Development and Deployment of UAV Autonomous Flight Control Systems

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***Abstract*—Unmanned Aerial Vehicles (UAVs) are gaining increasing global attention, and various initiatives are in progress to establish routine and safe integration of UAV operations. At the moment, operations of unmanned aerial vehicles are restricted to special airspace or are constrained in their entry due to safety concerns by a strict authorization procedure. The quadcopter's primary flight principles, which include pitching, rolling, and yawing, are examined for controlling the quadcopter. To generate lift for the quadcopter, a combination of four motors with mounted propellers is used. These motors are affixed to the ends of the arms of the frame, which has a cross shape. The rotational motion of the motors creates the necessary thrust and torque, which is utilized to displace and elevate the quadcopter. The motors, fixed to the arms, rotate in sync with each other to ensure that the torque generated by one motor is counteracted by another, thus maintaining a consistent speed. The primary method for implementing autopilot systems in unmanned aerial vehicles is through the use of Proportional-Integral-Derivative (PID) control systems, which have shown outstanding performance in stable conditions.**

The method for realizing stability and control of a multirotor unmanned aerial vehicle (UAV) is outlined in this paper. The data from inertial sensors such as the accelerometer and gyroscope contain noise, and these sensors are utilized to determine the orientation and attitude of the UAV.

***Keywords*—UAV, multirotor drones, flight controller, classification, copters, ESC, Radio**

I. INTRODUCTION

An unmanned aerial vehicle (UAV) or drone, a flying robot, has the capability to carry out a specific mission either autonomously or under remote control. The vehicle has the capability to be guided either autonomously or by a human operator remotely using onboard computers and robots. In recent years, the use of drones has grown significantly. As advancements in control technologies increased and expenses decreased, their application broadened to various non-military uses. These uses encompass aerial photography, precise agriculture, monitoring forest fires, observing the environment, law enforcement and surveillance, inspecting infrastructure, smuggling, delivering products, and entertainment. Copter drones have become essential tools for tasks that used to be impractical or expensive due to their capability to navigate and hover in tight spaces, along with the progress in miniaturized sensors and efficient propulsion systems.

Continuous technological advancements are driving rapid evolution in the field of copter drones. Staying up-to-date with the latest developments enables researchers, engineers, and practitioners to utilize state-of-the-art technologies to improve drone performance, safety, and efficiency.

UAV autopilot systems usually consist of two main components: an "inner loop" that handles aircraft stabilization and control, and an "outer loop" that focuses on mission-level objectives. UAVs mainly utilize Proportional-Integral-Derivative (PID) control systems for their flight control. PIDs have shown outstanding performance in various situations, such as drone racing, where precision and agility play crucial roles.

Research in the field of intelligent flight control systems is currently focused on the utilization of embedded systems, which are considered appealing due to their universal approximators and ability to withstand noise.

Analyzing changes over time can be done using the Google Earth Engine (GEE) platform to detect urban area changes using optical data and machine learning (ML) algorithms, both of which are used for classifying the Earth's surface. The combination of Sentinel-1 (S-1) and Sentinel-2 (S-2) data [15], [16], can be integrated using drones.

II. TYPES OF UNMANNED AERIAL VEHICLES

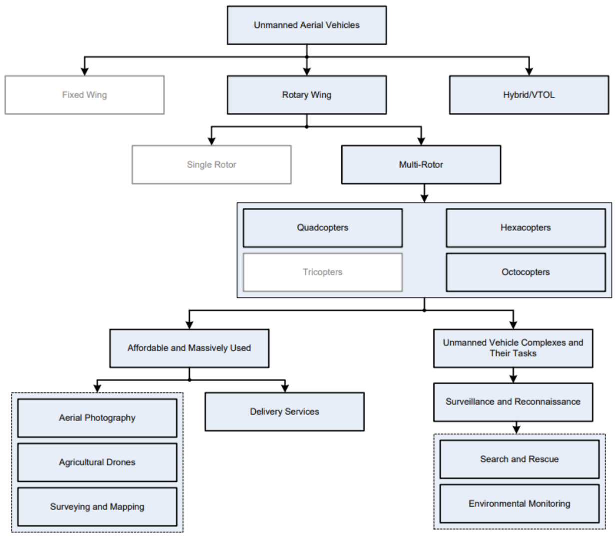

Fig. 1 Types of Unmanned Aerial Vehicles

The following part offers categorization of UAVs and then delves into the primary varieties and designs of UAVs, with an emphasis on those that are widely utilized and cost-effective. The discussion in this section is outlined in a block diagram. The primary block signifies the main subject: different types of UAVs. The subsequent blocks indicate the categories of UAVs based on their structural and operational characteristics.

III. A TYPICAL UAV COMPONENTS

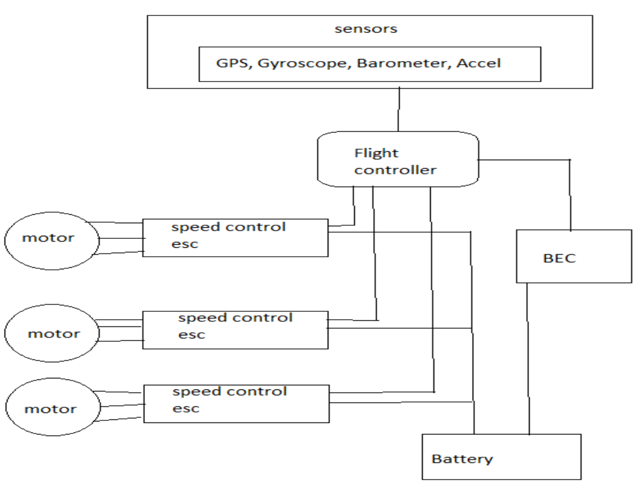

Fig. 2 Block diagram of a typical UAV

UAVs come in many different shapes, mechanisms, configurations, and characteristics. Their hardware and software design can vary depending on their intended purpose as they are typically developed for specific tasks. Below, I will outline the system design, implementation, and software of a standard modern UAV.

A. *Flight controller*

The flight controller, present on the UAV, is a microprocessor/microcontroller responsible for adjusting the power output of each motor to stabilize the flight and carry out commands from the operator. Various control algorithms are utilized, including variable pitch and servo thrust vectoring. Variable pitch models typically apply differential cyclic control to non-coaxial propellers, enabling precise control and the potential to replace individual electric motors with belt-driven props connected to a central motor. Servo thrust vectoring involves differential thrust and at least one motor mounted on a servo, allowing it to freely change its orientation. This type of algorithm is commonly found in bi copters and tri copters.

The UAV's flight-control system is essentially the "brains" of the aircraft. An embedded computer, often running on Linux, is equipped with specialized software to manage the aircraft and can be reprogrammed by users using a software development kit (SDK). In certain configurations, the main computer is a distinct module with connection ports. Alternatively, in consumer products, there might be a single circuit board (PCB) housing the main computer, gyros/sensors, electronic speed controllers (ESCs), and other essential flight electronics.

B. *Sensors*

In order for autonomy to be operational, the flight of the aircraft must be monitored by the MC. To achieve this, a sensor array of some kind is utilized. Typically, this array will consist of accelerometers, inertial measurement units (IMUs), and gyros, and may also utilize positional data from an optical flow system or GPS/compass. Essentially, these sensors provide information to the UAV regarding the rate and direction of its acceleration, as well as its orientation. Those who are familiar with motorized gimbal camera stabilizers may recognize that the same sensor technology is employed in gimbals as well.

C. *Electronic Speed Controllers (ESC)*

Every motor is equipped with an ESC, although certain designs integrate all ESCs onto a single board. At its simplest, an ESC controls the power supplied to its corresponding motor. Advanced systems may also transmit information back to the main controller, providing crucial data on the motor performance. When using six or more rotors, real-time feedback enables the aircraft to remain airborne (sufficiently to land safely) in the event of a single motor failure.

D. *Motor*

The brushed DC motor is the most basic type of motor, where coils within a fixed magnetic field have electrical current flowing through them. This current creates magnetic fields in the coils, causing the coil assembly to rotate as each coil is pushed away from the like pole and pulled toward the unlike pole of the fixed field. To keep the rotation going, it is essential to periodically reverse the current to ensure that the coils continually "chase" the unlike fixed poles. Fixed conductive brushes that make contact with a rotating commutator supply power to the coils, and it is the commutator's rotation that leads to the reversal of the current passing through the coils. The commutator and brushes are the critical components that set the brushed DC motor apart from other motor types. Figure 1 provides a visual representation of the general principle of the brushed motor.

E. Battery

The components of drones have been the subject of many discussions as their usage continues to rise in popularity. Drone pilots are particularly interested in drone batteries, as they play a crucial role in ensuring that drones remain airborne for extended periods of time. Understanding the capabilities of various batteries and learning how to maintain them properly can greatly enhance the duration of your flights. Keep reading for a thorough overview of drone batteries.

Rechargeable batteries for drones, known as drone batteries, are typically constructed using Lithium Polymer (LiPo) or Lithium-ion Polymer (Li-ion) and are available in various sizes and capacities. These batteries are crucial for extending flight durations and can present a fire risk if mishandled. Therefore, understanding the specifics of your drone batteries is crucial for optimizing their performance.

Types of Drone Batteries:

- Nickel Cadmium (Ni-Cd)
- Lithium-ion (Li-ion)
- Lithium polymer (LiPo)
- Brand Specific Batteries

F. BEC

In their most basic configuration, BECs utilize a linear fixed voltage regulator with the recommended circuit outlined in the manufacturer's datasheet, typically requiring a 5 V power supply for the receiver. Low-dropout variations are the preferred choice, particularly for batteries with a limited number of cells.

The linear regulator BEC incurs power dissipation losses stemming from the deviation between the main battery's voltage and the 5-volt target voltage, multiplied by the necessary current.

The battery eliminator circuit (BEC) functions as an electronic voltage regulator that supplies power to a subsystem at a different voltage, eliminating the need for an additional battery.

IV. HARDWARE

The central hardware hub is where all the drone parts will connect. Components such as ESCs, GPS, telemetry, RC input, and other parts will attach to it.

Every flight controller needs to be outfitted with both a gyroscope and accelerometer (IMU). These components work together to automatically stabilize your drone without requiring any manual adjustments.

A. MPU-6050

The MPU-60X0 represents the first 6-axis Motion Tracking device in the world, integrating a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™ (DMP) in a compact 4x4x0.9mm package. It has a dedicated I2C sensor bus, allowing direct input from an external 3-axis compass to produce a full 9-axis Motion Fusion output.

The MPU-60X0 is equipped with three 16-bit analog-to-digital converters (ADCs) used to digitize the gyroscope outputs and three 16-bit ADCs for digitizing the accelerometer outputs.

B. STM32F103C8T6

The family of STM32F103C8T6 medium-density performance line incorporates the high-performance Arm Cortex-M3 32-bit RISC core, which operates at a frequency of 72 MHz There are high-speed embedded memories, including Flash memory up to 128 Kbytes and SRAM up to 20 Kbytes, and a wide range of enhanced I/O and peripherals connected to two APB buses. All the devices offer two 12-bit ADCs, three general purpose 16-bit timers plus one PWM timer, as well as standard and advanced communication interfaces, such as up to two I2Cs and SPIs, three USARTs, USB, and CAN.

The device’s function using a power supply ranging from 2.0 to 3.6 V. They can be found in both the temperature range of -40 to +85°C and the extended temperature range of -40 to +105 °C.

C. Drone Frame

The structure of a drone serves as a protective housing for its electrical components and other delicate elements. It plays a crucial role in a drone's weight, stability, aerodynamics, and longevity.

Frames can be choose based on:

- Size class
- Weight
- Stiffness
- Material
- Style

D. RC Transmitter Receiver

The operation of RC planes relies on wireless communication between the transmitter and the receiver. Using the transmitter, the pilot sends commands that are received and processed by the receiver installed on the plane. Subsequently, the receiver triggers the servos and ESCs to manipulate the control surfaces and regulate the throttle, allowing the plane to fly and maneuver according to the pilot's instructions.

RC planes depend on RC transmitters and receivers, which play a crucial role in various types of aircraft, affecting control, responsiveness, and the overall flight experience.

E. ESC

F. Motor

V. Software Implementation

A. Control Loop

Control engineering typically employs feedback in designing control systems. Feedback is when the output of a system is looped back as input, creating a cause-and-effect chain. The control loop, consisting of control functions and physical components, is the core of control systems. It is responsible for adjusting the measured process variable (PV) to match the desired setpoint (SP). Components of the control loop include the controller function, the process sensor, and the final control element (FCE). The widely used feedback mechanism in industrial control systems is the "PID controller," which is based on a specific mathematical formula.

$$u(t) = K_p e(t) + K_i \int_0^t e(t')dt' + K_d \frac{de(t)}{dt}$$

The meanings of the terms are as follows:

• The coefficient for the proportional term is denoted as Kp.

• Ki represents the coefficient for the integral term.

• Kd is used to represent the coefficient for the derivative term. • These coefficients are all non-negative. • Typically, they can be initially determined based on the application type, but they are usually adjusted or optimized later on.

B. Mains loops

In general UAVs use two main loops or combination of the two.

• Open loop: This loop provide a control signal (right, left, up, down) without feedback from sensor data.

• Closed loop: This loop provide a sensor feedback in order to adjust the behaviour such as stability.

C. PID Controller

A Proportional-Integral-Derivative controller is employed in a wide range of applications that need continuous modulated control. It computes an "error value e(t)" by finding the difference between the desired setpoint and the measured process variable, and then adjusts the corrections using proportional, integral, and derivative terms.

The initial examination and real-world use of this control principle occurred in the development of automated navigation systems for maritime vessels. Following that, it was also put into practice in the manufacturing sector, initially using pneumatic control and later transitioning to electronic controllers.

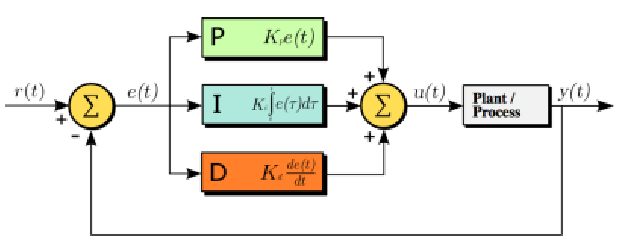

Fig. 3 Block diagram PID loop

• **Term P:** The current value SP − PV = e(t) determines this term's proportionality. When the error is significantly positive, the resulting output will be correspondingly large and positive due to the K gain factor. Employing only proportional control in a compensated process leads to a disparity between the setpoint and the actual process value, as it necessitates an error to prompt the proportional response. In the absence of an error, there will be no corrective response.

• **Term I:** This term takes into account the past values of SP − P V = e(t) error and integrates them over time to produce the term I. After the application of proportional control, if there is a residual error, the integral term I tries to eliminate the residual error by adding a control effect due to historical cumulative value of the error and, when the error is removed, the integral term will cease to grow. This will result in a reduction in the proportional effect when the error decreases, but this is offset by the increase in the integral effect.

• **Term D:** Sometimes is called "anticipatory control". This term is an estimation of the future trend of the SP −P V = e(t) error, based on its current rate of change. It is effectively trying to reduce the effect of the residual error, exercising the influence of the control generated by the change in the error rate. The effect of control or damping is greater if there are more rapid changes.

VI. Path Planning

The navigation and mission handling are managed by path planning in the autopilot system. This involves algorithms that determine the direction and timing of the UAV's movement. The path planning component may include specialized sections for various tasks, such as search operations. The thesis's mission requirements involved path planning capabilities for search, as well as target tracking and following. Different methods exist for developing these capabilities, including programming algorithms directly into the onboard autopilot or utilizing a ground station and radio link. The algorithm described in this context is designed to be integrated into the onboard computer.

VII. UAV Applications

A. Civil Applications:

Unmanned aerial vehicles have a variety of civilian applications because they are inexpensive to maintain, easy to deploy, highly mobile, and capable of hovering.

- Disaster management
- Construction and infrastructure inspection
- Agriculture and remote sensing
- Healthcare
- Waste management
- Utility inspecting
- Urban planning
- Wildlife conservation
- Geographic mapping
- Weather forecasting
- Mining
- Law enforcement
- Real-time monitoring of road traffic flow

VIII. IMPLEMENTATION

This section addresses implementation aspects, emphasizing the software rather than the physical design of the plane and autopilot. The emphasis is on configuring the control loop system parameters and essential UAV parameters, including takeoff speed and servo action limits.

Identifying the target market and user requirements is the initial phase of drone software development. This includes gaining insights into the needs and preferences of various user categories like hobbyists, professional filmmakers, or industrial workers.

After identifying the target market and user requirements, the development team concentrates on designing a user-friendly interface with a seamless and intuitive design. This is vital because drones can be intricate to operate, and it is crucial for users to have convenient access to all the required controls.

IX. RESULT

The primary goal of this project was to create and implement a system for controlling the autonomous flight of an unmanned aerial vehicle (UAV).

Throughout the conducted work, the groundwork has been established for advancements in hardware and software innovation within the realm of autopilot technology, despite the existence of multiple issues that may not be immediately apparent, including:

1. Refrain data from sensors.
2. The optimal selection of an STM32 microcontroller, which is compact and delivers high performance.
3. Adjust the transfer speed of data from the smartphone to the Arduino, addressing the producer/consumer problem.
4. Adjusting the parameters of the PID control algorithm.
5. Having difficulty reading the PWM signal from the radio control.
6. Facing an issue with transferring data between microcontrollers.

We have attempted to address the primary issues cited earlier by implementing a variety of methods.

X. CONCLUSION

We have thoroughly researched unmanned aerial vehicles (UAVs) or drones, including their components, functioning, various types, applications, target users, relevance in today's world, future prospects, forces acting on them, design concepts, and the nature of the loads they experience. We also considered the advantages and disadvantages of drones in daily life, the challenges faced by drone users, and the potential materials for drone manufacturing, along with the best options and those commonly used. Additionally, we explored the necessary improvements for current drones to perform diverse and challenging operations that are difficult or risky for humans, such as data collection from remote areas and other navigation and control tasks. We examined the required innovations for drones and suggested that rocket propulsion could significantly enhance drone speed, especially beneficial for military purposes and efficient data collection. Through our research, we identified feasible materials for drone construction and investigated the enhancement of material strength using composite materials. Our analysis included conducting various tests using finite element analysis (ANSYS) software, exploring different shapes and materials, and ultimately determining that a composite of balsa wood and carbon fiber is the most viable and effective material for UAV manufacturing. This composite material offers high bending and torsional strength compared to other materials, along with excellent resistance to corrosion and the ability to be easily molded into various shapes and sizes.

The quadcopter is a highly adaptable unmanned aerial vehicle that has a multitude of potential uses across various fields. This research involves experimenting with a simple quadcopter constructed from a DIY kit that adheres to fundamental flight principles and aerodynamics.

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