that there is no known conflict of interest that may affect publication of this article.

Author Contributions

Esther M. Aina: Investigation, Methodology, Writing and Original Draft; Damilola A. Baiyeroju; David A. Fadare; David E. Fadare; Ayodeji Falana: Supervision, Validation, Conceptualization; Rasaq A. Kazeem: Editing, and Data analysis and interpretation; Omolayo M. Ikumapayi: writing, Review and Editing, project administration, correspondence, Fund acquisition; Temitayo S. Ogedengbe: review, revise, and editing. Dorcas A. Fadare: Investigation and Writing; Tien-Chien: Editing as well as fund acquisition; Esther T. Akinlabi: project administration, Fund acquisition.

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