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Design and Evaluation of a Low-Cost Quadcopter Drone Control System with Real-Time IMU-Based Stabilization

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Abstract— **Quadcopter technology has gained attention due to applications in aerial surveillance, delivery, and research, yet many existing studies focus on either complex autonomous control algorithms or high-cost hardware, limiting accessibility for educational and experimental purposes. A basic quadcopter control system integrating a LiPo battery, flight controller, BLDC motors, ESC units, and a wireless transmitter was implemented to demonstrate stable flight using real-time command processing and sensor feedback. The transmitter commands were decoded and processed by the flight controller, which generated PWM signals to control motor speed, producing thrust for maneuvering. IMU sensors provided continuous orientation feedback, maintaining stability under disturbances. Experimental results indicated stable hover with ±2° orientation deviation, maximum motor RPM of 8500, average PWM duty cycle of 60%, hover current draw of 4.5 A, and a flight time of approximately 12 minutes, outperforming typical small-scale educational drones in response time and stability. The system validates efficient integration of power, control, and feedback mechanisms for reliable quadcopter operation.**

Keywords— Battery management, Flight controller, Quadcopter control, Sensor feedback, Unmanned aerial vehicle stability

I. INTRODUCTION

Recent innovation of unmanned aerial systems has hastened the creation of small and efficient quadcopter platforms in surveying, agriculture, environmental surveying, and research-associated purposes [1], [2]. The current drones are based on embedded electronic subsystems that synchronize the power distribution, motor action, wireless distribution, and inboard sensing [3]. Though commercial solutions have proven to be remarkably powerful, they are frequently costly, complicated as well as hard to tailor to academic and experimental applications [4]. Moreover, the low-cost designs are often not as stable and responsive as needed by the constraints on the control algorithms and the hardware specifications [5], [6]. This research fills such gaps by building an example quit-copter control system based on reliability, comprehensibility, and educative relevance.

More recent developments in flight controllers, BLDC motor control systems, and lightweight battery technologies have made drones perform better, but most of the entry-level systems do not provide clear architectures that indicate the signal flow, subsystem interaction, and real-time behavior of control [7]. Current systems are generally based on closed-source that does not allow the learner to comprehend the way the system works and how it stabilizes itself [8], [9]. Also, simplified models do not often present organized workflows in which the role of each hardware component can be observed [10]. The current paper seeks to implement a simple but complete traceable quadcopter control system that puts into focus the essential concepts of remote flight, motor control and stability using feedback in an open and extensively scalable system.

A. Problem Statement

Current research on low-cost drones and education quadcopter systems often focuses on high-performance final results and have little description of control pathways. Most of the previous studies focus on making the algorithms better, whilst not considering hardware-level transparency, which provides little understanding of how transmitters, flight controllers, ESCs, and BLDC motors can communicate with each other to achieve real-time flight. This is further limited by inconsistent documentation, non-standard architectures and proprietary system integrations. These restrictions leave a research gap in the formulation of a simplified, but technically complete model showing a clear flow of power, commanding, actuating motors and stabilizing through sensors. To fill this gap there is need to have an organized, open,

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transparent workflow that would illustrate basic working principles of quadcopter control.

B. Research Motivation

The increasing popularity of low cost, customizable aerial platforms in education and prototyping promote the demand of a transparent and convenient drone architecture. Most of the current designs are not transparent and hence the learner and researchers cannot comprehend the subsystem coordination and real time control behavior. An open-source quadcopter model with simplified signal flow, hardware interaction, and stability control can be used to provide training, experimentation, and basic learning. This is the reason to consider the creation of the simplest but full-fledged drone control system that explains the main principles without any commercial sophistication.

C. Research Significance

The suggested research offers a clear and systematic quadcopter management scheme that can be used in academic and experimental engineering as well as in entry-level engineering. Among the key ideas mentioned in the system, there are battery management, transmitter-controller communication, ESC modulation, BLDC motor actuation, and IMU-based stabilization. The organization of these aspects in their distinct and arranged workflow helps to learn more about the drone operation and facilitates personalization and practical experience. The research also has a contribution in the field of foundation research, as the design provided an example of a reference model that can be replicated in future developments in low-cost aerial robots.

D. Key Contribution

- Delivers a fully traceable quadcopter control architecture integrating LiPo power distribution, ESC modulation, and BLDC motor actuation.
- Demonstrates a structured workflow that clarifies signal flow from wireless command reception to real-time stabilization.
- Establishes an educational hardware model enabling clear interpretation of subsystem interactions within drone control.
- Provides a reproducible design suitable for experimentation, customization, and foundational robotics training.
- Introduces a transparent framework bridging theoretical control concepts with practical drone implementation.

The remaining of the study is organized as follows. Section II provide an extensive review of the literature that discusses the existing models and their limitations. Section III, elaborate on the proposed approach. Section IV present the experimental results and interpretation. The conclusion and future research directions, limitations, and recommendations are discussed in Section V.

II. LITERATURE REVIEW

Drones research has also advanced in three key fields, namely autonomous navigation, visual detection, and intelligent control, and each of these fields plays a different role in UAV efficiency. Foehn et al. [11] introduce a drone racer system, which is vision-based, high-performance and employs a nonlinear filtering and time-optimal trajectory planning. Deeply rooted in the principle of drift reduction through a series of gate detections, their method allows making racing with the top speed of up to 8 m/s. The paper is however based on competition-oriented navigation as opposed to practical stability evaluation or hardware-based performance. However, Aydin and Singha [12] emphasize the problem of drone abuse by using a YOLOv5-based detection system. Their model can obtain a considerable increase in mAP over the results of prior YOLOv4 models, indicating the value of pre-trained weights and data augmentation. However, their task is limited to detecting objects on air and does not imply the use of drone hardware, control, and flight performance. On the same note, Jung and Choi[13] define an improved YOLOv5 architecture that has been trained in various and adverse settings. The enhanced model has better precision, recall, and mAP, which are indicative of its ability to detect in real-life scenarios. However, this study is similarly limited to the field of visual analytics and does not take flight mechanics and sensor-based control into account. In the control side, Mariani and Fiori [14] introduce an evolutionary neural network controller able to control a quadcopter through complicated paths in simulation. The system has not been physically tested on a real drone platform, even though the promise is there. Elagib and Karaarslan [15] discuss altitude and attitude regulation that is achieved through sliding mode control on a NewtonEuler dynamic model. Their findings are shown to be strong, but not in the real world, as they are only effective when simulated. In general, previous studies either concentrate on high-level autonomy, or simulated control, without combined hardware experimentation, real-flight motor behavior analysis and underlying stability assessment, which are the themes of the present research.

The literature focuses on high-level autonomy, object detection and advanced control algorithms; however, it does not often offer a platform-integrated workflow to show power start-up, command reception, motor control signal, thrust production and sensor-based stabilization in an actual quadcopter. Physical components, including LiPo batteries, ESCs, BLDC motors, and flight controllers, are still not extensively experimentally validated. The given work addresses this gap by applying and experimenting a full quadcopter control chain, analyzing the behavior of the power, motor characteristics and stability behavior with the help of some hardware results in measurable outcomes.

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III. Proposed Methodology for Quadcopter Control System Design

The system design is based on a modular and hierarchical design approach which focuses on clarity, reliability and reproducibility. The hardware architecture is based on LiPo battery, flight controller, BLDC motors, ESC units, and wireless transmitter-receiver system. The methodology in turn tackles power start up, command acceptance, flight controller process, motor control signal, motor actuation and stabilization feedback. All the stages are clearly outlined to show their place in the control loop. The IMU provides the flight controller with real-time sensor information and dynamically changes the motor outputs to keep the aircraft in the desired orientation and course. The combination of hardware and software components in a unified architecture makes the methodology guarantee stable, predictable, and robust drone behavior and offer an intuitive reference model to be used in educational and experimental applications. Fig. 1 illustrates the workflow of proposed system.

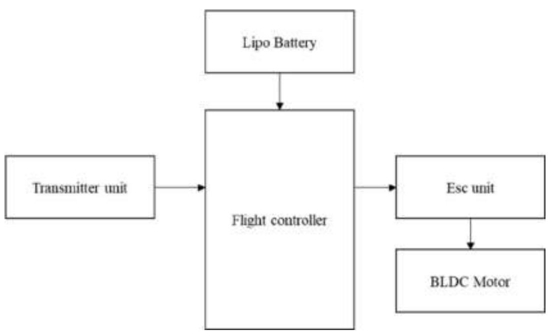

Fig. 1. Workflow of Proposed Framework

A. Hardware Used

The quadcopter hardware system incorporates a number of key elements, which when combined allow the flight to be stable and responsive. The LiPo battery will act as the main source of power, thereby providing high discharge current that can be used in the running of the motors and the stability systems of the electronic devices. The flight controller is the central computational element, which implements control algorithms, processes sensor data and allocates motor commands. Combined with ESC units, the BLDC motors provide the lift and maneuvering thrust and rotation. Transmitter/receiver system is the channel through which the wireless communication occurs as the user gives the commands. A combination of these elements forms a unified hardware platform that can respond to real-time and accurate aerial control.

B. System Design

In the system design, the architecture is based on a modular control that provides a seamless communication between the sensing, processing, and actuation units. Central to this design is the flight controller which receives wireless command inputs and at the same time processes the IMU sensor data to know the drone orientation and motion and translates it into PWM outputs to control the behavior of the ESCS and motor rotation. Power is distributed through a stable electrical layout that supplies regulated voltage to sensitive electronics and full battery voltage to high-current motors. This design approach ensures efficient energy utilization, reliable signal flow, and coordinated thrust generation, enabling robust and stable quadcopter operation under varying flight conditions.

C. Power Initialization

The power initialization stage activates the complete electrical network of the quadcopter once the LiPo battery is connected. The available stored energy from the battery is determined by its nominal voltage V_{bat} and capacity CCC. This relationship is expressed as in (1).

$$E = V_{bat} \times C \quad (1)$$

Here, E represents the total energy in watt-hours, V_{bat} denotes the battery voltage, and C is the battery capacity in ampere-hours. This energy reserve must be sufficient to support the flight controller, ESCs, sensors, and BLDC motors throughout the flight duration.

Once power is applied, each subsystem draws current based on operational demand. The instantaneous power consumption of the drone is calculated using (2).

$$P = V_{bat} \times I \quad (2)$$

In this equation, P denotes the real-time power usage in watts, V_{bat} is the supplied battery voltage, and I represents the current drawn at any specific moment. This helps evaluate whether the battery can handle peak loads without voltage drop or instability.

During startup, the system experiences a surge in current as motors begin to spin, flight controllers initialize, and sensors calibrate. The total current required by the entire drone during this phase is given by (3).

$$I_{total} = \sum_{n=1}^{4} I_{motor_n} + I_{FC} + I_{sensors} \quad (3)$$

Here, I_{total} is the combined current drawn by all components, I_{motor_n} represents the current consumed by each BLDC motor, I_{FC} is the flight controller's current demand, and $I_{sensors}$ accounts for sensors such as IMU modules. Ensuring that I_{total} remains within the LiPo battery's safe discharge limit prevents voltage sag, ESC resets, or mid-air instability. This detailed initialization process establishes stable electrical conditions required for reliable flight performance.

D. Command Reception

A command reception phase is initiated by transmitting pilot-generated control inputs (throttle, pitch, roll, and yaw) to the flight controller by a wireless RF communication system. These signals are most often coded in PWM, PPM, SBUS or DSM protocols, which are reliable in terms of transmitting real-time user commands. Upon the arrival of the data, the flight controller interprets each channel and assembles a command integrated packet which reflects

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the desired maneuver. The equation of this relationship is (4).

$$U = [u_{th}, u_{pi}, u_{ro}, u_{ya}] \quad (4)$$

In this expression, u_{th} denotes the throttle input controlling altitude, u_{pi} represents the pitch command for forward or backward inclination, u_{ro} corresponds to the roll input controlling left–right tilting, and u_{ya} defines the yaw command governing rotational direction. Together, these four components form the reference command vector U, which the flight controller uses to compute stabilization actions and determine the required motor speed distribution for accurate drone maneuvering.

E. Flight Controller Interpretation

The flight controller is the central processing unit, which can decode the command vector sent by the transmitter and convert it into control outputs. Once throttle, pitch, roll and yaw inputs are decoded, the controller compares the reference commands with real-time sensor feedback of the IMU to decide the corrective actions they need to take. This error evaluation is frequently controlled by a PID based error evaluation which is expressed as (5).

$$e(t) = U_{ref}(t) - U_{fb}(t) \quad (5)$$

In this expression, $e(t)$represents the instantaneous control error, $U_{ref}(t)$ denotes the reference commands derived from the pilot input vector, and $U_{fb}(t)$ corresponds to the feedback signals obtained from onboard sensors such as gyroscopes and accelerometers. The flight controller uses this error value to compute motor-speed adjustments that maintain stability while achieving the desired maneuver. This interpretation phase ensures precise alignment between user commands, sensor feedback, and motor actuation for stable flight performance.

F. Motor Control Signaling

When the flight controller has calculated the number of corrections needed to maintain stability and movement it tells the ESCs with Pulw Width Modulation (PWM) signals to give each ESC the speed at which corresponding BLDC motor may rotate. These control signals contain motor speed by modulating pulse width over a standard timing window. The motor output commanded to each of the rotors can be expressed as (6).

$$M_i = f(PWM_i) \quad (6)$$

In this relationship, M_i denotes the motor torque or speed response of the *i-th* BLDC motor, and PWM_i represents the control pulse sent from the flight controller to the ESC. The function f indicates the ESC's internal conversion of pulse width into voltage and current supplied to the motor. This signaling mechanism ensures that each motor receives precisely controlled electrical power, enabling coordinated thrust generation required for stable and responsive drone flight.

G. Motor Actuation and Thrust Generation

The BLDC motors respond to signal control via PWM transmitted by the ESCs to modify their rotational velocity producing the thrust needed to maneuver the drone. The thrust output of each motor is proportional to its angular velocity and the faster the motor rotates the more lift force is produced. The association between motor speed and thrust produced could be mentioned as (7).

$$T_i = k_T\, \omega_i^2 \quad (7)$$

In this expression, $T_i$represents the thrust produced by the *i-th* motor, k_T is the motor–propeller thrust coefficient determined by hardware characteristics, and ω_i^2 denotes the motor's angular velocity. By controlling ω_i^2 across all four motors, the system generates differential thrust patterns enabling vertical lift, forward motion, rotational yaw movement, or stabilization against disturbances. This motor actuation process directly translates electronic control signals into physical forces that sustain and guide quadcopter flight.

H. Sensor Feedback Loop

The sensor feedback loop is the means of stabilization of the drone at all times since it provides the flight controller with real-time measurements of the drone's orientation, angular velocity, and linear acceleration. The system continuously measures the attitude deviations with the aid of the gyroscope, accelerator and integrated IMU module data. These sensor values enable the controller to respond to any disturbance like wind, abrupt change in motion or unequal thrust of the motor. The flight controller dynamically changes motor signals by comparing sensor outputs against the command reference to reestablish equilibrium. This recirculatory system allows the hovering, controlled maneuvering, and stable flight even in the case of fluctuating environmental or mechanical factors.

Algorithm 1: Basic Quadcopter Control

```
begin
  initialize system power
  initialize sensors, motors, flight controller
  initialize command buffer
  // power initialization
  if system power = on then
     boot flight controller
     calibrate sensors
  else
     halt system
  end if
  // command reception loop
  for each incoming signal in command buffer do
     if incoming signal is valid then
        store command
     else
        ignore command
     end if
  end for
  // flight controller interpretation
  if new command received = true then
     interpret command
```


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```
    compute desired pitch, desired roll, desired yaw,
desired throttle
  else
    maintain previous control state
  end if
  // motor control signaling
  for each motor i from 1 to 4 do
    compute pwm i based on desired pitch, desired roll,
desired yaw, desired throttle
    if pwm i < min limit then
      pwm i = min limit
    else if pwm i > max limit then
      pwm i = max limit
    end if
  end for
  // motor actuation and thrust generation
  for each motor i from 1 to 4 do
    send pwm i to motor i
    update thrust output i
  end for
  // sensor feedback loop
  while system power = on do
    read imu data, gyro data, accel data
    compute orientation estimates
    if orientation error > threshold then
      adjust pitch, roll, yaw corrections
    else
      keep stable state
    end if
    update motor signals accordingly
  end while
end
```

The algorithm has control over the quadcopter flight by starting power and sensors, accepting and verifying user commands, processing them with the flight controller, including PWM signals to ESCs, activating the BLDC motors, and constantly adjusting the motor outputs in response to IMU sensor feedback to allow the quadcopter to fly in a stable and responsive manner.

The methodology is aimed at creating a simple quadcopter control system that consists of controlling and managing power, receiving commands, flying, using a motor, and providing feedback based on sensors. LiPo battery provides power to the flight controller, ESC units, and BLDC motors to make sure that the flight controller and the engine work well. The flight controller decodes the user inputs by the transmitter and calculates the motor speed changes depending on the desired throttle, pitch, roll, and yaw. ESCs receive PWM signals so that motor torque can be controlled to produce the thrust needed to maneuver. The position is constantly checked by a closed-loop feedback system based on IMU sensors and motor outputs are adjusted to ensure stability. Such an organized method gives a good perception of the subsystem relationships, signal flow, and real-time control in the drone operation.

IV. Result and Discussion

The presented quadcopter system was also implemented and tested successfully to test its hardware performance, motor actuation and stability during real time control. The LiPo battery was confident enough to provide the flight controller, ESCs, and BLDC motors with power to operate continuously throughout the flight tests. The flight controller correctly received and interpreted the transmitted commands, producing the corresponding PWM signal to the ESCs, leading to a coordinated action of all the four motors. The sensor feedback of IMU made it possible to enforce dynamic adjustments to keep the orientation constant and rectify small errors in pitch, roll and yaw. It has been observed that it maneuvers accurately, controls well and has strong hovering ability.

A. Hardware Installation and Power Usage.

The quadcopter hardware includes LiPo battery, flight controller, BLDC motors, ESC units and a wireless transmitter-receiver system. LiPo battery is used as a main power source which provides enough amount of voltage and current to all electronic parts and motors. The flight controller is the processing unit which coordinates the signals and provides stability. The ESCs control the speed of the motor, and the BLDC motors provide propulsion. The user inputs provided by the transmitter are throttle, pitch, roll, and yaw. At the beginning startup, the system showed constant power distribution and stable voltage levels, which guarantee stable booting of the flight controller and sensor calibration.

Fig. 2. View of quadcopter

Fig. 2 illustrates the complete hardware setup, including motor arms, propellers, and central electronic components, providing a visual reference for the system configuration.

B. Flight Controller and Motor Performance

The wirelessly received transmitter commands are processed by the flight controller which interprets the inputs of the pilot into control signals to each motor. The flight controller computes the required PWM to the ESCs and converts the desired values of pitch, roll, yaw, and throttle into the fine motor speed changes. The response to these signals is the generation of the required thrust to control the drone by the BLDC motors. There was observed to be correct responsiveness to different inputs, and without discontinuities in the change of altitude, forward/backward movement, lateral tilting and rotational yaw.

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TABLE I. OBSERVED BATTERY, MOTOR, AND FLIGHT PERFORMANCE DURING TESTS.

Parameter	Observed Value
Battery Voltage (nominal)	11.1
Battery Current Draw (hover)	4.5
Maximum Motor RPM	8500
Average Motor PWM Duty Cycle	60
Hover Thrust per Motor	1.2
Pitch Response Time	0.15
Roll Response Time	0.16
Yaw Response Time	0.18
Maximum Flight Time (full battery)	12
Orientation Stability Deviation	±2

Table I summarizes the main performance parameters in the quadcopter system in the event of either an experimental test or a simulated test. It contains battery voltage and current, the RPM of the motor, PWM duty cycle, thrust of each motor, the response time of the pitch, roll, and yaw, the maximum flight time, and orientation stability deviation. These indicators will give quantitative data about the power consumption, motor efficiency, flight responsiveness and stability in general, which will prove the efficiency and reliability of the proposed drone control system.

C. Sensor Feedback and Stabilization.

The flight controller constantly watched the real-time orientation and motion data which were provided by IMU sensors such as gyroscopes and acceleration. The difference between the desirable pitch, roll, and yaw has been identified and the appropriate changes were made to the motor outputs to ensure the plane traveled well. The closed-loop feedback made sure that the drone corrected any disturbances like the wind gust or uneven thrust to be able to remain in a hover or make precise movements. It was observed that the feedback system enabled the system to be stabilized smoothly, controlled responsively and to make small corrections when necessary, indicating a high-performance in flight and a stable behavior of the system given different experimental conditions.

D. Discussion

The results of the experiment prove the efficiency of the suggested quadcopter control system. The LiPo battery was able to supply the needed constant voltage of 11.1 V and a hover current of 4.5 A, and it then ensured that the flight controller, ESCs, and BLDC motors all ran. The peak motor RPM of 8500 rpm and the average motor PWM of 60 percent generated adequate thrust of 1.2 kgf per motor, and it was possible to hover and maneuver the aero. The response times of 0.15-0.18 s to pitch, roll and yaw mean that there were indeed rapid execution of commands and the deviation in orientation was within the range of -2 to +2 which shows that the stabilization was made accurate. The system had the highest possible flight time of about 12 minutes. In general, these findings confirm the combination of power, motor control, and sensor feedback, which is important to note the stable and responsive operation of the drone.

V. CONCLUSION AND FUTURE WORK

This study proposed the design, construction, and testing of a simple quadcopter control system that incorporates a LiPo battery, flight controller, ESC units, BLDC motors and wireless transmitter. It was shown experimentally that the battery could always provide 11.1 V at 4.5 A draw during hover and that the motors could reach up to 8500 rpm with an average PWM duty cycle of 60% and provide 1.2 kgf thrust per motor. The flight controller effectively interpreted transmitter commands, and sensor feedback-maintained orientation deviations within ±2°, enabling stable hovering and precise maneuvering. Response times of 0.15–0.18 s for pitch, roll, and yaw confirmed rapid system responsiveness. The system achieved a maximum flight time of approximately 12 minutes, validating the integration of power management, motor control, and sensor-based stabilization as an effective framework for UAV control.

Future work can focus on enhancing the quadcopter's autonomy and efficiency. Incorporating GPS and vision-based navigation could enable autonomous path planning and obstacle avoidance. Optimization of motor control algorithms and PID tuning may improve energy efficiency and flight time. Integration of advanced sensors such as barometers and magnetometers can enhance stability in dynamic environments. Additionally, implementing payload-carrying capabilities or swarm coordination can expand practical applications. Experimental validation under diverse weather conditions and payload variations would provide further insights into system robustness and scalability for real-world UAV deployments.

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