A VTOL DRONE WITH ONLY TWO PROPELLERS

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1 Introduction

1.1 Problem

Nowadays, drones, as an important carrier of modern technology and advanced productivity, have become a vital part of the development of new aviation forms. They have been used in many different areas such as military, civilian, commercial, and so on. Traditional drones like helicopters have shortcomings in flight speed while fixed-wing aircraft require a runway for takeoff and landing. Vertical takeoff and landing (VTOL) aircraft not only have helicopters' accessibility and flexibility to take off and land in small spaces, thus they can fly to destinations that are not easily accessible by traditional aircraft, such as remote areas or areas with poor infrastructure; the design of VTOL also allows for faster deployment and response times which is especially important in emergency situations where every second counts. Additionally, simpler construction of this drone not only reduces overall cost but requires less energy in longer flight time. Overall, VTOL aircraft offer a level of flexibility and efficiency that traditional aircraft cannot match, making them a valuable tool in a variety of industries, including transportation, military, and emergency services.

1.2 Solution

We plan to design a small VTOL UAV with a wingspan of about one meter to achieve both vertical takeoff and landing and horizontal flight like a fixed-wing aircraft by means of a horizontal tail and rotatable propellers located at the ends of the mean wings. Such two flight modes and the transition between them require a very precise perception and adjustment of the aircraft's attitude. To do this, we need a high-frequency motherboard and some gyroscopic sensors to receive and process the aircraft's attitude information and make feedback adjustments. This places high demands on the control section, and on the mechanical side to ensure structural rigidity, reduce unpredictable jitter in the wings and other components, and thus reduce additional attitude adjustments. What's more, we also need to give more thought to the design of the rotatable propeller section. It is important to reduce the inertia of the rotating part while reducing the complexity of the structure and making it more reliable. For our aircraft, the arrangement of internal electronics and storage space has a significant impact on the center of gravity. While designing the aircraft structure with sufficient strength. We also consider the arrangement of the location of each electronic component, the heat dissipation of electronic components, sufficient storage space, certain water resistance, easier maintenance, etc. We believe that with the cooperation of team members from different disciplines, we can be responsible for our own sub-projects and take full consideration of the design of other sub-projects to complete the overall design.

1.3 Visual Aid

Our VTOL UAVs are operated by both a human controller and a flight control system. The controller controls the remote control with both hands, and the remote control converts the signal into a radio signal to a signal receiver on the drone. The Teensy 4.0 development board then receives signals from the receiver and sensors and outputs signals to control the servo and propellers on both ends of the aircraft's wings. Thus, stable flight is achieved.

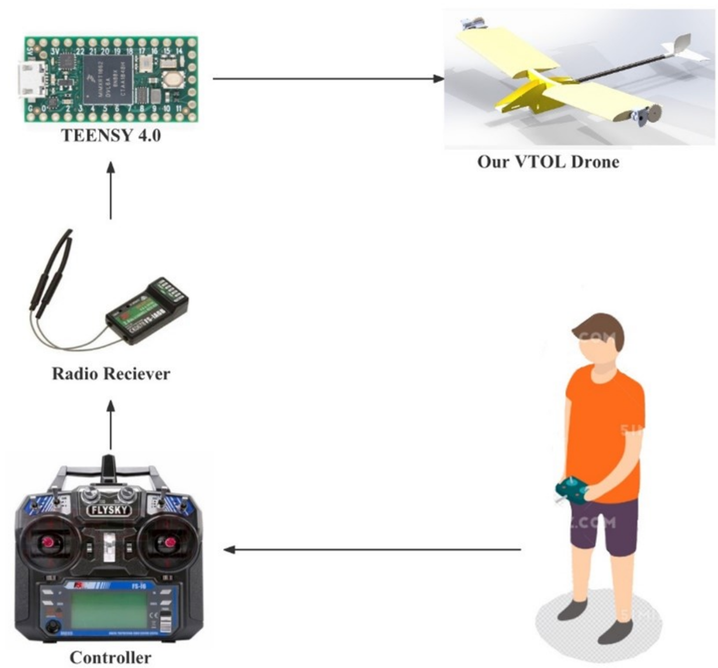

Figure 1: Visual Aid of our VTOL Drone

1.4 High-level requirements list

- The two propellers combined must provide a force greater than 15N to ensure that the aircraft can take off vertically. Also ensure that the gravitational force on the aircraft itself is less than 15N.
- The wings need to provide at least 15N of lift to ensure that the aircraft can fly horizontally at the preset speed.
- The development board needs to reach approximately 2 kHz flight control loop rate in order to receive the attitude changes from the sensors in time

and react quickly.

2 Design

2.1 Block Diagram

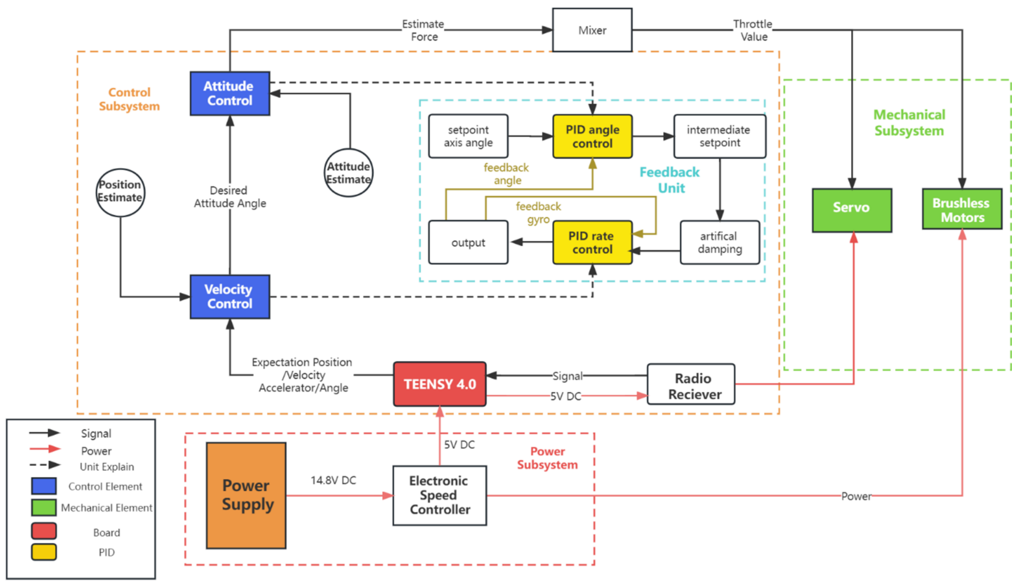

Figure 2: Block Diagram of our VTOL Drone

2.2 Subsystem Overview

- Power Subsystem: This subsystem supplies power to the whole drone. We use a power supply with 14.8V DC and we use ESC to power the TEENSY 4.0 of the Control Subsystem and the motors in the Mechanical Subsystem.
- Control Subsystem: This system consists of two PID controls, one for angle control and another one for velocity control. The board will send commands to the motor through the control subsystem.
- Mechanical Subsystem: This subsystem consists of two servos and two brushless motors. They will operate according to the output signal from the control system.

2.3 Subsystem Requirements

Power subsystem

The power subsystem includes a 14.8V lithium battery and two 50A electronic speed controllers. The battery should be able to supply 14.8V DC to the ESCs while the ESCs are connected to the Teensy 4.0 in the control system and Sunnysky V2216 KV800 brushless motors in the mechanical subsystems. In ESC, the battery elimination circuit converts the 14.8V battery output to 5V to power the Teensy 4.0 and the three-phase pulsating direct current, whose duty cycle is controlled, must be supplied to the brushless motors.

Control subsystem

The control subsystem is almost a software subsystem with the help of TEENSY 4.0. The control subsystem actually consists of two parts including Velocity control and Angle control. Both are based on the model of feedback control, and we use a feedback unit in the block diagram to explain it in detail.

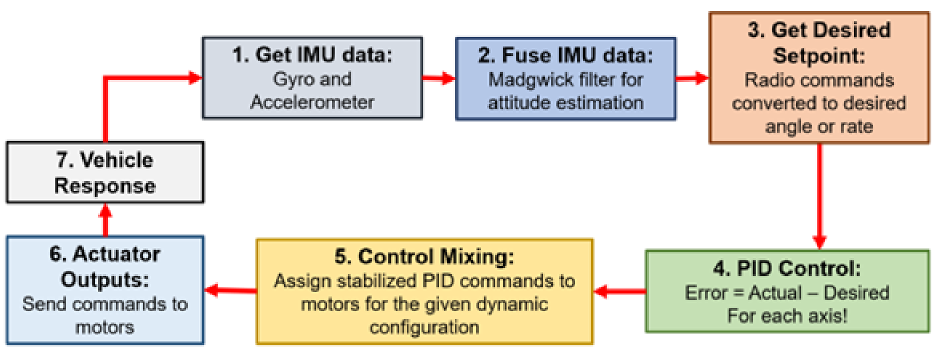

Figure 3: General overview of a flight control loop allowing stabilization of a small aerial vehicle[1]

Feedback Unit

The drone control system processes this data and generates feedback signals in real-time that are sent to the drone's actuators like motors, servos, and other control surfaces. These actuators then adjust the drone's speed, direction, altitude, and other parameters to maintain the desired flight path.

The feedback unit is also responsible for providing feedback to the pilot or operator about any deviations in the drone's flight path or changes in its operating conditions. This feedback can be in the form of warning signals, alarms, and telemetry data. Thus, allowing them to take corrective action or change the mission parameters as necessary.

Feedback is a process that involves comparing the actual output of a system to a desired setpoint and using this difference to adjust the system input to improve its performance.

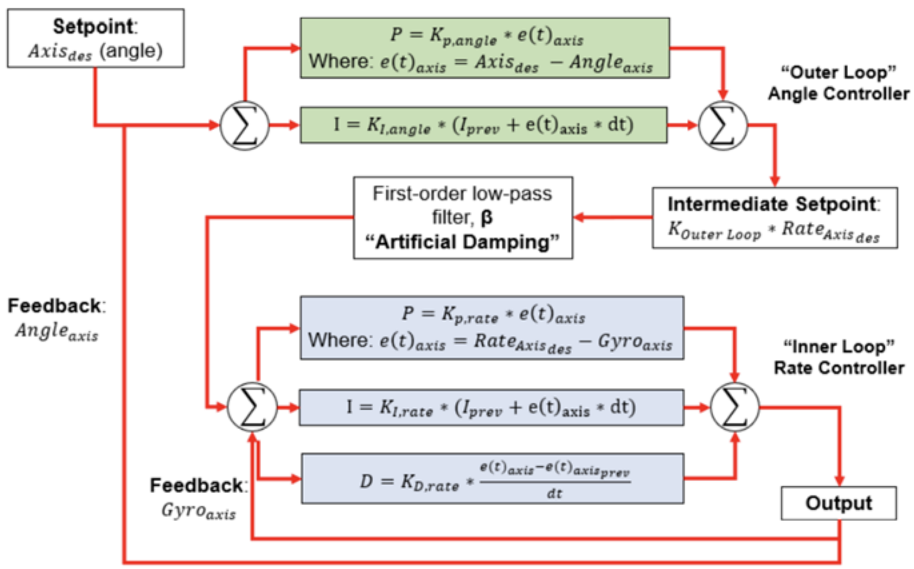

Figure 4: Cascaded PID controller stabilizing on angular rate setpoint (inner loop) generated by outer loop angle controller. [1]

PID (Proportional-Integral-Derivative) control is a common feedback control algorithm that is widely used in industry. The PID controller takes the error signal (the difference between the setpoint and the actual output) and calculates a control action that is proportional to the error (P), the integral of the error over time (I), and the derivative of the error (D) with respect to time.

The proportional term (P) is responsible for providing an immediate response to changes in the error signal. The constant factor (i.e., the proportional gain) determines how strongly the controller responds to the error signal.

The integral term (I) is used to eliminate steady-state error, which can arise due to imperfections in the system or disturbance inputs. The integral action accumulates the error signal over time and adjusts the control action proportionally to the accumulated error.

The derivative term (D) is used to anticipate the response of the system to changes in the error signal. The derivative action provides a dampening effect that reduces the overshot and settling time of the control system.

The three terms (P, I, and D) are combined to calculate the control action, which is then sent to the system to adjust its output. The PID algorithm continues to monitor the output and adjust the control action based on the measured error signal until the system reaches the desired setpoint.

Mechanical subsystem

The MG996R servos, powered directly by the radio receiver and controlled by the Teensy 4.0, should be able to rotate in a range of 180 degrees and thus, change the output angle of the brushless motors. And the brushless motors should be able to supply enough lift force, which is higher than the total weight (about 1.5 kg) of the plane, during the VTOL process and thrust during level flight.

2.4 Tolerance Analysis

The airflow, especially in extreme weather conditions, can greatly affect the takeoff of our VTOL drone and it presents a great challenge to our design. In our design, we chose Sunnysky V2216 KV800 brushless motors as propellers. According to the parameter diagram, the maximum thrust of each motor is 1240g, about 12.15N at 14.8V input. So the two motors could provide a maximum lift force of 24.3N which means there is $\eta = \frac{F_{max} - G}{G} = 62\%$ more thrust to deal with the external forces in all directions generated by those extreme air flow conditions. As shown in the following figure, the motor could provide enough lift force while overcoming the force of wind by tilting the motors.

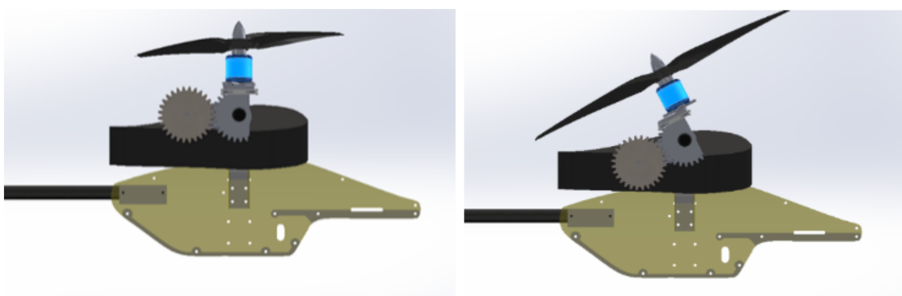

Figure 5: Side view of the rotatable propeller

3 Ethics and Safety

3.1 Ethics

Our design aims to improve the performance of current ordinary drones, providing the people with more convenient and efficient tools for production and life. After careful consideration of the UAV's functionality and potential range of applications, we promise that we would put the safety, health and welfare of the public first [2], refusing to provide any products or related technology to the wrongdoers in any way and prohibiting the use in espionage or military activities. Besides, in order to avoid "endangering the public and the environment" [2], we guarantee that we would inform relevant people of the possible potential hazards of our UAV products and preventive measures. What's more, considering this is a design task, challenge and study process, we would accept honest criticism of our UAV, acknowledge and correct errors in time as well as making statements according to reliable data [2].

3.2 Safety

As a UAV, we need to take many safety factors into consideration during the design and manufacturing process and subsequent flight. First, when testing the aircraft, we need to be very careful of the aircraft's high-speed rotating propellers, and to do brushless motor and remote-control power-off at the moment when hands are likely to touch the propellers. Secondly, we need to do a good job of fireproofing the electronic components. Water leakage and exposed wires may lead to short circuits, so we avoid flying on rainy days until we can ensure that the system is completely waterproof. Not only that, we should also try to avoid crowds and various facilities during the flight, so as to reduce the danger caused by the plane crashing. Finally, we need to do a good job of heat dissipation of the electronic components to prevent the PLA materials used to build the main part of the aircraft from melting and deforming due to high temperatures.

4 Citations and References

[1] Nicholas Rehm. (2022). dRehmFlight VTOL, [Online]. Available at: https://github.com/nickrehm/dRehmFlight
[2] IEEE. (2016). IEEE Code of Ethics, [Online]. Available at: https://www.ieee.org/about/corporate/governance/p7-8.html