DESIGN AND IMPLEMENTATION OF ATMOSPHERIC ENVIRONMENT MONITORING SYSTEM BASED ON QGC PLATFORM

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Although unmanned aerial vehicle (UAV) has been widely used in atmospheric environment monitoring, its role is limited to the carrying platform of gas sensors. There needs to be more industrial and integrated systems for the specific requirements of atmospheric environment monitoring. This paper addresses the specific functional requirements of atmospheric environment monitoring and develops a highly integrated UAV atmospheric environment monitoring system based on the open-source QGroundControl (QGC) platform. The research content includes a UAV carrying platform, gas concentration detection board, integrated transmission of atmospheric monitoring data and UAV status data, and ground station monitoring platform. The integrated transmission mode of the constructed atmospheric monitoring data and the UAV data avoid the disadvantages of the traditional multiple communication links and multiple ground display equipment and enhance the data's synchronization and reliability. The ground station monitoring platform covers the real-time display of monitoring data, air quality evaluation, intelligent distribution of pollution source monitoring points, optimization of monitoring path, database storage, and report management. The atmospheric environment monitoring system based on the QGC platform built in this paper can complete the designed functions and has characterized by flexible maneuverability, intelligent distribution, optimized flight path and high integration. The research results can provide the relative department with a professional atmospheric environment monitoring platform.

Keywords: Unmanned aerial vehicle, QGroundControl, Atmospheric monitoring

1. Introduction

With the gradual maturity of unmanned aerial vehicle(UAV) technology, UAV has been widely used in atmospheric environment monitoring and has played an important role. Current research shows that the use of UAV-carrying

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microsensors for environmental monitoring activities has the advantages of high efficiency and high density [1-3], which can provide a new platform and tool for environmental monitoring, governance, and decision-making. Zhongren Peng et al. [4-5] used UAV to study the monitoring and spatial-temporal distribution of particulate matter 2.5(PM2.5) and other pollutants in Hangzhou and Shanghai and analyzed the regional transport process of typical contaminants. Schuyler et al. [6] used a small UAV to monitor trace gas concentration in the troposphere in Oklahoma. Corrigan et al. [7] monitored the spatial distribution of aerosol and water vapor over the Indian Ocean with an autonomous uncrewed aerial vehicle equipped with a small measuring instrument. Other relevant scholars have also used UAVs to monitor the atmospheric environment for their research problems [8-11]. At present, the following problems still exist in the research of UAV-based atmospheric environment monitoring system. (1) The role of the UAV is limited to the carrying platform of the gas sensors, and the wireless transmission path of UAV status data and atmospheric monitoring data are entirely independent. Redundant multiple data transmission links will not only lead to the energy consumption of UAVs but also may affect communication quality and data synchronization. (2) At present, the vast majority of unmanned aerial vehicle ground stations have general functions developed for UAV flight control, positioning, and navigation. There needs to be more atmospheric monitoring integrated system research for specific requirements of the environmental monitoring industry.

Because of the above problems, it is necessary to develop a set of UAV atmospheric monitoring system specially used for atmospheric environment monitoring, which organically integrates various modules such as a UAV carrying platform, gas concentration detection board, the integrated transmission of UAV status and atmospheric monitoring data, and ground station monitoring platform. In addition to the traditional UAV flight control and positioning and navigation, it organically integrates the real-time display of atmospheric monitoring data, air quality assessment, intelligent distribution of pollution source monitoring points, optimization of monitoring path, database storage and report management, and other targeted professional functions.

2. Design of atmospheric monitoring system

2.1. The overall design of the system

The atmospheric environment monitoring system is generally divided into four parts: UAV carrying platform, airborne monitoring module, data integration transmission module, and ground station monitoring module. The overall frame is shown in Fig. 1. The UAV carrying platform includes the UAV body structure, power system, control system, and communication system, which can receive information from the ground, realize the UAV flight mode switch, and carry out or end the mission. The airborne monitoring module is mounted on the UAV. It is used for the detection of atmospheric environment parameters, including the monitoring board core microcontroller, power conversion module, onboard particulate matter sensor, gas sensors, and meteorological parameter sensor. The data integration transmission module transmits the sensor monitors' real-time environmental data to the flight controller. The flight control system integrates the UAV's attitude, position, and other information with the atmospheric environment monitoring information. Then the integrated data is sent to the ground station through the wireless communication module, and the data is analyzed and extracted. The UAV ground station is an essential part of the whole UAV system. On the one hand, the ground station receives basic information such as attitude and state of flight, geographical location, and battery power from the UAV. At the same time, it also carries out the real-time display of atmospheric monitoring information, air quality evaluation, intelligent distribution of pollution source monitoring points, optimization of monitoring path, database storage, and report management.

Mission Planner and QGroundControl(QGC) are open-source ground station software widely used. Compared with Mission Planner, QGC has clear logical hierarchy and powerful function and its source code is easy to obtain. At the same time, the QGC ground station can be used in conjunction with the UAV flight controller Pixhawk and PX4 firmware, and the built-in Mavlink protocol also provides a good development basis for data transmission and analysis. Therefore, This article is based on the QGC platform for the secondary development of a UAV atmospheric environment monitoring system. The technical route of the atmospheric environment monitoring system based on the QGC platform is shown in Fig. 2. The key work of the system research and development includes the establishment of the atmospheric monitoring system development environment, data integration and transmission, ground station data management and quality evaluation, intelligent distribution control module, optimal path algorithm design, comprehensive function testing, and analysis, etc.

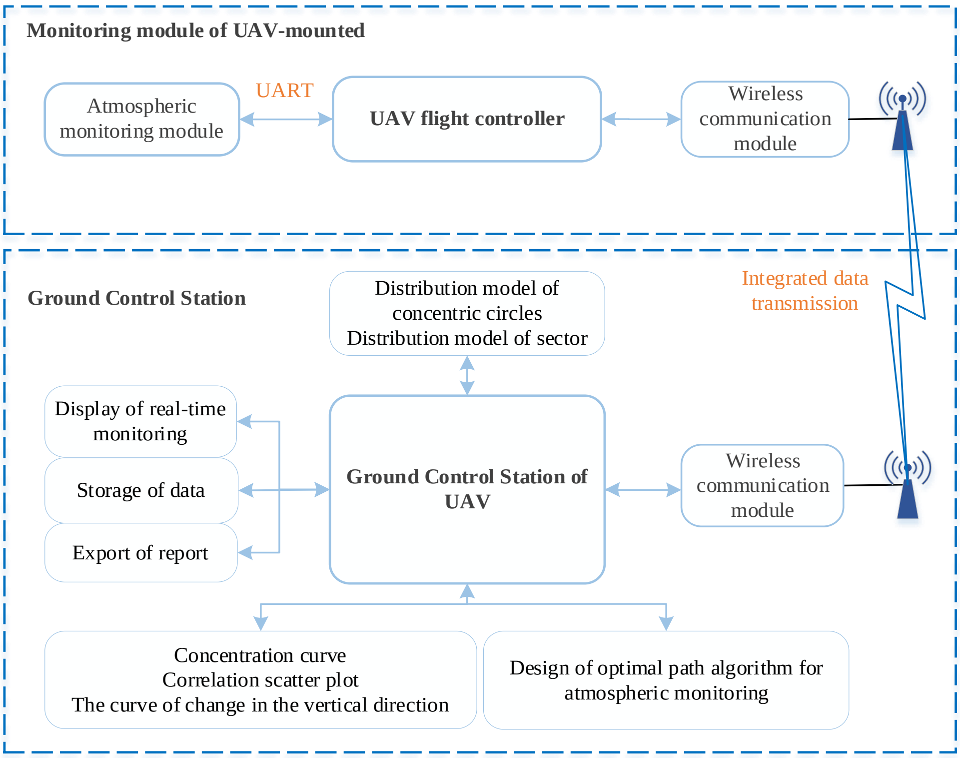


Fig. 1 Schematic diagram of UAV atmospheric environment monitoring system

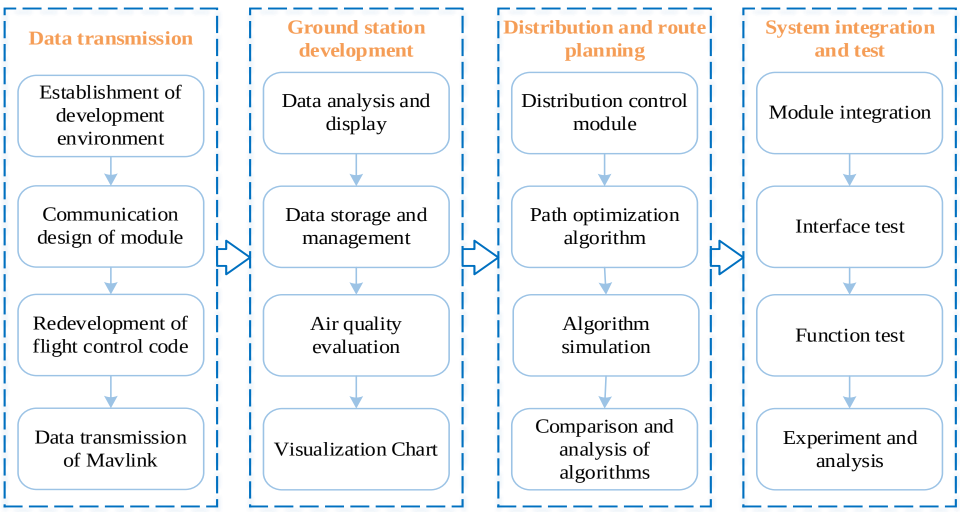


Fig. 2 Technical roadmap of UAV atmospheric environment monitoring system

2.2. UAV-mounted platform

As the main monitoring platform of the whole experiment, the selection and assembly of the UAV should be based on the actual situation and consider the potential of subsequent function expansion and performance optimization. In this system, the six-rotor UAV is selected as the carrying platform of an atmospheric sensor, mainly based on the following considerations: 1) there are space limitations around the monitoring points, which cannot provide a long runway. The rotorcraft can take off and land vertically, and the space requirement is much lower than that of fixed-wing aircraft; 2) Fixed-wing aircraft cannot hover in the air, and the airflow during a flight will have a significant impact on the measurement; 3) Compared with helicopters and four-rotor UAVs, six-rotor UAVs can provide greater load capacity and higher flight stability. The UAV has a load of 4kg, a wheelbase of 845mm, and a no-load flight time of 25~30min. It is equipped with a Pixhawk open-source flight controller, which can meet the needs of secondary development. In addition to using the remote control to the flight controller, the planned monitoring track can also be downloaded to the flight controller in the ground station software. The UAV can fly autonomously according to the predetermined path. This kind of flight mode does not require human intervention, greatly enhances the safety and automation degree of the aircraft and can be used to complete monitoring tasks beyond the visual range. All the monitoring operations in this paper are completed in the automatic flight mode of the UAV.

Fig. 3 Six-rotor UAV atmosphere monitoring platform

Fig. 4 Picture of UAV-mounted module

2.3. The monitoring module of UAV

This system chooses STM32F103C8T6 as the control core of the airborne monitoring module, which has the advantages of high performance and low power consumption and contains SPI, IIC, and other rich hardware resources. Wireless communication module E01-ML01DP5, which is relatively mature and stable in the market, is selected as the 2.4G wireless transmission module. The O_3, SO_2, CO, and NO_2 gas sensors use Alphasense (UK) or Honeywell (Germany) sensors. The PMS3003 laser sensor is selected as the particle sensor, which can accurately monitor the concentration of particulate matter 2.5($PM_{2.5}$) and particulate matter 10(PM_{10}). Regarding meteorological parameters, the MS5611 pressure sensor and Si7021 temperature and humidity sensor are used to collect information. The bus structure of USART3 (Universal Synchronous/Asynchronous Receiver/ Transmitter) is designed to solve the connection problem between a single-chip microcomputer and six gas sensors. The temperature and humidity module uses the I2C protocol to communicate with the microcontroller unit(MCU), and the PM2.5 sensor occupies USART2 separately. The bus structure makes the barometer and the 2.4G wireless module share a hardware serial peripheral interface(SPI). The airborne monitoring module is mounted on the UAV platform and powered by the UAV battery.

Related studies and practical experiments show that the center area above the UAV is least affected by the airflow, so the PCB shape size and installation hole are designed according to the platform structure in this position. Since the center of the rack has occupied a part of the space by the GPS base, the gas monitoring board is designed as a ring shape to be flexible for installation and disassembly. The gas monitoring board is divided into two parts: board A and board B. A 40 PIN connector is tightly connected between circuit boards A and B, with a circular area of 4cm in diameter reserved for the GPS base. There is a mounting hole at each side near the center for stable mounting on the UAV platform (Fig. 4). From the circuit point of view, board A in Fig. 4 assumes the central control function and is the motherboard of the entire onboard monitoring module. The interfaces of most sensors in the system are arranged on board A. Board B integrates three gas sensor interfaces and a $PM_{2.5}$ sensor interface, which is complementary to the monitoring index of board A.

2.4. Data integration and transmission module

The data integration and transmission module integrates the UAV's attitude, position, and other information with atmospheric environment monitoring information. The integrated information is uniformly sent to the ground station through the wireless communication module, and the data is analyzed and extracted in the ground station. The integrated transmission mode has the following advantages: (1) It can ensure that the status data of UAV and atmospheric monitoring information can be synchronized in time; (2) The unified use of UAV flight controller communication transmission is relatively stable to avoid mutual interference among various data communication modes; (3) Using a data integration transmission module can reduce the power consumption of additional communication and enhance endurance. The data link of the data integration and transmission module is shown in Fig. 5 and Fig. 6, including three parts: data transmission of airborne atmospheric monitoring module based on universal asynchronous receiver/transmitter(UART), interaction and sharing of atmospheric monitoring data based on the micro object requst broker(uORB) and communication of ground station based on Mavlink. Mavlink is a very lightweight messaging protocol specifically designed for communication between ground stations and UAVs (as well as onboard UAV components). In this system, Pixhawk open source flight controller with many interfaces and superior performance is selected as the flight controller of UAV, and 3DR data transfer module is specially customized for Pixhawk UAV flight controller. Data communication between atmospheric monitoring mode and Pixhawk open-source flight controller is conducted through the UART port. Pixhawk flight controller has two sets of open-source firmware, namely APM and PX4. This system uses the uORB mechanism inside PX4 to realize data sharing and interaction between processes. In the aspect of the data link layer, the Mavlink communication protocol is selected, which is specially used between UAVs and ground stations.

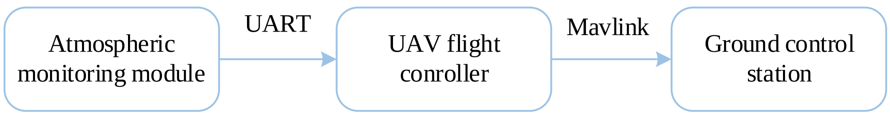


Fig. 5. Link diagram for integration and transmission of environmental monitoring data

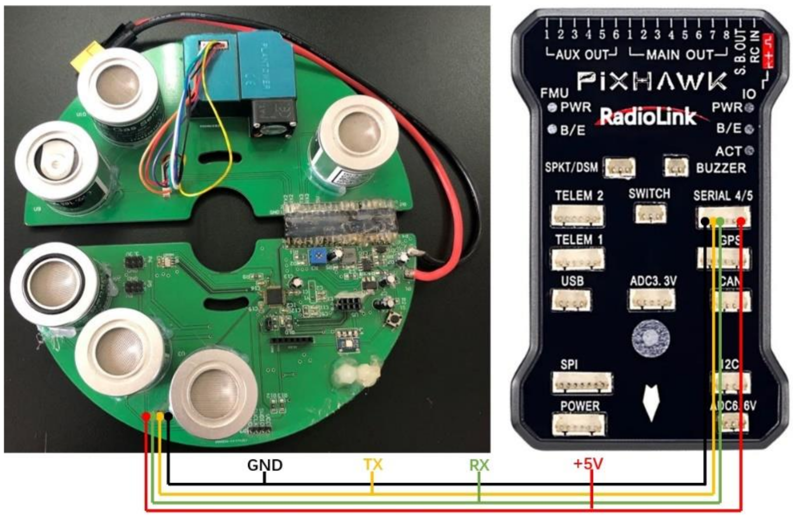


Fig. 6. Connection mode between monitoring module and Pixhawk flight controller

2.5. Monitoring software based on QGC

The ground station monitoring software based on QGC includes two functions. One is its electronic map, virtual instrument, route planning, and navigation control. The second is the air environment monitoring function developed on the open-source QGC platform. QGC development uses Qt development framework, background logic writing using the C++ Programming Language, interface programming using the QML scripting language, data management using the MySQL database. The overall function design is shown in Fig. 7, including the intelligent distribution control, data management, and quality evaluation modules.

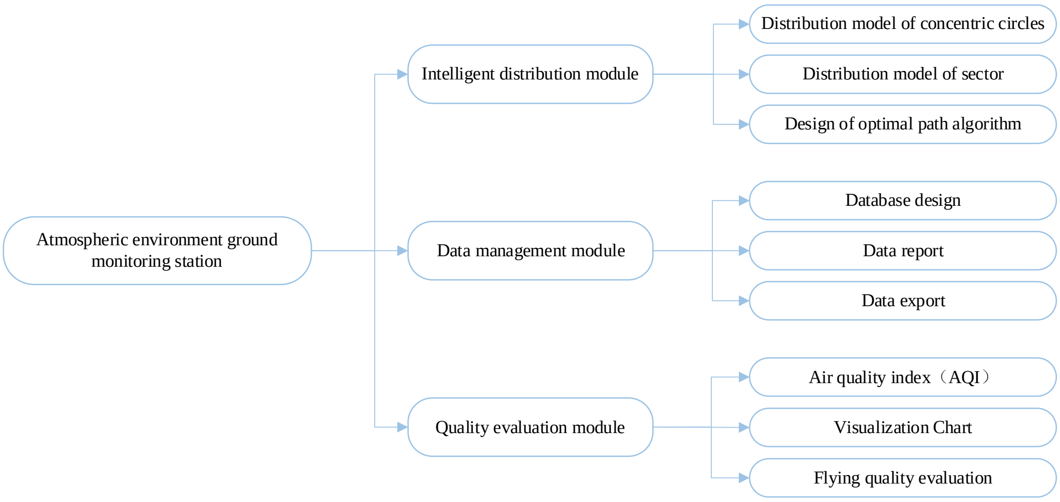


Fig. 7 Function design of ground monitoring module

(1) Intelligent distribution control module includes concentric circle, fan, and other intelligent distribution models, which can quickly build models and layout navigation points in UAV ground stations and provide personalized functions such as UAV hovering time and monitoring radius parameter setting, without manually clicking on a single navigation point, to improve operational efficiency. The optimal route planning function quickly generates the optimal monitoring path based on each monitoring navigation point. The UAV traverses each monitoring navigation point in the shortest time.

(2) The data management module is mainly used for atmospheric monitoring data management, including database design and storage, data report management, etc.

(3) The environmental quality assessment module includes the real-time display of atmospheric monitoring data, quality assessment, hierarchical early warning and calculation of air quality index(AQI). Upon completion of the

atmospheric monitoring mission, visual charts of the flight can be viewed, including the time concentration curve, correlation analysis scatter plot, and vertical concentration change curve.

3. Integration of systems and test analysis

3.1. Integration of systems

The UAV platform is the basis of the system operation. After the construction, the UAV firmware needs to be input, and the gyroscope, compass, accelerometer calibration, and other works need to be carried out to ensure the smooth flight of the UAV. The integrated hardware system is shown in Fig. 3. The UAV platform must have a specific carrying capacity and wind resistance. After installing the airborne monitoring module, the UAV is unlocked for the test flight. After the test, the UAV equipped with the monitoring module flew stably and met the expected requirements. The main interface of the air monitoring system based on the QGC platform is shown in Fig. 8. Fig. 8 includes two parts: one is the UAV attitude instrument display panel, the electronic map showing the real-time position of the UAV, the UAV flight track and other functional modules of the original QGC software; at the same time, there are functional buttons to control takeoff, mission execution and landing. The second is the atmospheric environment intelligent distribution control module, data management, and quality evaluation module. The real-time atmospheric monitoring data in Fig. 7 is presented in Drawer form, including real-time atmospheric environment monitoring values, latitude and longitude, and air quality. In the main interface, the air environment quality evaluation, monitoring data report, intelligent distribution of pollution source monitoring points, and other functions can be switched freely.

3.2. Test of intelligent distribution model

The atmospheric environment intelligent distribution control module can select the distribution mode, such as concentric circle and sector distribution mode, according to the characteristics of fixed pollution sources and monitoring requirements and can adjust the monitoring route according to the radius, number of turns, Angle and other parameters, which can be dragged on the electronic map and automatically uploaded to the flight controller. The optimal monitoring path planning can be generated intelligently for multiple monitoring points in regional atmospheric environment monitoring. The project team chooses to conduct experiments in China Jiliang University's East playground to verify the above functions. During the experimental test, the number of concentric circles is set as four circles, the flight altitude is 25 m, the radius spacing of concentric circles is 4 m, and the flight hover time is 0 s. The actual flight is shown in Fig. 9. The yellow numbered points in the figure are the navigation points of the UAV, H is the home point, and the UAV follows the navigation points 1,2,3 to flight. The red line shows the flight path of the UAV, and the yellow line is the planned route. The fan-shaped distribution flight path is shown in Fig. 10. Fan-shaped distribution setting fan angle is 45°, radius of spacing of 10 m, 25 m altitude, hover time 0 s, and circle number is 6, starting angle is 335 °. The optimal path planning function selects 20 points randomly arranged in the playground for path optimization. As shown in Fig. 11, the actual flight path of the UAV has a slight deviation from the planned route, which is caused by the drift of GPS signals.

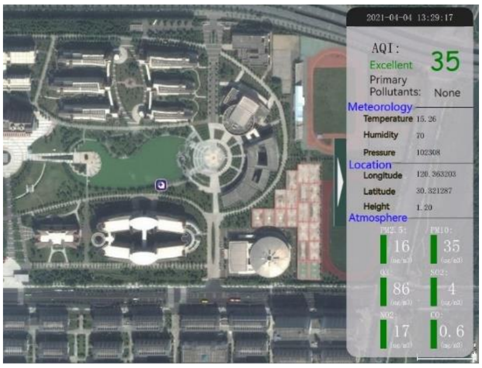


Fig. 8 Main interface of monitoring system

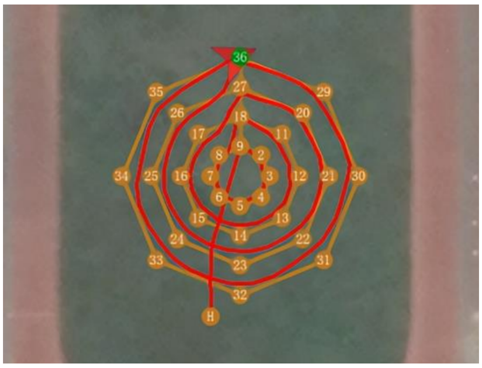


Fig. 9 Flight diagram of concentric distribution model

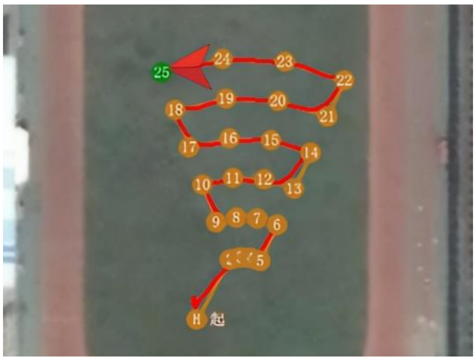


Fig. 10 Flight diagram of fan-shaped distribution model

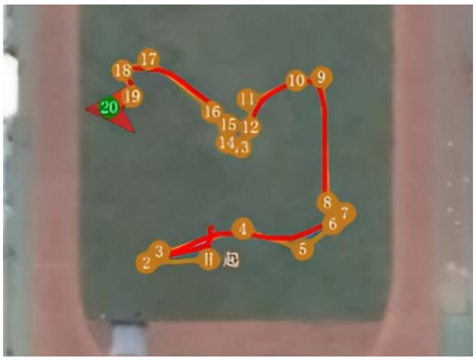
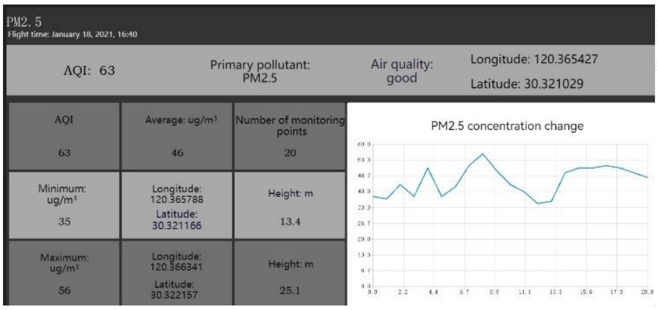


Fig. 11 Flight diagram for optimal path planning

3.3. Function test of data management and quality evaluation module

The data management interface can realize real-time display, real-time evaluation, data storage, and atmospheric environment monitoring data report management. It can select flight monitoring sites and export reports in comma separated values(CSV) format.CSV format is the most common import and export format for spreadsheets and databases. The quality evaluation module can carry out the quality evaluation, including calculation of air quality index(AQI), pollutant concentration average calculation, maximum concentration, and minimum concentration coordinate acquisition; The concentration change curve, correlation scatter diagram, and vertical concentration change diagram are shown in Fig. 12 and Fig. 13.



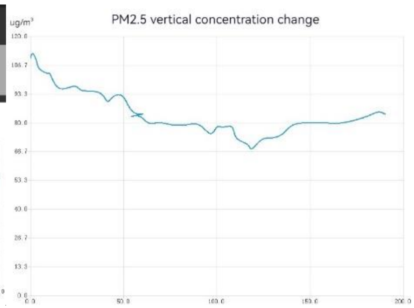


Fig. 12 Atmospheric environment quality assessment interface

Fig. 13 Diagram of vertical concentration change

4. Conclusions

Aiming at the specific functional requirements of atmospheric environment monitoring and based on the open-source QGroundControl (QGC) platform, this paper studies and develops a set of highly integrated UAV atmospheric environment monitoring system. The main conclusions are as follows: (1) A set of atmospheric environment monitoring system targeting $PM_{2.5}$, PM_{10}, SO_2, VOC, O_3, NO_2, CO, and meteorological parameters is designed and implemented by taking the six-rotor UAV as the flight-carrying platform and supported by STM32 microcontroller and sensor technology. (2) Integrated transmission of atmospheric monitoring data and UAV data is realized. Based on PX4 software architecture, uORB communication mechanism, Mavlink communication protocol, and QGC source code, the accurate and stable integrated transmission of customized data from the gas monitoring module to flight controller and then to the ground station is realized. (3) Completed the design and implementation of the ground station software based on the QGC platform. It realizes real-time display, real-time evaluation, data storage, report management of atmospheric environment monitoring data, and intelligent distribution of atmospheric environment for fixed and regional pollution sources. (4) The system runs stably through the comprehensive testing of the hardware and software systems and realizes the designed functions.

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