ECE 445
SENIOR DESIGN LABORATORY
Final Report

FIXED-WING DRONE WITH AUTO-NAVIGATION

By

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Abstract

This report details the development of an automated V-tail fixed-wing drone equipped with air quality monitoring capabilities, aiming to provide early warning in disaster situations. The drone swiftly collects air quality data in complex terrains during events such as volcanic eruptions and wildfires. The project includes the design of the drone's fuselage and wings, along with manual and automated control systems. With manual control for takeoff, landing, stable flight, and autonomous navigation capabilities, the drone effectively navigates challenging environments. Utilizing an Arduino microcontroller and BME280 sensor, the drone achieves real-time transmission of air quality data via Wi-Fi. The integration of advanced technologies offers a reliable solution for assessing potentially hazardous atmospheric conditions. This report provides a detailed description of the design and implementation process of the fixed-wing drone, contributing to the existing material of V-tail drones.

Contents

1. Introduction

1.1 Problem and Solution

In recent years, the increase in natural disasters such as chemical leaks, wildfires, and volcanic eruptions has led to the need for prompt notification of affected areas and the collection of accurate environmental data to reduce casualties and prevent environmental damage. Traditional methods of communication and data collection may not be effective in hazardous or hard-to-reach areas, creating a need for a novel solution.

This project aims to build a fixed-wing drone with auto-navigation. The designed drone can automatically fly along a specified route based on computer instructions when it receives an alarm signal. This will improve the response speed to disasters and reduce the risks of flight operation. Additionally, the drone will carry an air quality sensor to collect air condition data including temperature, humidity, and air pressure, during flight and transmit it in real-time or store it in SD card for later analysis.

Considering the drone is easy to get damaged, we have to get prepared to repair the mechanical part of the drone, our plan is to design replaceable components of the drone, we use 3D printing, laser cutting and other methods to manufacture the replacement parts, when some components damage, we can very quickly change them and recover the drone's mechanical function.

1.2 High-level Requirements List

(1) The drone can be controlled manually so that we can control the drone to high altitude area about over 100m to collect data including the air quality.

(2) The drone can realize self-stabilization in the air, ensuring that it will not roll over and crash while flying steadily in the air

(3) The drone can navigate autonomously so that the drone can collect data from different places

(4) The air quality sensor installed on the drone can detect the air data including temperature, humidity, and pressure and then we can access the Wi-Fi to get the data.

2 Design

2.1 Block Diagram

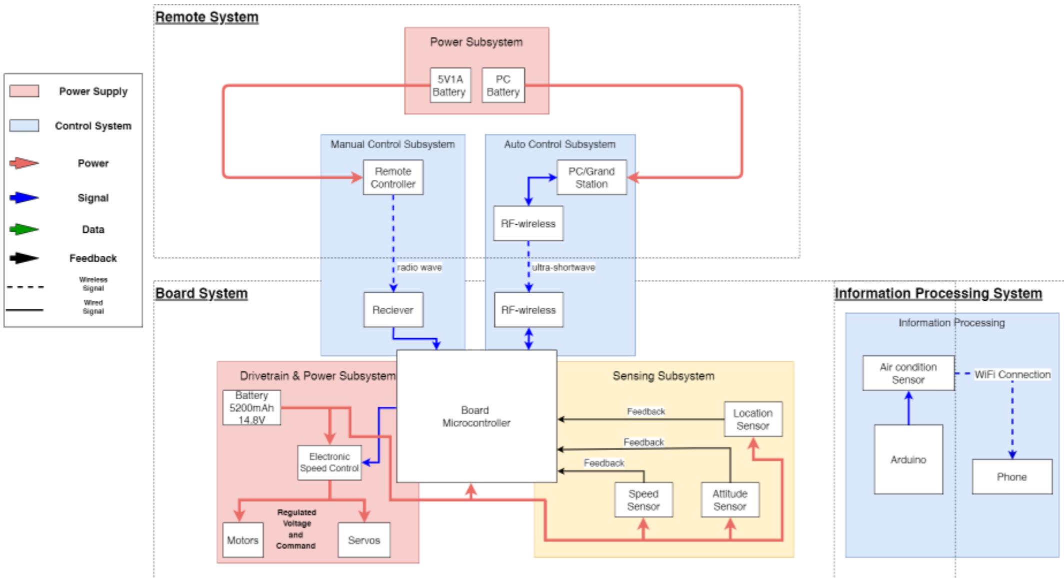

Figure 1. Block Diagram

2.2 Mechanical Design of The Drone

The mechanical design of a drone is critical to its overall performance and functionality. The mechanical components of the drone, including the wing, fuselage, and other structural elements, must be designed to be strong, lightweight, and aerodynamic to ensure efficient flight and stability. We will discuss the design process and details for the wing and fuselage of our drone, as well as the verification and testing of these components to meet the performance requirements outlined in our proposal.

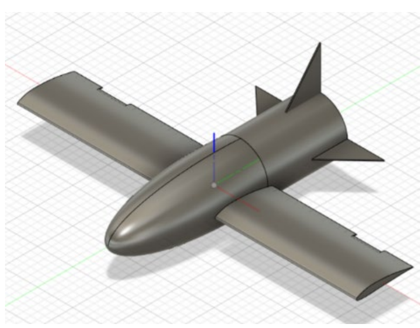

Figure 2. The CAD model of the drone

2.2.1 Fuselage Design

The fuselage is the main body of the drone and houses all of the components necessary for the drone to function properly. In our design, we aimed to create a lightweight and sturdy fuselage that could withstand the stresses of flight while also being easy to assemble.

In designing the body of our drone, we prioritized aerodynamic efficiency and system integration. To minimize air friction, we opted for a streamlined design, ensuring that the drone could move through the air with minimal resistance. The length is 75 cm, and the radius is 10 cm. To maintain balance and control the direction and lift of the drone, we employed a Vertical-tail design, a commonly used tail configuration in aircraft design.

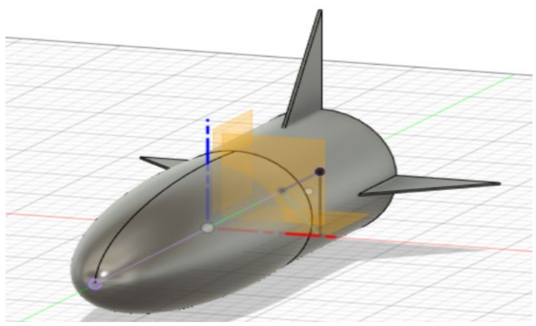

Figure 3. The fuselage model

To achieve this, we used light wood as the skeleton of the fuselage and covered it with KT board. The skeleton was first designed using CAD software and then laser cut to ensure accuracy and precision in the manufacturing process. We also designed three empennages, which were initially too small in size, but were later adjusted to the proper dimensions using the same CAD software and laser-cutting process.

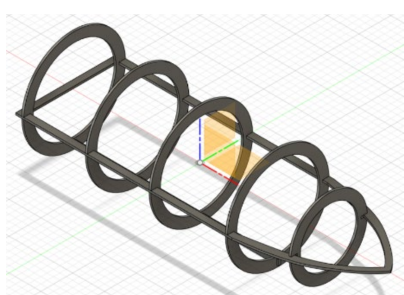

Figure 4. The skeleton of the fuselage

Requirements:

1. Size: The fuselage should be designed to accommodate all necessary objects and equipment required for the drone, ensuring sufficient space for proper installation and functionality.
2. Aerodynamic Efficiency: The fuselage design should minimize aerodynamic drag and turbulence, ensuring smooth airflow around the body to optimize flight performance and stability.
3. Weight: The fuselage should be lightweight, aiming to keep the weight below 600 g. This is important for maximizing flight efficiency and maneuverability while adhering to regulatory restrictions and payload limitations.

2.2.2 Wings design

The most important part for a drone is its wings, the airfoil of the wing determines the properties of the drone, so it's significant to choose a good airfoil for our drone. Considering the size and working environment, we choose NACA airfoil series [1], and finally we choose NACA4412. The NACA 4412 have many advantages like high lift Coefficient and low sensitivity to roughness [2]:

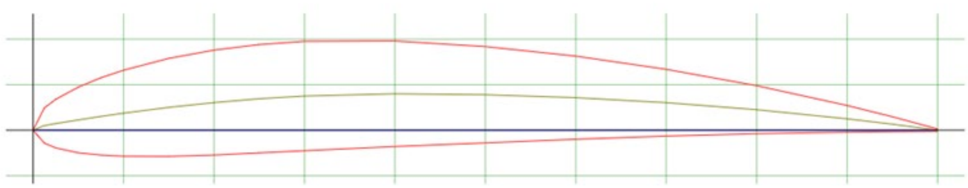

Figure 5. The airfoil of NACA 4412 [2]

The wing has a span of 20 cm and a chord length of 60 cm, providing sufficient lift and stability for our drone.

To ensure the structural integrity of the wing, we integrated a series of design features into the wing. Specifically, we incorporated holes within the wing structure to embed carbon rods, providing additional strength and support for the wing structure. Additionally, a groove was integrated into the wing to accommodate the steering gear, while a tunnel was included to house the wire connections, providing a streamlined design, and reducing drag.

Overall, these design features enhance the performance and durability of our drone, allowing for efficient and stable flight maneuvers.

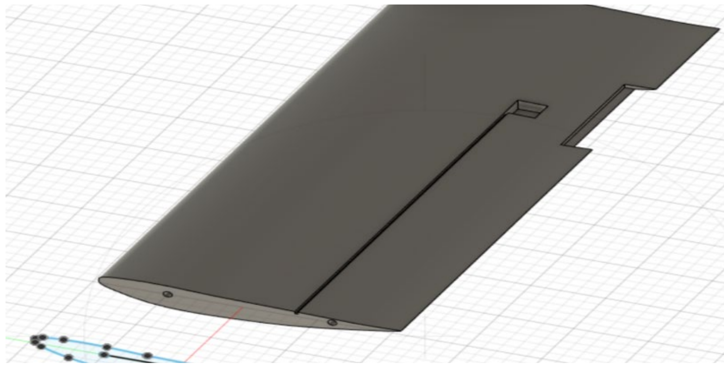

Figure 6. Wing of the drone

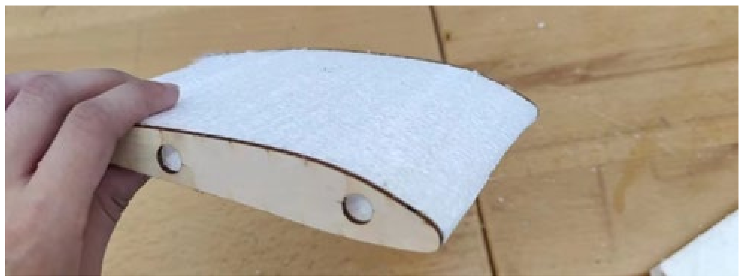

Figure 7. The Styrofoam wings.

We use hot knife to cut the Styrofoam into the shape of airfoil, by adding the wood skeleton and the carbon rod, the structural strength of the wing can be enough to stand several times of the crash.

And to ensure that the wing can provide enough force to set off, we calculated the lift force generated by wings and compare it to the gravity of the drone.

The equation of the lift calculation is following [3]:

$$L = \frac{1}{2} Cl \times \rho \times v^2 \times A \tag{1}$$

Where L is lifting force, Cl is lifting coefficient, ρ is the density of the air, v is the velocity of the drone, and the A is the area of the wing.

Requirements:

1. Provide a minimum lift force of 20 N.
2. Ensure structural integrity to withstand flying forces and minimize the risk of breakage.

2.3 Drivetrain & Power Subsystem and Manual Control Subsystem

For the manual control subsystem and the drivetrain & power subsystem, we design how the drivetrain and power subsystem is installed on the drone. For our fixed-wing drone, there are a pair of ailerons and a V-shaped tail wing. We design that we can install two steering engines on the bottom of the ailerons, which are used to control the steering of the drone and then two steering engines on the V-shaped tail to control the pitch of the drone and make sure the course is stable. Then we will install the motor at the end of the drone, and a propeller to the motor to ensure that the drone is powered by the drivetrain & power subsystem. Then we should use the remote control to control the subsystem and we design the circuit of the drivetrain & power subsystem and the manual control subsystem. In order to better control the steering of the drone, we design to connect the steering engines mounted on the aileron through a y-wire, and then connect it to channel 1 of the receiver of the remote control so that when we push the right rocker of the remote control left and right, the two servos installed on the ailerons can work together to make the drone rotate. Then we design servo installed on the left tail wing to channel 4 and servo installed on the right tail wing to channel 2 and then we decide to use the mix-control so that when we push the left rocker of the remote control to move left and right, the servos on the tail wings can make the left and right tail wings one up and one down and when we push the right rocker of the remote control to move up and down, the servos on the tail wings can make the tail wings up and down together. Finally, we design to connect the motor through the electronic speed controller to the channel 3 so that when we push the left rocker of the remote control up and down, the motor can work to power the drone.

2.4 Auto Control Subsystem

To achieve autonomous control, a combination of hardware and software is essential. Regarding the hardware aspect, we have acquired Pixhawk, the world's most popular open-source flight controller manufactured by 3DR, a globally recognized leader in open-source flight controller hardware.[4] Pixhawk incorporates various sensors, including an accelerometer, gyroscope, magnetometer, and barometer, which are utilized to measure acceleration, angular velocity, navigation orientation, and altitude information.

In addition to the essential flight controller, we have also purchased additional hardware such as GPS, telemetry radio, power monitor, safety switch, buzzer, and an airspeed sensor. Among these, GPS, safety switch, and buzzer are indispensable components. GPS provides aircraft positioning information and serves as an external compass for more accurate direction indication. The safety switch plays a protective role during the debugging process, preventing propellers from starting due to operational errors. The buzzer is configured within Pixhawk to provide various audio alerts and notifications.

The airspeed sensor and telemetry radio are optional, but also very important. Airspeed sensor comprises two differential pressure sensors used to measure the relative velocity of the aircraft with respect to the surrounding air, ensuring the aircraft does not stall during flight. One of the differential pressure sensors is exposed to the airflow through a pitot tube protruding from the front of the model aircraft, while the other is enclosed within a static pressure port. As the aircraft flies, the airflow passing through the exposed differential pressure sensor generates a pressure difference that is directly proportional to the dynamic pressure of the surrounding air. By measuring this pressure difference using the differential pressure sensor and combining it with the static pressure data from the barometer and ambient temperature, accurate airspeed measurements are obtained through calculations and calibrations.

Telemetry radio enable us to connect Pixhawk with my laptop remotely. And we purchase the telemetry radio made by 3DR, which works on 915 MHz and provide a stable connection with a range of 2 kilometers in unobstructed conditions. The picture below is the hardware configuration of our automatic control system.

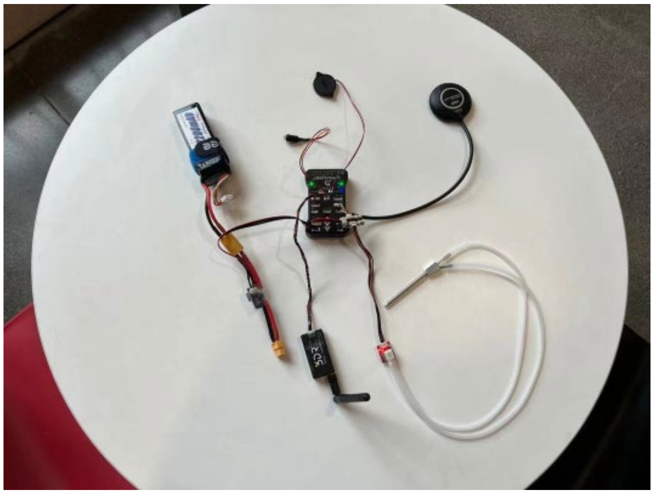

Figure 8. The Hardware Configuration of The Automatic Control System

On the software side, we utilized a ground station software called Mission Planner. This software provides features including firmware writing for Pixhawk, GPS system utilization, and the ability to set up automatic flight tasks.

Figure 9 is the basic GUI of Mission Planner. The window in the upper left corner displays the real-time attitude of the flight control and contains some other information about the aircraft. The window in the lower left corner is a console, which displays the information of the aircraft like speed, yaw, altitude. On the right side is a satellite map, which provides a visual representation of the surrounding area.

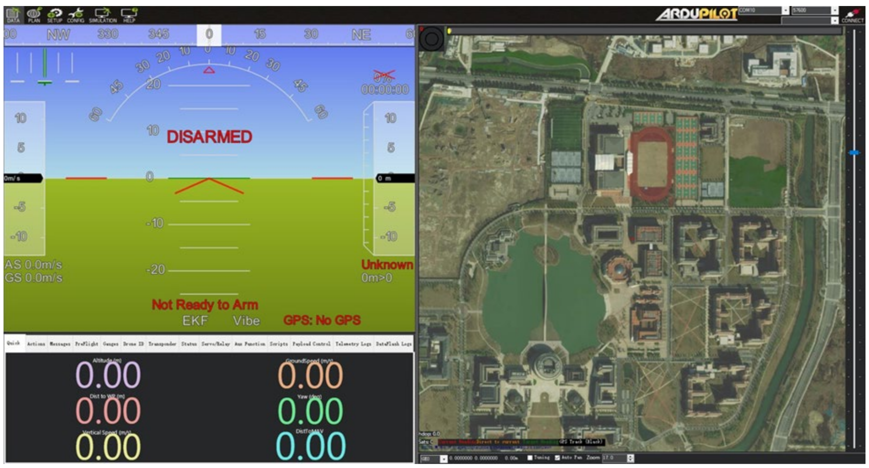

Figure 9. Mission Planner Software

Firstly, we connected Pixhawk to the laptop using a USB data cable, with a baud rate of 115200 and COM7 port. We loaded the parameters for the fixed-wing firmware using Mission Planner. Next, I paired the telemetry devices and established a wireless connection with Pixhawk's flight controller on COM10 port, with a baud rate of 57600.

After completing the aforementioned tasks, we proceeded to calibrate and fine-tune the built-in sensors of Pixhawk. This involved sequentially calibrating the gyroscope, accelerometer, magnetometer, and compass. Subsequently, we connected the BUS line of the flight controller to the BUS port of the remote-control receiver, enabling the flight controller to receive signals from the remote control. We recalibrated and fine-tuned the PWM signal range of the remote control to achieve a more desirable and controllable range.

Afterwards, we also transferred the signal wires of the servos and motors from the receiver to the flight controller. In order to continue utilizing V-tail mixing control, we inverted the signals for channels 2 and 4 within the software. This adjustment ensures that the servos on the aircraft maintain the correct motion logic in manual mode.

Finally, we began adjusting the firmware parameters written into Pixhawk. Initially, the software provided a basic fixed-wing parameter template, which required customization and reprogramming for our specific aircraft model.

Firstly, our remote control offered three mode options. we selected the commonly used "Manual-Stable-Auto" mode sequence. During initial testing, we modified the "Auto" mode to "RTL" (Return to Launch) mode to ensure safety.

In Manual mode, the aircraft is fully controlled by the operator using the remote control. And in Stable mode, the flight controller automatically adjusts the elevator and aileron to maintain the aircraft's balance in pitch and roll, ensuring stable flight at the current altitude without any manual input. In the final Auto mode, the aircraft follows the pre-set flight path we programmed through Mission Planner, autonomously navigating along the designated route.

Besides, we implemented a fail-safe feature. In the event of a loss of remote-control signal or a stall caused by excessively low throttle, the system automatically switches to "RTL" mode, initiating a return to the home point. Upon reaching the home point, the aircraft engages in a circular holding pattern at an altitude of 25 meters. The radius of the circle is set at 45 meters, with the home point as the center of the orbit.

Through the aforementioned efforts, we have achieved the basic implementation of auto control. After multiple test flights and experiments, we successfully accomplished manual takeoff, stable flight, and automatic RTL. The aircraft is capable of maintaining a stable and desired attitude in the air, ensuring sufficient safety and reliability throughout the experiments.

Name	Value	Units	Options	Desc	Fav
SERIAL5_BAUD	57		1:1200 2:2400 4:4800 9:9600 19:19200 38:38400 57:57600 111:111100 115:115200 230:230400 256:256000 460:460800 500:500000 921:921600 1500:1500000 2000:2000000	The baud rate used for Serial5. Most stm32-based boards can support rates of up to 1500. If you setup a rate you cannot support and then can't connect to your board you should load a firmware from a different vehicle type. That will reset all your parameters to defaults.	
SERIAL5_OPTIONS	0			Control over UART options. The InvertRX option controls invert of the receive pin. The InvertTX option controls invert of the transmit pin. The HalfDuplex option controls half-duplex (onewire) mode, where both transmit and receive is done on the transmit wire. The Swap option allows the RX and TX pins to be swapped on STM32F7 based boards.	
SERIAL5_PROTOCOL	-1		-1:None 1:MAVLink1 2:MAVLink2 3:Frsky D 4:Frsky SPort 5:GPS 7:Alexmos Gimbal Serial 8:SToRM32 Gimbal Serial 9:Rangefinder 10:FrSky SPort Passthrough (OpenTX) 11:Lidar360 13:Beacon 14:Volz servo out 15:SBus servo out 16:ESC Telemetry 17:Devo Telemetry 18:OpticalFlow 19:RobotisServo 20:NMEA Output 21:WindVane 22:SLCAN 23:RCIN 24:EFI Serial 25:LTM 26:RunCam 27:HottTelem 28:Scripting 29:Crossfire VTX 30:Generator 31:Winch 32:MSP 33:DJI FPV 34:AirSpeed 35:ADSB 36:AHRS 37:SmartAudio 38:FETtecOneWire 39:Torqeedo 40:AIS 41:CoDevESC 42:DisplayPort 43:MAVLink High Latency 44:IRC Tramp	Control what protocol Serial5 port should be used for. Note that the Frsky options require external converter hardware. See the wiki for details.	
SERIAL6_BAUD	57		1:1200 2:2400 4:4800 9:9600 19:19200 38:38400 57:57600 111:111100 115:115200 230:230400 256:256000 460:460800 500:500000 921:921600 1500:1500000 2000:2000000	The baud rate used for Serial6. Most stm32-based boards can support rates of up to 1500. If you setup a rate you cannot support and then can't connect to your board you should load a firmware from a different vehicle type. That will reset all your parameters to defaults.	
SERIAL6_OPTIONS	0			Control over UART options. The InvertRX option controls invert of the receive pin. The InvertTX option controls invert of the transmit pin. The HalfDuplex option controls half-duplex (onewire) mode, where both transmit and receive is done on the transmit wire. The Swap option allows the RX and TX pins to be swapped on STM32F7 based boards.	
SERIAL6_PROTOCOL	-1		-1:None 1:MAVLink1 2:MAVLink2 3:Frsky D 4:Frsky SPort 5:GPS 7:Alexmos Gimbal Serial 8:SToRM32 Gimbal Serial 9:Rangefinder 10:FrSky SPort Passthrough (OpenTX) 11:Lidar360 13:Beacon 14:Volz servo out 15:SBus servo out 16:ESC Telemetry 17:Devo Telemetry 18:OpticalFlow 19:RobotisServo 20:NMEA Output 21:WindVane 22:SLCAN 23:RCIN 24:EFI Serial 25:LTM 26:RunCam 27:HottTelem 28:Scripting 29:Crossfire VTX 30:Generator 31:Winch 32:MSP 33:DJI FPV 34:AirSpeed 35:ADSB 36:AHRS 37:SmartAudio 38:FETtecOneWire 39:Torqeedo 40:AIS 41:CoDevESC 42:DisplayPort 43:MAVLink High Latency 44:IRC Tramp	Control what protocol Serial6 port should be used for. Note that the Frsky options require external converter hardware. See the wiki for details.	
SERIAL7_BAUD	57		1:1200 2:2400 4:4800 9:9600 19:19200 38:38400 57:57600 111:111100 115:115200 230:230400 256:256000 460:460800 500:500000 921:921600 1500:1500000 2000:2000000	The baud rate used for Serial7. Most stm32-based boards can support rates of up to 1500. If you setup a rate you cannot support and then can't connect to your board you should load a firmware from a different vehicle type. That will reset all your parameters to defaults.	
SERIAL7_OPTIONS	0			Control over UART options. The InvertRX option controls invert of the receive pin. The InvertTX option controls invert of the transmit pin. The HalfDuplex option controls half-duplex (onewire) mode, where both transmit and receive is done on the transmit wire. The Swap option allows the RX and TX pins to be swapped on STM32F7 based boards.	
SERIAL7_PROTOCOL	-1		-1:None 1:MAVLink1 2:MAVLink2 3:Frsky D 4:Frsky SPort 5:GPS 7:Alexmos Gimbal Serial 8:SToRM32 Gimbal Serial 9:Rangefinder 10:FrSky SPort Passthrough (OpenTX) 11:Lidar360 13:Beacon 14:Volz servo out 15:SBus servo out 16:ESC Telemetry 17:Devo Telemetry 18:OpticalFlow 19:RobotisServo 20:NMEA Output 21:WindVane 22:SLCAN 23:RCIN 24:EFI Serial 25:LTM 26:RunCam 27:HottTelem 28:Scripting 29:Crossfire VTX 30:Generator 31:Winch 32:MSP 33:DJI FPV 34:AirSpeed 35:ADSB 36:AHRS 37:SmartAudio 38:FETtecOneWire 39:Torqeedo 40:AIS 41:CoDevESC 42:DisplayPort 43:MAVLink High Latency 44:IRC Tramp	Control what protocol Serial7 port should be used for. Note that the Frsky options require external converter hardware. See the wiki for details.	
SERVO_AUTO_TRIM	0		0:Disable 1:Enable	This enables automatic servo trim in flight. Servos will be trimed in stabilized flight modes when the aircraft is close to level. Changes to servo trim will be saved every 10 seconds and will persist between flights. The automatic trim won't go more than 20% away from a centered trim.	
SERVO_BLH_AUTO	0		0:Disabled 1:Enabled	If set to 1 this auto-enables BLHeli pass-thru support for all multicopter motors	
SERVO_BLH_DEBUG	0		0:Disabled 1:Enabled	When set to 1 this enabled verbose debugging output over MAVLink when the blheli protocol is active. This can be used to diagnose failures.	
SERVO_BLH_MASK	0			Enable of BLHeli pass-thru servo protocol support to specific channels. This mask is in addition to motors enabled using SERVO_BLH_AUTO (if any)	
SERVO_BLH_OTYPE	0		0:None 1:OneShot 2:OneShot125 3:Brushed 4:DShot150 5:DShot300 6:DShot600 7:DShot1200	When set to a non-zero value this overrides the output type for the output channels given by SERVO_BLH_MASK. This can be used to enable DShot on outputs that are not part of the multicopter motors group.	
SERVO_BLH_POLES	14		1 127	This allows calculation of true RPM from ESC's eRPM. The default is 14.	
SERVO_BLH_PORT	0		0:Console 1:Mavlink Serial Channel1 2:Mavlink Serial Channel2 3:Mavlink Serial Channel3 4:Mavlink Serial Channel4 5:Mavlink Serial Channel5	This sets the mavlink channel to use for blheli pass-thru. The channel number is determined by the number of serial ports configured to use mavlink. So 0 is always the console, 1 is the next serial port using mavlink, 2 the next after that and so on.	
SERVO_BLH_REMASK	0				
SERVO_BLH_TEST	0		0:Disabled 1:TestMotor1 2:TestMotor2 3:TestMotor3 4:TestMotor4 5:TestMotor5 6:TestMotor6 7:TestMotor7 8:TestMotor8	Setting SERVO_BLH_TEST to a motor number enables an internal test of the BLHeli ESC protocol to the corresponding ESC. The debug output is displayed on the USB console.	
SERVO_BLH_TMOUT	0	s	0 300	This sets the inactivity timeout for the BLHeli protocol in seconds. If no packets are received in this time normal MAVLink operations are resumed. A value of 0 means no timeout	
SERVO_BLH_TRATE	10	Hz	0 500	This sets the rate in Hz for requesting telemetry from ESCs. It is the rate per ESC. Setting to zero disables telemetry requests	
SERVO_RATE	50	Hz	25 400	This sets the default output rate in Hz for all outputs.	
SERVO_ROB_POSMAX	4095		0 4095	Position maximum at servo max value. This should be within the position control range of the servos, normally 0 to 4095	
SERVO_ROB_POSMIN	0		0 4095	Position minimum at servo min value. This should be within the position control range of the servos, normally 0 to 4095	
SERVO_SBUS_RATE	50	Hz	25 250	This sets the SBUS output frame rate in Hz.	
SERVO_VOLZ_MASK	0			Enable of volz servo protocol to specific channels	

Figure 10. Full Parameters list (Part)

Lastly, using the Plan module in Mission Planner, we completed the configuration of the flight mission. On the campus playground, we set a total of six waypoints with a flight altitude of 30 meters. Additionally, we defined a tolerance range of 50 meters for each waypoint to account for potential GPS positioning inaccuracies. This setup allows the aircraft to autonomously navigate and complete the flight mission even in situations where GPS accuracy may be limited, enabling automatic navigation.

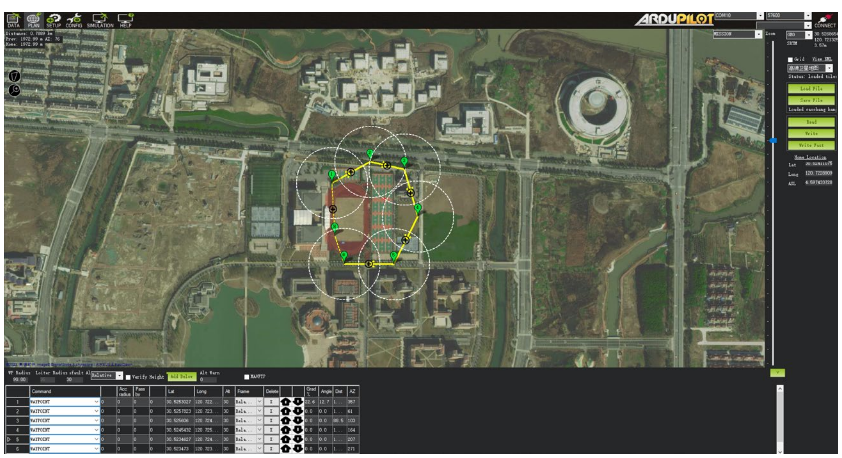

Figure 11. Automatic navigation path setting

2.5 Information Processing Subsystem

For the information processing subsystem, we have already designed the basic circuit. For the circuit, the pin SDI of the sensor is connected to the pin D2 of the Arduino for the data input and the pin SCK is connected to the pin D1 for the clock input. And for the VCC and GND, they are used to supply for the sensor. And for our project, we plan to install the circuit on our drone, and they can detect the air quality in the sky and transmit the data back. We design to use the Wi-Fi to transmit the data back and my plan is that we will design the program on the Arduino to create a network with its own IP address and then we can use the phone or computer connected to this network to get the data value.

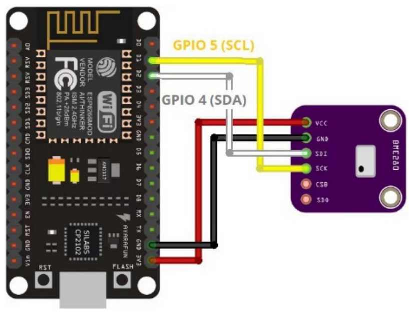

Figure 12. Basic schematic for the system

For the principle of the system, the ESP8266 server creates its own wireless network so that the electronic devices can be connected to this network through the password. And then users can use the devices to make an HTTP GET request to the server to request sensor data. It only needs to use the server's IP address to make a request on a specific path. And finally, the server receives the incoming request and the appropriate sensor reading will be sent through HTTP response after the request is made.

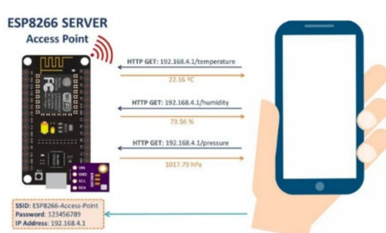

Figure 13. Logic diagram of the system

3. Design Verification

3.1 Replaceable components

3.1.1 The fuselage

Structural tests were conducted to evaluate the strength and load-bearing capacity of the fuselage. The tests involved subjecting the fuselage to various stress scenarios, including bending and torsion, to simulate real-world conditions. The objective was to ensure that the fuselage could withstand these forces without deformation or failure.

In addition to structural tests, computational fluid dynamics (CFD) simulations were performed to analyze the frictional characteristics of the fuselage. The simulations provided valuable insights into the airflow patterns and drag forces acting on the fuselage during flight. By optimizing the fuselage design and surface properties, the aim was to minimize friction and enhance the overall aerodynamic performance.

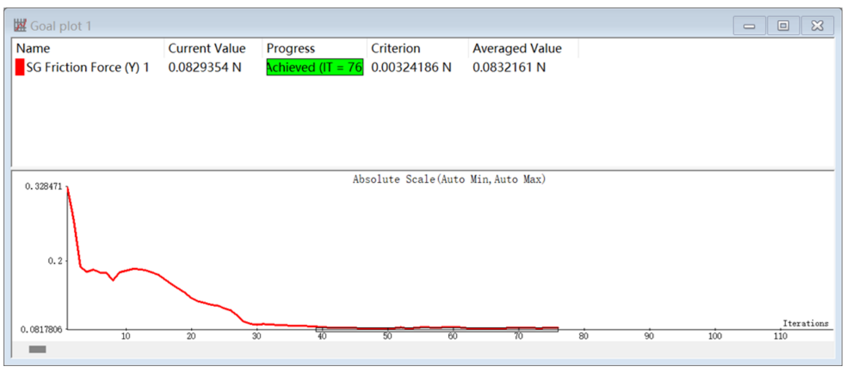

Figure 14. The friction of the fuselage

The verification process confirmed the successful manufacture of the fuselage using laser-cut balsa wood, precise assembly techniques, and foam board covering. Structural tests demonstrated its ability to withstand expected loads and stresses, ensuring the safety and reliability of the drone. The CFD simulations provided valuable information for optimizing the fuselage's aerodynamic properties, resulting in improved efficiency and maneuverability.

3.1.2 The wing

Aerodynamic performance was assessed through computational fluid dynamics (CFD) simulations. The total lift force is 39 N, although it’s smaller than the calculation result, it’s still enough for the

16 N's gravity. The wing's shape, airfoil profile, and wingtip design were optimized to minimize drag and enhance lift generation. The goal was to achieve efficient and stable flight characteristics, allowing the drone to maneuver effectively in various conditions.

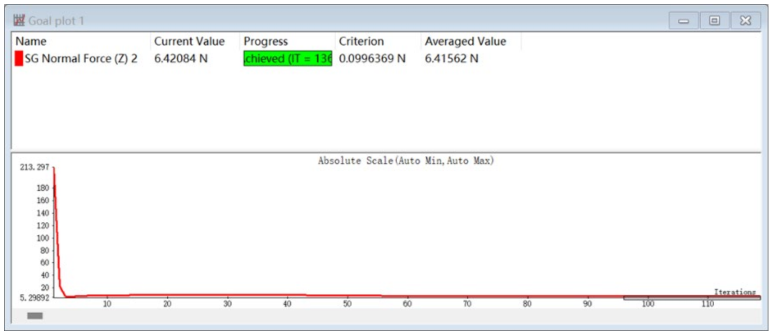

Figure 15. Lift force simulation

The verification process validated the design and construction of the wing, ensuring its structural integrity and optimal aerodynamic performance. The wing successfully withstood anticipated loads and stresses, delivering stability and lift throughout the flight. The implementation of aerodynamic optimizations significantly enhanced the wing's efficiency and control, resulting in overall improved drone performance.

3.2 Drivetrain & Power Subsystem and Manual Control Subsystem

Drivetrain & Power Subsystem consists of a 2200mAh battery that powers the remote's receiver, one electronic speed controller, four steering engines and one motor. This subsystem provides power to various electronic components on the aircraft and adjusts the power to control the flight of the aircraft based on commands from the manual or automatic control subsystems. This subsystem is connected to the control subsystem through electronic speed controller and the receiver of the remote control. And Manual Control Subsystem consists of the remote control and its receiver, which receives signals from the remote control and signals from the flight control system and sends signals to the drivetrain system. This subsystem is connected to the auto control subsystem through the receiver and with the power subsystem through the remote control. For the signal transmission distance, it is about 800m and when the drone is out of the range, the manual control system could not work, and we should use the auto control system to control the drone.

3.2.1 Receiver

The Receiver works as a bridge that connects flight control system with the servos and engine. Its type matches the controller, receiving the monitoring signal from the controller and ground station. It works while controller sends the signal or when the ground station sends the signal. At the same time, the command set to the drone to fly "mission" which is set to scan in this project case is also sent through receiver control.

3.2.2 Controller

The controller enables the users to control the drone by hand. Under specific conditions, like signal interference or program failure, users can control the engines and servos by hand, using the controller, to ensure the safety of the drone.

3.2.3 Power

A 2200mAh battery packet is used as the power supply. A one-to-two XT60 connects the battery packet to the electronic speed controller, providing a 11.1V supply. Then, the battery packet provides a 11.1 V supply to the flight control system, Pixhawk. For safety considerations, a voltage buzzer alarm is added to the battery. It will buzz when the voltage reaches below 3.7 V and above 11.1 V.

3.2.4 Servos

There are 4 servos on our drone to adjust its flying attitude. They are attached to the ailerons and tail wings. The servos receive signals from the control module to change their directions, to adjust the flying altitude of the drone.

3.2.5 Motor

The motor can provide power to the whole drone. It receives electric power from the battery and receives the signal from the controller and the flight control system, Pixhawk. With the signal received, the motor will receive different contents of power, then output different rotate, adjusting the flying speed. With the speed adjustment, the drone can perform better under the environmental influence.

3.3 Auto Control Subsystem

In manual mode, the vertical movement of the left joystick on the remote control can control the throttle, adjusting the motor speed. The horizontal movement of the left joystick can control the rudder, enabling yaw control of the aircraft. The vertical movement of the right joystick on the remote control can control the elevator, enabling the aircraft to ascend or descend. The horizontal movement of the right joystick can control the ailerons, enabling roll control of the aircraft. In stable mode, without any manual control inputs, the aircraft's attitude can be altered, and the aircraft's rudder and ailerons will automatically respond to make adjustments. In auto mode, the aircraft is capable of flying along the predetermined path, with an error range of no more than 50 meters for each waypoint.

Based on the mentioned requirements, we conducted corresponding experiments for validation. In manual control mode, we individually and simultaneously manipulated the joysticks to observe if the ailerons, tails, and motors responded in accordance with the control logic of a V-Tail aircraft. In stable mode, we manually tilted the aircraft forward, backward, left, right, and performed flips to observe if the elevators and ailerons automatically attempted to make adjustments. In auto mode, we observed the aircraft's flight path on the satellite map to check if it remained within the error circle of each waypoint.

Based on our experimental validation, the aircraft was able to fully meet the three requirements. Within a range of 2 kilometers, the aircraft responded properly to the commands from the remote controller. In stable mode, the aircraft maintained stable flight throughout both on the ground and in the air. Under windy conditions, the aircraft was able to autonomously adjust its flight attitude. In auto mode, the deviation from the intended flight path was maintained within approximately 5 meters, which aligns closely with the desired path.

3.4 Information Processing Subsystem

The subsystem consists of a circuit which includes the Arduino, the air condition sensor and voltage source power. This is an independent subsystem, and it will be installed on the drone. This circuit will create a wireless network which can be used to transmit data. While in the air, the drone can detect air quality through the sensor and then transmit data to the ground through the network.

3.4.1 Arduino ESP8266

For the type of the Arduino, it can create its own wireless network, and other devices can connect to that network and get data through that network.

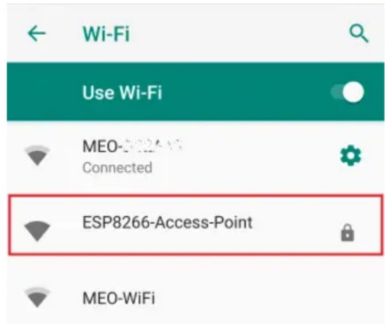

Figure 16. The network that ESP8266 creates

3.4.2 Air conditioning sensor BME280

This air conditioning sensor can detect the air temperature, air humidity and air pressure in real time. Figure 17 shows that the sensor can work and show the data on the serial of laptop.

Temperature	Pressure	Humidity
temperature:29.38*C	pressure:993.73hPa	humidity:50.72%
temperature:29.39*C	pressure:993.62hPa	humidity:50.73%
temperature:29.39*C	pressure:993.62hPa	humidity:50.73%

Figure 17. The data that the sensor detects

Then after designing the circuit including the sensor and Arduino, we can use our electronic devices connected to the network to get the air quality data.

4. Cost and Schedule

4.1 Cost Analysis

Our fixed development costs are estimated to be 30 ¥/hour, 20 hours/week, in total 10 weeks for four people.

$$4 \times \frac{30¥}{hour} \times \frac{10hours}{week} \times 10weeks \times 2.5 = 30000¥ \quad (2)$$

Our parts and manufacturing prototype costs are estimated as flows:

Table 1. Cost of the project

Description	Quantity	Manufacturer	Vendor	Cost/unit (RNB)	Total cost (RMB)
Remote Controller	1	Wenzhou Yifeng Store	Taobao	138	138
Motors	1	Wenzhou Yifeng Store	Taobao	95	95
Electronics Speed Controller	1	Wenzhou Yifeng Store	Taobao	45	45
Propellers	1	Wenzhou Yifeng Store	Taobao	14	14
Servos	4	Wenzhou Yifeng Store	Taobao	25	100

Flight Controller	1	Wenzhou Yifeng Store	Taobao	75	75
Battery	1	Wenzhou Yifeng Store	Taobao	135	135
Charge	1	Wenzhou Yifeng Store	Taobao	108	108
Frame	1	Wenzhou Yifeng Store	Taobao	399	399
ESP8266	1	DFRobot Store	Taobao	89	89
BME280	1	DFRobot Store	Taobao	39	39
Total					1237

The grand total is,

$$1237\,(parts) + 30000\,(Labor) = 31237¥\ (Total) \tag{3}$$

However, when we design the sensor connected to the circuit, we should use the bread board and some wires, which are not estimated in our total cost. Also, For the parts that will be 3D printed, our drone, the cost not only includes the material cost, but also includes the electric cost for 3D printers because the process is time-consuming.

4.2 Schedule

Table 2. Cost of the project

03/20/23	Complete the design document	All
	Complete the assembling of the prototype and try to have a flight test.	Zhibo Teng

	Design the circuit to test whether the motor and servos can work properly.	Ziyang An
	Complete the connection of the data transmission module and test whether the data transmission signal can work properly.	Zhanhao He
	Complete the assembling of the prototype and try to have a flight test.	Yihui Li
03/27/23		All
	Start to design our own done model by CAD software.	Zhibo Teng
	Complete to test whether the motor and servos can work properly installed on the drone and design the circuit of the Arduino and BME280 sensor.	Ziyang An
	Set the automatic flight of the aircraft through the ground station software	Zhanhao He
	Start to design our own done model by CAD software.	Yihui Li
04/03/23		All
	Use Fusion 360 to simulate our own model and improve it	Zhibo Teng

	Help to complete the flight control system.	Ziyang An
	Adjust parameters, set aircraft autopilot, and conduct simulated flight tests	Zhanhao He
	Continue to complete the improve the CAD design.	Yihui Li
04/10/23		All
	Manufacture and assemble our designed drone prototype.	Zhibo Teng
	Complete the circuit of the Arduino and the BME280 sensor.	Ziyang An
	Complete the circuit design of the speaker based on Arduino	Zhanhao He
	Manufacture and assemble our designed drone prototype.	Yihui Li
04/17/23		All
	Based about our prototype, improve the CAD design and simulation.	Zhibo Teng
	Complete the code of the Arduino and input the code to the Arduino.	Ziyang An
	Complete the speaker code section	Zhanhao He

	Based on the situation of our prototype, improve the CAD design.	Yihui Li
04/24/23		All
	Improve the design and simulation.	Zhibo Teng
	Test whether the circuit can work properly.	Ziyang An
	Integrate the entire drone and test	Zhanhao He
	Improve the design and debug.	Yihui Li
05/01/23	Flight test and start final report.	All
05/15/23	Final testing and debugging. Finish final report.	All
05/22/23	Functionality Demonstration.	All

5. Conclusion

5.1 Accomplishments

5.1.1 Control system

We have successfully completed the two assigned tasks: manual control and auto control of the aircraft. In the manual control aspect, the aircraft is capable of responding to remote control signals in accordance with the correct motion logic, enabling takeoff and landing operations. In the auto control module, the aircraft can achieve stable flight in the Stable mode and follow the set waypoints to complete the flight plan in the Auto mode.

5.1.2 Information processing system

We accomplished the circuit of the air quality sensor. We chose to use ESP8266 Arduino and BME280 air quality sensor. The ESP8266 created Wi-Fi and the sensor detected air data and then the circuit can transmit the data back through Wi-Fi. The drone can take the circuit to the sky, and we can use my phone connected to that Wi-Fi to get the data.

5.2 Uncertainties

5.2.1 Control system

The uncertainty in the control system mainly arises from external disturbances. We have not tested the aircraft's ability to resist interference under conditions such as strong winds, strong magnetic fields, and complex terrains. Under the mentioned harsh conditions, the aircraft may struggle to maintain a balanced attitude, fail to execute the intended flight mission, and potentially experience stalls, loss of communication, or even crashes, resulting in serious consequences.

5.2.2 Information processing system

The uncertainty is mainly due to the weather conditions such as strong wind and rain. This is because the data transmission depends on the Wi-Fi function. When the weather is bad, the Wi-Fi signal transmission will be interfered, which will lead to weak signal strength or slow signal transmission speed when we use Wi-Fi.

5.3 Future Work

5.3.1 Control system

1) Implement automatic adjustment of the aircraft's flight altitude based on terrain maps to enable long-distance flights in complex terrains.
2) Achieve long-distance flight control for the aircraft by utilizing external antennas to enable signal transmission over distances exceeding 100 km.
3) Install a flight camera to enable image signal transmission, allowing for better execution of flight missions and providing real-time visual information.

5.3.2 Information processing system

We plan to add a new storage function to this system. When the weather is bad, the collected data can be temporarily stored in the SD card, so that the same data can be obtained by reading the data card. In addition, I plan to add a new power supply system. Now the circuit is powered by two 1.5 V AA batteries, so the circuit may not last very long. When a power supply module is added, the circuit will last longer.

6. Ethics and Safety

6.1 Ethics

6.1.1 Privacy

As we collect and process environmental data in remote areas, we must ensure that the data is collected and stored in a secure manner to protect the privacy of individuals and sensitive information. This ethical issue is particularly relevant to the ACM Code of Ethics [5], Section 3.7, To avoid ethical breaches related to data privacy, we will adhere to relevant data privacy regulations such as the General Data Protection Regulation (GDPR) [6]. We will also implement secure data storage practices such as encryption and access controls.

6.1.2 Autonomy and Responsibility

Autonomy and Responsibility: The use of autonomous drones raises questions about responsibility and accountability in the event of accidents or other incidents. The IEEE Code of Ethics [7] emphasizes the importance of ensuring that autonomous systems are designed and used in ways that are consistent with ethical principles and that prioritize human welfare.

6.2 Safety

6.2.1 Electrical safety

Electrical safety is a major concern as the drone will be battery-powered and may carry sensitive electronic components. The use of high-voltage batteries and charging systems may pose a danger of electric shock or fire. It is important to use batteries that meet the voltage and current requirements of the drone. Batteries should be stored and charged in a fireproof container or area, away from flammable substances and liquids. To minimize the risk of electrocution, it is important to follow relevant safety standards and guidelines for battery selection, charging, and handling, such as those provided by the U.S National Committee (USNC) [8] of the International Electrotechnical Commission (IEC), National Electric Code (NEC) [9] It is also important to ensure that all lines and connections are properly insulated and grounded. A battery management system should be used to prevent overcharging or short circuits.

6.2.2 Mechanical safety

Mechanical safety is another important consideration. To minimize the risk of a crash or collision, we will need to implement safety features such as obstacle avoidance sensors and emergency landing systems. We will use durable materials and designs that can withstand harsh environmental conditions and resist damage caused by impacts or collisions. Refer to the MECHANICAL SYSTEMS QUALIFICATION STANDARD [10] by the U.S. Department of Energy for regular inspection and maintenance of all mechanical components and systems to ensure they are in good working condition. We also need to ensure that the drone is properly balanced and stable during flight. The Federal Aviation Administration (FAA) [11] have strict regulations governing the operation of drones, including requirements for registration, certification, and flight restrictions.

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Appendix

Manual Control Subsystem

Remote Controller & Receiver

The MICROZONE controller is used to control the drone to take off and turn. It is chosen for its affordability and the speed of the signal transmission 2.4GHz, which allows low interference degree and remote-control distance about 800m. The receiver, MC7RB matched with the remote control, is used to receive the signal from the remote control and the signal from computer through the flight control system.

Table 3. Remote Controller & Receiver R&V table

Requirements	Verifications
1. The remote control can send and transmit the signal to the receiver with low interference degree and remote-control distance. 2. Receiver can receive the signal from the remote control. 3. Receiver can receive the signal from the flight control system.	1. A. Match the receiver with remote control. B. Connect the servos with the receiver through channel 1,2,4 and motor through channel 3. (The two servos installed on the ailerons connected to channel 2 through a y-wire, servo installed on the left tail wing connected to channel 4 and servo installed on the right tail wing connected to channel 1.) C. Install the motor and servos on the model drone. D. Keep a distance between the receiver and remote control and set some obstacles between them. E. Operate the remote control. When pushing the left rocker of the remote control up and down, the motor can work to power the drone. Push the left rocker of the remote control to move left and right, the servo on the left can pull the tail wing to turn the drone. When pushing the right rocker of the remote control up and down, the two servos installed on the ailerons can work together pull the ailerons to make the drone go up and down. Push the right rocker of the remote control to move left and right, the servo on the right can pull the tail wing to turn the drone. 2. A. Match the receiver with remote control. B. Connect the servos with the receiver through 1-6 channels. C. Operate the remote

	control to see whether the servos can work under the command of the remote control. 3. A. Connect the servos with the receiver through 1-6 channels. B. Connect the flight control system with the receiver through the bus channel. C. Input the command in computer to see whether the servos can work under the command from the computer.

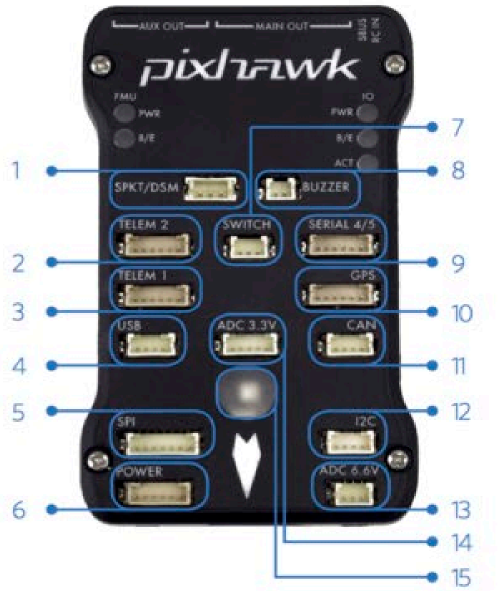
Auto Control Subsystem

RF-wireless Module

The software Mission Planner and microcontroller are connected wirelessly through a pair of RF-wireless modules. One module is connected to the laptop, while the other is connected to the Microcontroller on board the aircraft, establishing a bidirectional wireless communication link between them.

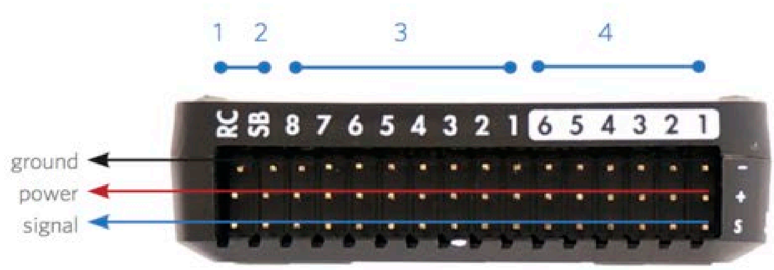
Table 4. RF-wireless Module R&V table

Requirements	Verifications
1. The airborne RF-wireless module and the RF-wireless module connecting the ground station can be connected normally within an obstacle free range of 2 kilometers. 2. The RF-wireless modules can correctly transmit ground station instructions for flight control.	1. A. Pairing two RF wireless modules. B. Using the positioning function of mobile phone GPS, move two RF-wireless modules about 2km apart in an open area. C. Observe the indicator light on the RF-wireless modules. If it remains permanently green, it indicates that the connection is normal, which satisfies the requirement. 2. A. Set “Auto” mode on Mission Planner software. B. Test whether the drone can maintain horizontal flight. C. Set “Manual” mode on Mission Planner software. D. Test whether the drone can return to manual control.



1 Spektrum DSM receiver
2 Telemetry (radio telemetry)
3 Telemetry (on-screen display)
4 USB
5 SPI (serial peripheral interface) bus
6 Power module
7 Safety switch button
8 Buzzer
9 Serial
10 GPS module
11 CAN (controller area network) bus
12 I²C splitter or compass module
13 Analog to digital converter 6.6 V
14 Analog to digital converter 3.3 V
15 LED indicator

1 Input/output reset button
2 SD card
3 Flight management reset button
4 Micro-USB port



1 Radio control receiver input
2 S.Bus output
3 Main outputs
4 Auxiliary outputs

Figure 18. Schematics of Microcontroller

Microcontroller

The microcontroller receives commands from the ground station software and sensor data from the Sensing Subsystem, which it uses to control the aircraft through the Drivetrain & Power Subsystem. Additionally, the microcontroller will transmit data from various sensors described in the Sensing Subsystem back to the laptop via RF-wireless communication.

Table 5. Microcontroller R&V table

Requirements	Verifications
1. The microcontroller can automatically control the drone for stable horizontal flight. 2. The microprocessor can automatically control the drone to fly along a given path by performing functions such as climbing, descending, and turning during the flight. 3. The microprocessor will remain idle in manual mode and will not affect manual control operations.	1. A. Fly the drone smoothly in manual mode. B. Set the mode to "Auto". C. Observe whether the drone can maintain the previous stable flight. If it can, then the requirement is satisfied. 2. A. Set waypoints in Mission Planner. B. Set the mode to "Navigation". C. Observe whether the drone can fly along the waypoints and perform operations such as climbing, turning, and descending in the correct locations using GPS and visual observation. If it can, then the requirement is satisfied. 3. A. Switch back to "Manual" mode while in "Auto" or "Navigation" mode. B. Use the remote control for manual control. C. Observe whether the drone can adjust according to the remote controller commands. If it can, then the requirement is satisfied.

Sensing Subsystem

Location Sensor

The GPS M8N is essential for accurate positioning and navigation of the drone. It uses satellite signals to provide the drone's location, altitude, and speed.

Table 6. Location Sensor R&V table

Requirements	Verifications
1. The GPS M8N can provide accurate location data within 5 meters. 2. The GPS M8N can provide accurate altitude data within 10 meters	I. A. Connect the GPS M8N to the microcontroller. B. Power on the GPS M8N and allow it to acquire a GPS fix. C. Read the location data output by the GPS M8N from software. D. Compare the location data to a known location within 5 meters of the GPS M8N. If the location data is within 5 meters of the known location, the requirement is satisfied. I. A. Connect the GPS M8N to the microcontroller. B. Power on the GPS M8N and allow it to acquire a GPS fix. C. Read the altitude data output by the GPS M8N from software. D. Compare the altitude data to a known altitude within 10 meters of GPS M8N. If the altitude data is within 10 meters of the known altitude, the requirement is satisfied.

Velocity Sensor

The MPU6000 gyroscope is responsible for measuring the drone's rotational movements and provides information on its pitch, roll, and yaw. The L3GD20 gyroscope measures changes in angular velocity and provides information on the drone's angular acceleration.

Table 7. Velocity Sensor R&V table

Requirements	Verifications
1. The Velocity Sensor can provide accurate angular velocity measurements	1. A. Connect the Velocity Sensors to the microcontroller. B. Power on the Velocity Sensors and allow them to initialize. C. Rotate the who board around its three axes, varying the rotation speed. D. Read the angular velocity measurements output by the Velocity Sensors. E. Compare the angular velocity measurements to known rotation speeds. If the angular velocity measurements match the

	known rotation speeds within an acceptable margin of error, the requirement is satisfied.

Altitude Sensor

The MS5611 barometer is used to measure changes in air pressure, which can be used to determine the drone's altitude. It is also useful for providing information on changes in weather conditions. Finally, the LSM303D magnetometer is used to measure changes in magnetic fields, which can be used to determine the drone's orientation and heading.

Table 8. Altitude Sensor R&V table

Requirements	**Verifications**
1. The Attitude Sensor can provide accurate orientation and heading measurements.	A. Connect the Attitude Sensor to the microcontroller. B. Power on the Attitude Sensor and allow it to initialize. C. Rotate the Attitude Sensor around its three axes, varying the rotation speed. D. Read the orientation and heading measurements output by the LSM303D magnetometer. E. Compare the orientation and heading measurements to known orientations and headings. If the orientation and heading measurements match the known orientations and headings within an acceptable margin of error, the requirement is satisfied.

Drivetrain & Power Subsystem

Battery

The battery has 2200mAh capacity which supplies the receiver through the electronic speed controller. And the battery supplies 11.1V voltage.

Table 9. Battery R&V table

Requirements	Verifications
1. The battery can supply 11.1V +/-5% voltage 2. The battery can have 2200mAh capacity.	1. A. Charge the battery in the way specified by the battery manufacturer B. Connect the multimeter to the battery C. Get the value of the voltage 2. A. Charge the battery in the way specified by the battery manufacturer. B. After fully shelving discharge at 1C rate to the cut-off voltage and record the released capacity. C. Test can be repeated 3 times to take the mean value to improve accuracy.

Electronic Speed Controller

The electronic speed controller is connected to the battery and the receiver so that the battery can supply the receiver. And the electronic speed controller is also connected with the motor and can transmit the signal from the receiver to the motor, allowing that the remote control can control the motor.

Table 10. Electronic Speed Controller R&V table

Requirements	Verifications
1. Electronic speed controller can supply the receiver 2. The motor can be controlled by the remote control through the electronic speed controller.	1,2 A. Connect the electronic speed controller with the battery and motor and install the motor on the drone. B. Connect the electronic speed controller with the receiver C. Match the receiver with the remote-control D. Operate the remote control. When pushing the left rocker of the remote control up and down, the motor can work to power the drone.

Motor

We designed the motor installed on the tail of the drone. And the motor is connected to the propeller, which powers the drone.

Table 11. Motor R&V table

Requirements	Verifications
1. Motor can be controlled by the remote control 2. Motor can work properly on the drone and power the drone with a speed of 10-30m/s.	1. A. Connect the motor with the receiver through the electronic speed controller B. Match the remote control with the receiver C. Control the remote control 2.A. Install the motor on the drone B. Connect the motor with the receiver C. Install the propeller on the motor D. Control the remote control. E. We chose to throw the model drone into the air, install the steering engines on the ailerons and tail wings, and conduct a test flight. F. When the drone flies in the sky, we can look through the data that the speed sensor to get the speed of the drone and ensure the speed in the range of 10-30m/s.

Servos

We have four steering engines. We design two of the steering engines installed on the ailerons and the others on the tail wings of the drone. The steering engines installed on the ailerons are connected through a y wire and then connected to the receiver and the others are connected to the receiver independently. Then we can control the steering engines through the remote control.

Table 12. Servos R&V table

Requirements	Verifications
1. Servos can be controlled by the remote control 2. Servos can work properly on the drone and reverse the drone's tail wings and ailerons by between 30 and 40 degrees.	1. A. Connect the servos with the receiver B. Match the remote control with the receiver C. Control the remote control 2. A. Install the servos on drone B. Connect the servos with the receiver C. Adjust the position of the wings connected with the servos ensuring the balanced position without using the remote control. D. Control the remote control. Control the steering engines so that the tail wings and ailerons can reach the maximum angle that can be achieved and then

	measure the angle to ensure it is in the range of 30 to 40 degrees.

Power Subsystem

This subsystem consists of four AA batteries that power the remote control and the power supply that powers the computer.

AA battery

The battery can supply 1.5V voltage which supplies the remote control.

Table 13. AA battery R&V table

Requirements	Verifications
1. The battery can supply 1.5V +/-5% voltage	A. Connect the multimeter to the battery B. Get the value of the voltage

PC battery

The battery has 4480mAh capacity and supply 13.05V voltage.

Table 14. PC battery R&V table

Requirements	Verifications
1. The battery can supply 13.05V +/-5% voltage 2. The battery can have 4480mAh capacity.	1. A. Charge the battery in the way specified by the battery manufacturer B. Connect the multimeter to the battery C. Get the value of the voltage 2. A. Charge the battery in the way specified by the battery manufacturer. B. After fully shelving discharge at 1C rate to the cut-off voltage and record the released capacity. C. Test can be repeated 3 times to take the mean value to improve accuracy.

Information Processing Subsystem

This is an independent subsystem. We plan to design the system to use Arduino to control the sensors and the speakers and put the system on the drone. While in the air, the drone can detect air quality through the sensor and transmit data to the ground. It can also emit a warning sound in the air.

ESP8266

For the type of the Arduino, we choose the ESP8266 because it can create its own wireless network, other devices can connect to that network and get data through that network. We plan to design the Arduino to set the Wi-Fi and transmit the data through Wi-Fi and then we can use a computer or phone connected to this Wi-Fi to get the data.

Table 15. ESP8266 R&V table

Requirements	Verifications
1. The Arduino can create its own wireless network, and the phone or computer can connect to it.	A. Complete the code that create the Wi-Fi and set its IP address and password and then input the code some data to the Arduino. B. Connect the phone or computer to this Wi-Fi and test whether we can get the data.

BME280 air condition sensor

BME280 is an integrated temperature, humidity, air pressure, the trinity of environmental sensor.

Table 16. BME280 air condition sensor R&V table

Requirements	Verifications
1. The sensor can work properly (detect the air condition including temperature, humidity, air pressure).	A. Complete the code and input the code into the Arduino. B. According to the circuit below that we design, connect the sensor with Arduino. C. Record the data shown on the computer