Design and Performance Analysis of an Integrated Quadcopter System for Aerial Photography with Real-time GPS Tracking and Video Streaming Capabilities

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Abstract—**Remote operations and the automation industry has revolutionized the way drone technology can be utilized for non-commercial purposes. This paper presents the design, development, and successful implementation of an aerial photography drone, driven by the robust KK 2.1.5 flight controller, Arduino Mega microcontroller board, BLDC Motors, Propellers, ESC's and with a FS CT-6B Transmitter. Our drone is equipped with various functionalities, including precise GPS tracking capabilities using the NEO-6M module, ensuring accurate and reliable navigation. Additionally, it features real-time video streaming through the ESP32-CAM module, capturing the world below with clarity.**

The study developed a user-friendly drone that captures aerial images and videos, with potential applications in campus monitoring, event documentation, and various other fields requiring aerial surveillance.

This paper outlines the methodologies employed in designing and integrating the drone's components, along with insights into overcoming technical challenges. Furthermore, the paper presents a thorough analysis of the drone's performance based on various test flights, showcasing its ability to achieve the desired altitude and capture complete views. The insights provided in this paper aim to contribute to the ongoing advancements in drone technology, offering a foundation for future developments in this dynamic field.

Keywords—**Aerial photography drone, GPS tracking, real-time video streaming, KK 2.1.5 flight controller, Arduino Mega Microcontroller**

I. INTRODUCTION

The rapid advancements in unmanned aerial vehicle (UAV) technology have revolutionized various fields, offering new perspectives and capabilities for data acquisition, surveillance, and aerial imaging [1]. The evolution of UAVs, commonly known as drones, has significantly impacted sectors such as cinematography, urban planning, and environmental monitoring, enabling the capture of high-resolution imagery and the performance of complex sensing tasks from previously inaccessible vantage points [2][4]. The integration of precise flight control systems, advanced navigation capabilities, and high-quality imaging technologies has opened new avenues for applications such as campus monitoring, event coverage, and aerial surveillance [3].

This paper explores the development and implementation of an advanced aerial photography drone designed to capture high-resolution imagery for a range of applications. It presents the design, development, and successful implementation of an advanced aerial photography drone. Powered by the KK 2.1.5 flight controller for stability and precise control, our drone integrates the Arduino Mega, BLDC motors, propellers, ESCs, and FS CT-6B transmitter, blending advanced technology with practical functionality.

To make it more advanced, the drone is equipped with the NEO-6M GPS module, providing precise tracking capabilities essential for reliable navigation. Additionally, the ESP32-CAM module enables real-time video streaming, capturing high-quality footage from the sky. This capability is crucial for applications requiring live monitoring, such as event coverage, surveillance, and other real-time observation tasks.

The following sections will cover the literature review, system overview and design methodology, component integration, and the result and performance analysis of our aerial photography drone.

II. LITERATURE REVIEW

Prior to this study, numerous scholars have made significant contributions to the fields of unmanned aerial vehicles (UAVs) and wireless transmission, showcasing remarkable technological advancements.

Traditionally, many UAVs have relied on fixed-wing mechanisms for their flight [1]. Fixed-wing drones offer the advantage of longer flight times and greater range, enabling them to cover larger areas efficiently [2]. This choice also provides stability in windy conditions, making them suitable for long-distance monitoring and mapping [3].

However, the advantages of multirotor drones extend beyond mere flight duration; they encompass vertical take-off and landing (VTOL) capabilities and precise maneuverability as well [4]. While fixed-wing drones excel in covering large areas, they often falter in tasks requiring close-up inspections or hovering capabilities. Multirotor drones, on the other hand, exhibit the potential to perform intricate aerial maneuvers, making them ideal for applications such as aerial photography, search and rescue operations, and real-time video streaming [5].

To harness this potential, various multirotor configurations and control algorithms have been meticulously designed and rigorously tested to evaluate their performance [6]. For instance, studies have highlighted the efficacy of multirotor drones in urban environments, where they can navigate between buildings and capture high-resolution images from various angles [7].

This literature review underscores the shift from conventional fixed-wing drones to the innovative realm of multirotor UAVs, emphasizing the unique capabilities and adaptability that multirotor drones bring to performing diverse and demanding aerial tasks.

III. SYSTEM DESIGN

The aerial photography drone developed in this work is a culmination of carefully selected components and subsystems that work together to achieve stable flight, precise navigation, and high-quality image and video capture. This section provides a detailed overview of the key components used in the drone system, along with their specifications and functions.

A. Flight controller

KK 2.1.5 is a board with ATMEL mega 664PA, 8-bit AVR RISC based microcontroller with 64K of memory. It is easy for the beginner to start with and has firmware predefined in it. While activating or deactivating the board there is an audio warning from the piezo buzzer of KK 2.1.5. It is the most stable board because it has an inbuilt gyroscope, 6050 MPU, and auto level function. This board has eight motor outputs, five control inputs, an LCD display, polarity protected voltage senor input, an ISP header, six-axis accelerometer/gyroscope, a fuse protected piezo output. The user defined signals are passed to the ESC’s installed on the frame of the drone.

B. Frame and Motors

The drone's frame, constructed from lightweight yet durable materials, serves as the structural backbone of the system, providing support and housing for all the components. The HJF 450 frame, with its X-shaped configuration, offers a balance of stability and maneuverability, making it well-suited for aerial photography applications. The frame features mounting points for the motors, flight controller, battery, and other peripherals, ensuring secure and efficient integration of all subsystems. The drone is powered by four A22212/10T 1400KV brushless DC motors.

C. Battery and Power System

The drone's power system is centered around a 3-cell (3S) 11.1V 2200mAh lithium polymer (LiPo) battery, which provides the necessary energy to power the motors, flight controller, and other electronic components. LiPo batteries are chosen for their high energy density, allowing for longer flight times in a compact and lightweight package.

To ensure the safe and efficient distribution of power to the various components, the drone employs a set of four 30A ESCs. These ESCs are responsible for regulating the current and voltage supplied to the motors, based on the control signals received from the flight controller.

D. Radio Control and Telemetry

The drone is remotely controlled using an FS-CT6B radio transmitter and receiver system, operating on the 2.4GHz frequency band. The transmitter features multiple channels for controlling the drone's throttle, pitch, roll, and yaw, as well as additional switches and buttons for activating various flight modes and functions.

In addition to the primary radio control link, the drone also incorporates telemetry modules for real-time data transmission and monitoring. The NEO-6M GPS module provides accurate position and velocity data, enabling precise navigation and tracking of the drone's location. The ESP32-CAM module facilitates real-time video streaming, allowing users to view live footage from the drone's onboard camera.

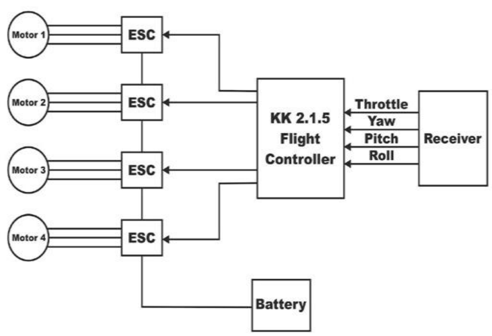

Figure 1. Circuit diagram of KK 2.1.5 quadcopter

The circuit diagram of a KK 2.1.5 quadcopter shown in Figure 1 showcases the key components and connections that enable flight control. These components include the flight controller board, receiver, ESCs, motors, battery, and sensors. The diagram illustrates how electrical signals and power flow between these elements, facilitating user command processing, stabilization, and motor control.

E. Electronic Speed Controllers (ESCs):

A brushless motor is a three-phase motor and cannot run directly on DC power. ESCs (Electronic Speed Controllers) are used to regulate the motor's speed and direction, which is essential for flight control and maneuverability. The motor's three-phase wires are soldered to the matching terminals on the ESCs, following color-coding for correct alignment. To reverse the motor's direction, any two wires can be swapped. The ESCs are powered by the main 11.1V battery through the positive and negative terminals. Each ESC's signal wire is connected to the flight controller's motor output pins (M1, M2, M3, M4), allowing the controller to manage motor speed and direction. The ESCs are connected to the first four output pins of the KK2.1.5 board as per the designated pin configuration.

In figure 2, the connection of 1 ESCs with KK2.15 board is shown. Similarly, we can connect all four ESCs with KK2.1.5 board.

Figure 2. ESC Connections with KK 2.1.5 board

F. BLDC Motor Settings

Motors one and four rotate clockwise (CW), while motors two and three rotate counterclockwise (CCW), as shown in figure 4. We set the direction of all motors using the FlySky transmitter. First, the battery is connected to the power Dean connector, and the ESC of the first motor is connected to channel 3 of the receiver, which controls the throttle.

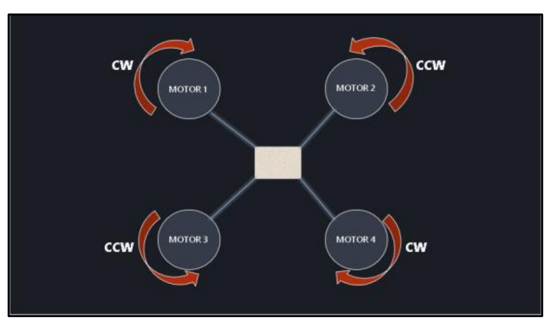

Figure 3. Quadcopter motor rotation

After switching on the transmitter, we slightly move the throttle to start the motor and observe its rotation direction. If the motor rotates in the wrong direction, we reverse the two end wires between the motor and the ESC. After adjusting, we move the throttle again to confirm that the motor is rotating correctly. This process is repeated for each motor. Both the motor and the ESC have three wires, which are connected as shown in figure 4.

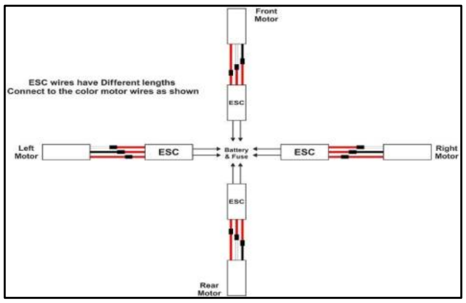

Figure 4. BLDC Motor connection structure

G. Receiver Connections:

The input pins are located on the left side of the LCD display, with five available connections for the receiver. These pins should be connected to the receiver as outlined in Table I. The first channel (CH1) of the receiver is connected using three wires (signal, Vcc, and ground), while the remaining channels relate to a single wire each, as Vcc and ground are not required for the other channels. The receiver end connections should appear as shown in the images below, following the table's configuration.

Table I: Receiver pins and KK2.1.5 input pins connection

Receiver Channel	Connecting Wire Color	KK2.1.5 (Input Pins)
Aileron (CH1)	Orange (Signal), Red (Vcc), Green (Ground)	Aileron (1st Row)
Elevator (CH2)	Black	Elevator (2nd Row)
Throttle (CH3)	Yellow	Throttle (3rd Row)
Rudder (CH4)	Pink	Rudder (4th Row)
AUX1 (CH5)	White	AUX1 (5th Row)

H. ESP32 Cam Module Setup:

The ESP32 camera module was powered using two 3.7V lithium batteries, with the Vcc (power) and GND (ground) pins of the module connected to the positive and negative terminals of the batteries, respectively. Special care was taken to ensure that the voltage and current ratings of the batteries aligned with the camera module's requirements. Meanwhile, the Arduino Mega board was powered separately, either through a battery pack or a USB connection.

The communication between the camera module and the Arduino Mega board was facilitated through the UART protocol. The TX (transmit) and RX (receive) pins of the camera module were connected to the corresponding UART pins on the Arduino Mega board, ensuring correct data transfer. Proper pin mapping was done to connect the camera module's communication pins to the appropriate pins on the Arduino, following the UART protocol for smooth communication.

Additionally, control pins on the camera module, used for functions like triggering image capture and adjusting settings, were identified and connected to the digital pins of the Arduino Mega board. This allowed the Arduino code to send control signals through the digitalWrite() function, enabling precise management of the camera's operations.

I. Flight Control Mechanics for flight controller

The movement of a quadcopter equipped with the KK 2.1.5 flight controller is governed by varying the thrust of its four motors, with flight dynamics defined by three key angular motions: roll, pitch, and yaw. Roll occurs along an axis from the front to the back of the drone and tilts the quadcopter sideways, achieved by adjusting the speed of motors on opposite sides. Pitch involves the axis running from left to right and causes the drone to tilt forward or backward, controlled by altering the speed of the motors at the front and rear. Yaw refers to the rotation around the vertical axis, where the drone rotates horizontally by adjusting the speed of the motors in opposite directions.

To execute specific maneuvers, varying motor speeds generate these motions. Roll is controlled by increasing the speed on one side while decreasing it on the opposite side, causing the drone to tilt. Pitch is adjusted by changing the speeds between the front and rear motors, enabling forward or backward movement. Yaw is managed by varying the rotational speed of the motors in opposite directions, which causes the drone to rotate around its vertical axis.

As shown in Figure 5, the quadcopter transmitter joysticks control the following functions: the left joystick manages throttle (up/down) for ascending or descending and yaw (left/right) for rotating the quadcopter. The right joystick controls roll (left/right) for tilting and moving sideways.

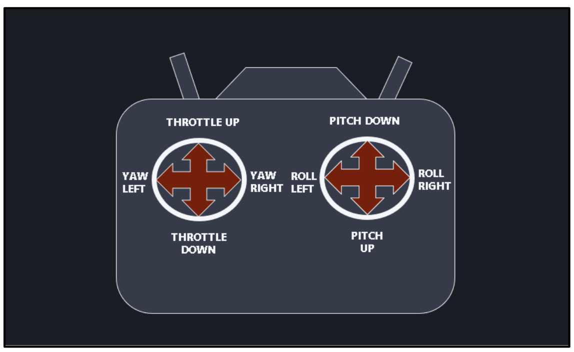

Figure 5. Quadcopter transmitter joystick function

IV. WORKING

The operation of the drone system begins with the connection of the LiPo battery to the power distribution board of the drone. This action not only powers up the entire system but also activates the camera module for live streaming and image capture functionalities. Before proceeding further, it's imperative to ensure that the remote transmitter is powered on and set to the correct mode for drone operation. Failure to activate the transmitter before powering up the flight control board (FCB) may result in errors and malfunction during flight.

Figure 6 shows how the LiPo battery is connected to the drone's power system, ensuring it supplies energy to the motors, flight controller, and ESCs for smooth operation.

Figure 6. Connectiong Lipo battery of drone to power

Once both the FCB and transmitter are powered on, a receiver test is performed to ensure seamless communication between the transmitter and receiver. Each channel on the receiver, including Aileron, Throttle, Elevator, Rudder, and Aux, should be calibrated to a neutral position (typically "0") to establish a baseline for flight control. With the receiver test successfully completed, the K.K 2.1.5 flight control board (FCB) is armed to initialize the motor control system. This ensures that all four motors rotate with equal orientation and speed, ready for flight. Figure 7 displays the drone in an armed state, fully powered and ready for flight.

Figure 7. Armed drone ready to fly

Subsequently, the throttle is gradually increased using the transmitter to stabilize the motor's speed. Throttle adjustment is crucial for achieving lift-off and maintaining stable flight. Incrementally increasing the throttle allows the drone to achieve a stable hover. Once the drone is airborne, the pilot can maneuver the aircraft using the remote transmitter. Control inputs from the transmitter are transmitted to the FCB, which adjusts motor speed and orientation to execute desired flight maneuvers.

Throughout the flight operation, it's essential to monitor telemetry data and adjust control inputs as necessary to maintain stability and control. Keeping an eye on battery levels, altitude, and orientation indicators ensures safe and efficient flight. When the flight operation is complete, the landing procedure is initiated by gradually reducing throttle input to descend the drone. Guiding the drone to a safe landing spot and gently lowering it to the ground prevents damage to the aircraft or onboard components.

V. EVALUATION

Fixed-wing drones and multirotor drones each offer unique advantages and are suited to different types of aerial tasks. The following table provides a comparative analysis based on various features and capabilities:

Table II. The comparison of the rotatory motor drone over the fixed wing drone

Feature/Capability	Multirotor Drone	Fixed-Wing Drone
Takeoff and Landing	Vertical (VTOL), require less room for take off and landing.	Need a Runway or catapult launch
Maneuverability	Highly maneuverable, easily turn in mid-air, better for hovering.	Limited maneuverability, cannot hover
Flight Time	Shorter (15-30 minutes)	Longer (1-2 hours or more)
Versatility	Easily adjust their altitude, hover in place, and more safety features built-in	Not so versatile.
Portability	Easy to pack away and transport, and even easier to set up and put to work.	Not easy to carry and work with.
Size	Smaller and easier to transport.	Tend to be larger than drones. The wings increase the overall footprint.
Cost	Most cost-effective solution.	More expensive.

Figure 8. Comparison between (a) Fixed wing drone and (b) Rotatory motor drone

The comparison between multirotor and fixed-wing drones highlights the strengths and limitations of each design approach. While multirotor options offer a balance of portability, ease of use, and range, making them ideal for most of the mapping and modeling applications [8]. Future advancements in drone technology will likely continue to enhance the capabilities of both types, potentially offering hybrid solutions that blend the best features of each.

VI. RESULTS

The aerial photography drone system underwent rigorous testing and performance evaluation to assess its capabilities in real-world scenarios. This section presents the key findings and results obtained from various test flights, focusing on the drone's flight stability, image quality, video streaming performance, and GPS accuracy.

A. Flight Stability and Control

To evaluate the flight stability and control of the drone, a series of test flights were conducted in different environments and weather conditions. The drone's performance was assessed based on its ability to maintain a steady hover, respond to user inputs, and navigate through predefined flight paths.

During the initial test flights, the drone demonstrated excellent stability, maintaining a consistent altitude and position even in the presence of mild wind disturbances. The KK 2.1.5 flight controller, with its built-in 6050 MPU gyroscope module and auto-leveling function, effectively compensated for any deviations, ensuring a smooth and predictable flight experience.

The responsiveness of the drone to user inputs was also evaluated, with particular attention paid to the precision and accuracy of the control system. The FS-CT6B radio transmitter provided seamless communication with the drone, allowing for precise adjustments to the throttle, pitch, roll, and yaw. The drone exhibited swift and accurate responses to user commands, enabling smooth and controlled maneuvers.

B. Image Quality and Video Streaming

The performance of the drone's aerial photography system was evaluated based on the quality of the captured images and the reliability of the video streaming functionality. A series of test flights were conducted in various lighting conditions and environments to assess the camera's performance and the effectiveness of the ESP32-CAM module.

Figure 9 depicts the high-resolution camera sensor of the ESP32-CAM module capturing stunning aerial images, with excellent clarity, sharpness, and color reproduction. The drone was able to capture detailed shots of landscapes, buildings, and objects from various altitudes and angles, showcasing its versatility as an aerial photography platform.

Figure 9. Final Drone flight

The video streaming capabilities of the drone were also put to the test, with real-time footage being transmitted to a ground station for evaluation. The ESP32-CAM module, with its built-in Wi-Fi connectivity, provided stable and reliable video streaming, even at considerable distances from the ground station.

C. GPS Accuracy and Telemetry

The accuracy and reliability of the drone's GPS navigation system were rigorously tested, with a focus on evaluating the performance of the NEO-6M GPS module. A series of flights were conducted in open areas with clear sky visibility to ensure optimal GPS signal reception. Figure 10 illustrates the result of the GPS data obtained through the Bluetooth module.

Figure 10. Result of GPS with Bluetooth module

The NEO-6M module consistently provided accurate position data, with a horizontal accuracy of within 2.5 meters in most test scenarios. The drone was able to maintain a stable position and altitude, even in the presence of wind disturbances, thanks to the precise GPS data being fed into the flight controller.

Figure 11. Final upper side view of drone

The results of the various test flights demonstrate the effectiveness and reliability of the aerial photography drone system. The drone exhibited excellent flight stability, precise control, and high-quality image and video capture capabilities. The GPS navigation system, coupled with the robust telemetry, ensured accurate positioning and real-time monitoring, enhancing the drone's suitability for a wide range of applications.

VII. CONCLUSION

This work successfully developed and tested an advanced aerial photography drone, demonstrating its capability in capturing high-resolution images, streaming real-time video, and navigating with precision using GPS tracking. The integration of the KK 2.1.5 flight controller, Arduino Mega microcontroller, BLDC motors, and other key components resulted in a robust system that performed reliably during various test flights.

The drone met the primary objectives of the work, showcasing its potential for applications in aerial photography, event documentation, surveillance, and real-time monitoring. The results confirmed the effectiveness of the design choices, particularly in terms of stability, maneuverability, and the quality of visual data captured during flight.

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