Design of Urban Air Quality Monitoring System Based on Big Data and UAV

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Abstract. In order to effectively evaluate China's air quality and provide technical support for maintaining a good atmospheric environment, the design scheme of urban air quality monitoring system based on big data and drone is studied. In the research process, a system hardware environment including a drone platform, an air quality sensor and anti-jamming equipment was constructed, which provided the basis and support for the development of system software. In the software design, the monitoring terminal program and the air quality information acquisition module are designed according to the system requirements, and the data received by the drone is restored, analyzed and stored and managed by the data multi-thread receiving module. The experimental results prove the effectiveness of the urban air quality monitoring system based on big data and drone. Applying the system to actual monitoring is beneficial to better analysis of the atmospheric environment and better maintenance of the atmospheric environment.

Keywords: Big data · Drone · Air quality · Monitoring

1 Introduction

At present, monitoring equipment for atmospheric environment in most cities relies on air quality monitoring stations and portable air quality detectors [1]. The air quality monitoring station is the basic platform for air quality monitoring and assessment of air quality, but it can only monitor the average air quality in the local area, and the cost and maintenance costs are high. In addition, the conventional air quality monitoring methods on the ground are also difficult to monitor the pollution sources in the vertical direction.

Uav air monitoring and real-time data processing can solve this problem. As the third generation of rocker technology, uav telemetry and induction technology is the key to uav air quality monitoring, which can collect, store and transmit urban atmospheric data. It has been paid more and more attention by scholars and experts at home and abroad, and is a hot topic in the academic field and enterprise research and

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development field. Telemetry and sensing of uav is a comprehensive system, in which the core technologies include telemetry sensor, data storage and real-time transmission technology. Airborne air quality monitoring sensor is the main equipment of uav to monitor air quality. Its work types mainly include sample collection, particle detection, infrared scanning, microwave radiation, etc. The data storage and real-time transmission system of uav is an important part of remote sensing system, which directly determines the scale and quality of the whole uav used for air quality monitoring. The information transmission between uav platform and ground console is realized through data link [2].

This study proposes a city air quality monitoring system based on big data and unmanned aerial vehicles to make up for the shortage of existing equipment. The drone has good stability and can fly at a long distance. The flight control is simple and reliable, and the cost is low. The hovering height is suitable for air quality monitoring. The airborne air quality sensor samples and processes the monitored area, avoiding the adverse effects of a few human errors on air quality monitoring results due to limited or unreasonable monitoring stations. The data storage and real-time transmission system of the drone is an important part of the remote sensing system, which directly determines the scale and quality of the entire UAV for air quality monitoring [3]. The information of the drone platform and the ground control station (including control commands, location information, task data) is transmitted through the data link. At present, the domestic research and development of air quality monitoring for drones has started shortly. The main indicators of monitoring are only particle concentration, NO2 content and O3 content. The encrypted big data is stored in the database; when the data is extracted, the data is decrypted by the chaotic encryption method to complete the safe storage of the urban air quality monitoring big data.

2 System Hardware Design

This UAV air monitoring system consists of two systems, the UAV platform and the ground station, which can carry out more sophisticated air quality monitoring for industrial areas, large construction projects and other areas [4]. When the drone performs the monitoring task: first place the drone platform in the open space, connect the power of the drone and the ground station, and initialize the hardware and software; then load the task data; the drone platform receives the ground. The flight instruction of the station begins to lift off; when the scheduled altitude is reached, the drone platform begins to level off to the mission point; after reaching the mission point, the drone begins to collect the air quality data at this point and simultaneously transmits it to the ground station; After the air monitoring task of this point, the drone platform flies to the next task point; after the two steps of the cycle, until the monitoring of all the mission points is completed, the drone returns spontaneously; if the drone platform experiences mechanical failure or power during the execution of the mission If the alarm is too low, the ground station should send the return flight instruction in time. Otherwise, the ground station will not receive the return instruction within 3 min, and the drone platform will return to the self-reliant emergency.

2.1 Hardware Component Framework

According to the design ideas and application analysis, the system hardware platform is built. The system uses the coaxial anti-slurry unmanned helicopter to carry the design hardware air quality monitoring system as the monitoring terminal. The ground-connected PC acts as the ground terminal and passes the collected air quality data information. The GPRS network is transmitted back to the ground terminal display, and finally the air quality monitoring function is realized. According to the design monitoring system requirements, the air quality data acquisition and processing part includes the acquisition module (sensor), the control processing chip, the storage module, the positioning module, the transmission module, etc. [5]. The data receiving part of the ground includes a data storage module, a data processing module, a display module, and the like. The use of various modules to coordinate and cooperate with the GPRS network to complete the collection, reception, processing and display of air quality data. The block diagram of each system module is shown in Fig. 1.

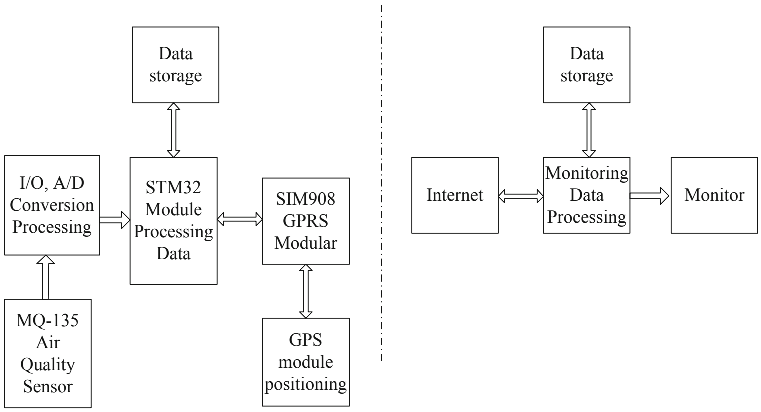


Fig. 1. System composition framework

2.2 UAV Platform Design

This section focuses on a relatively clear introduction to the hardware modules of the system data link, and integrates the modules to complete the hardware design of the air quality monitoring system. The air quality monitoring system device designed by the system is designed and built on the self-developed coaxial anti-slurry unmanned helicopter. The global coverage of the GPRS network is used to monitor the air quality of the area in real time, and the hovering characteristics of the helicopter are also It is easy to apply air quality to the vertical space of a specific location [6–8].

ARM (Advanced RISC Machines), a name derived from Reduced Instruction Computer (RISC) technology, is a popular name for a class of microprocessors. The main system of the ARM core consists of the core ICode bus, system bus, DCode bus and GP. - DMA four drive units constitute [9]. The STM32 chip selected by the system is an ARM microprocessor based on Cortex-M3 core. The architecture also includes three passive units in addition to four active units: internal SRAM, internal flash memory, AHB to APB bridge (AHB2APBx).), and adopted the ARMv7-M architecture.

2.3 Air Quality Sensor

The attitude measurement sensor module is mainly used to measure the three-dimensional posture information of the aircraft when flying in the air, that is, three attitude angles, angular velocities and the like. Accurate real-time acquisition of the attitude of the aircraft is the basis for the stability control of the four-rotor attitude, which directly determines the stability of the aircraft control. The entire attitude measurement module consists of a three-axis gyroscope, a three-axis accelerometer, and a three-axis magnetometer. In this paper, the MPU6050 micro inertial device and the AK8975 magnetic sensor are used to design the attitude measurement module [10].

The MQ135 gas sensor is highly sensitive to sulfides, NH3, aromatics, and benzene vapors and can also monitor smoke or other harmful gases. Because it can detect a variety of harmful gases, it is a long-life, low-cost air sensor suitable for monitoring. Therefore, the MQ135 gas sensor is used to complete the detection of some gases. The MQ135 sensor has good sensitivity to harmful gases in a large gas concentration range. Among them, the sensitivity to NH3, benzene vapor, H2S is high, and the typical sensitivity characteristic curve of the sensor under standard test conditions is shown [11, 12]. Wherein, the ordinate is the resistance ratio of the sensor Rs/Ro (Rs is the resistance of the sensor in different concentrations of gas, Ro is the resistance of the sensor in 1000 ppm NH3), and the abscissa is the concentration of the gas. The sensitive body power consumption Ps can be calculated by the following formula:

$$P\mathrm{s} = V\mathrm{c}^2 \times R_\mathrm{s}/(R_\mathrm{s} + R_L)^2 \tag{1}$$

2.4 System Anti-interference Design

Whether a system has anti-interference ability or not depends on whether the system is capable of fulfilling its functional mission is also the main indicator to prove the reliability of the system. In the hardware design system, its anti-interference ability must be fully considered [13]. In order to reduce interference during hardware design, it is necessary to take anti-interference measures and implement the following measures:

(1) The independent power supply line is used, and the battery on the unmanned helicopter is not used, and a power supply that can ensure the power consumption of the system is specially designed, so that the power supply line of the air quality monitoring system and the power supply part of the drone that is prone to interference are separately supplied with power. They are unaffected by each other, reducing the mutual coupling of the public power sources and improving the reliability of the system function circuits.

(2) Add a decoupling capacitor between the system power and ground. The decoupling capacitor can bypass the high-frequency noise of the device and can also be used as

the storage capacitor of the integrated circuit. The charge and discharge energy generated by the circuit switch gate can be provided or absorbed by it.

(3) Widening the broadband of the system power supply and ground wire, and selecting a thicker copper wire as the bottom line. The width is in order: ground wire > power wire > signal wire. Wiring avoids small angles and minimizes high frequency noise.

(4) A more reasonable layout. The system that has been miniaturized is mounted on the head of the unmanned helicopter, far from the motor part of the drone, and will not cause interference due to the close distance of the components. The internal power supply and high-frequency circuit parts of the system should be kept as far as possible, and the GPS antenna should be pulled to the tail rod for fixing, which is conducive to signal reception.

(5) Use a larger amount of magnetic beads in circuits such as power supply circuits and SIM908 modules. The magnetic beads have the effect of suppressing RF noise and peak interference on the transmission line, eliminating electrostatic pulses, etc., and largely attenuating the high-frequency current when passing through the wire.

(6) The clock signal is very susceptible to noise interference, and is also the source of some noise. When designing, try to make the clock circuit should be placed in the memory as much as possible. The crystal oscillator does not take the signal line between the two pins. The crystal oscillator case is connected to the capacitor and grounded.

3 System Software Design

3.1 System Software Development Tools and Environment

The system applies RealView MDK, an RM embedded development tool, which contains C language program, assembly language compiler, real-time kernel, debugger and other components. It has powerful functions and can help users complete the corresponding engineering tasks. Terminal application STM32 series microprocessors, the processor chip for Cortex-M3 kernel. The system microprocessor supports a variety of program download modes, such as ULink, J-Link and other online simulation debugging programmers, serial port download, Flash download and so on. J-link simulation debugger is selected in this study. The system can be connected to PC through USB port, which is convenient for online debugging when the hardware is running and for direct application of zero-cost serial port download.

3.2 Monitor Terminal Programming

The monitoring data terminal of the air quality monitoring system mainly completes the data collection, processing, positioning and other work, and finally transmits the data to the ground display terminal. On this basis, combined with the hardware design requirements to complete the corresponding software program design. After the system is started, the initialization of each module is completed first, and the network and information positioning are searched. The air quality sensor is a heat sensitive module, which needs to be warmed up for a certain period of time. After the process is finished, the module will collect. The air quality information of the location is connected to the system control unit through the AO port to process the AD conversion data, and the internal register storage related information is backed up by DAM. After the GPRS network connection is successful, the data information is sent to the server through the established IP protocol, and the remote display air quality of the ground display terminal is monitored.

3.3 Acquisition Process Module Design

The main task of the air quality data acquisition system is to complete the collection, processing and analysis of atmospheric dust particle concentration, carbon monoxide, temperature and humidity data, and transmit the collected data to the ground monitoring terminal. System software is designed in a modular fashion. After the system is powered on, firstly initialize the communication interface and related function modules used by the system, and wait for the acquisition of the acquisition signal. Once enabled, each detection sensor is driven to start collecting atmospheric data. After the processing is completed, the data is saved and saved to the SD card. Finally, it is sent to the flight control system through the serial port, and then the flight control passes the wireless data transmission module to forward the data to the ground data monitoring terminal.

(1) Dust particle concentration collection: The dust particle detection sensor PMS5003 uses the serial communication protocol to transmit data to the MCU through the serial port. To collect dust particle concentration data, it is necessary to initialize the serial port first, and then design the serial port driver. The carbon monoxide sensor and data transmission module also communicate through the serial port and are connected by different serial ports.

(2) Carbon monoxide concentration collection: The ZE07–CO type carbon monoxide detection sensor used in the system provides a UART output mode, and the data from the sensor can be read only through the serial port of the STM32F103ZET6 processor. When designing the carbon monoxide concentration acquisition program, first initialize the UART3 serial port. After the configuration is complete, open the serial port to start receiving interrupts. Then send a request to read the data frame, wait for the ZE07-CO sensor to respond to the output data, and then check the received data frame. If the verification is correct, save and parse the data frame to obtain carbon monoxide concentration data; If it fails, it will return to re-read the serial port data.

(3) Temperature and Humidity Data Acquisition: The system uses the temperature and humidity sensor SHT21 to communicate with the MCU through the standard I2C protocol. I2C is a two-wire serial bus consisting of data lines and clock lines. It is commonly used for communication between microcontrollers and peripherals. There are three types of signals, start, acknowledge, and end, during data transmission over the I2C bus. The data is transmitted and received through the cooperation of the clock SCL and the data line SDA.

The temperature and humidity acquisition process is as follows: first, the sensor is powered on and then enters the idle state; after being stabilized, the sensor is ready to receive commands from the MCU. MCU first sends start transmission signal, that is, when SCL is high, SDA is converted from high level to low level, then sends acquisition command (00000011 represents acquisition temperature, 00000101 represents acquisition relative humidity), waits for the end of acquisition, reads temperature and humidity measurement data in turn, and checks the data through CRC check code. Finally, the measurement signal is converted into actual temperature and humidity data, and the relative humidity signal and temperature signal output by the sensor are:

$$RH = -6 + 125 \times \frac{S_{RH}}{2^{16}} \tag{2}$$

$$T = -46.85 + 175.72 \times \frac{S_T}{2^{16}} \tag{3}$$

3.4 Data Multithreaded Receiving Module

In order to make the functions of the data receiving program not conflict, the receiving program of the design display terminal adopts multi-threading technology. First, a main thread is created, and then a sub-service thread is created by the main thread. When the display terminal program starts, the sub-service thread is used to wait for the connection request of the client, that is, the drone air quality monitoring system, to collect the terminal data. After the request is received, the main thread creates another data receiving sub-thread to process the request, and then returns a connection request waiting for another client. The three threads do not affect each other, operate independently, and send data to transfer data between threads.

4 Simulation Experiment and Result Analysis

In order to verify the practical application performance of the urban air quality monitoring system based on big data and UAV designed in this study, the following simulation experiment is designed.

After completing the hardware and software design of the entire UAV atmospheric environment monitoring system, it is necessary to debug the functions of each module of the system to ensure stable operation of the system. The UAV and air quality acquisition system were debugged separately, the feasibility of the system was tested, and the test results were analyzed. Finally, the whole system function was verified.

After completing PID parameter setting and basic debugging, flight test is carried out. Test system performance based on actual flight data. During the test, the flight parameters were sent to the ground terminal in real time through the wireless data transmission module, and the data was saved and analyzed by MATLAB. The experimental workflow is shown in Fig. 2.

The experimental environment is as follows: ambient temperature: 20–24 °C; wind speed: level 2; uav flying altitude: 100 m.

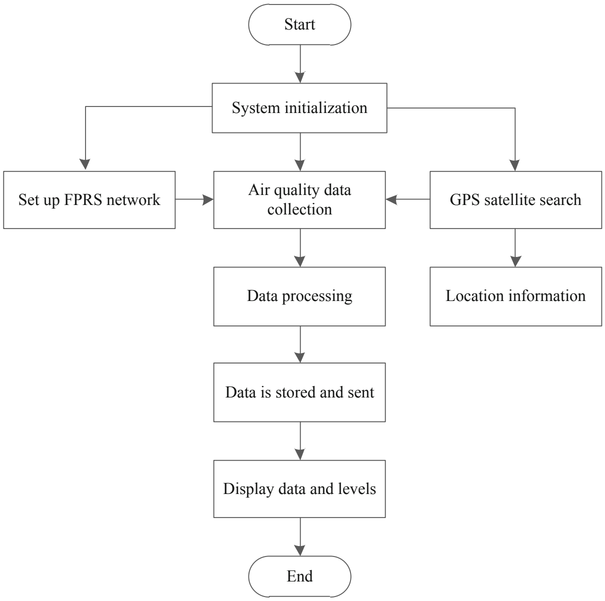


Fig. 2. Schematic diagram of the experimental process

The working environment of uav is as follows: the dual-frequency board card has good shielding function and anti-interference ability, the 80-pin pin provides a rich communication interface, it has very low power consumption of BD920 and the standard data update rate of 20 Hz. The dual-frequency board card is responsible for the output of high-precision base station coordinate data; The u-blox positioning module USES the ds-26-u8l GPS/GLONASS/Beidou module, which is a super-high power consumption and ultra-high sensitivity, ultra-small appearance GNSS receiving module, built-in SAW+LNA, can support multi-system positioning.

4.1 Anti-interference Performance Test

When the drone is hovering, the aircraft is disturbed by artificially displacing the frame to test the anti-jamming performance of the system. In the case of interference, the attitude response is shown in Fig. 3.

Analysis of Fig. 3 shows that at 86.5 s, the UAV's pitch and roll angles are disturbed, the pitch angle has a disturbance amplitude of up to 10°, and the roll angle interference is less than about 3.5°. The aircraft then responds quickly to adjust the flight attitude. After about 1.5 s, it gradually returns to the hovering state, and the adjustment speed is faster. It can be seen that the roll angle and the pitch angle have strong anti-interference performance. In about 116 s, the yaw angle of the drone is disturbed, the interference amplitude reaches 26°, and the interference is removed at about 116.8 s. Then the aircraft adjusts the yaw angle posture by itself, and returns to the initial state after about 4 s. In the yaw angle adjustment process, a 12° overshoot is

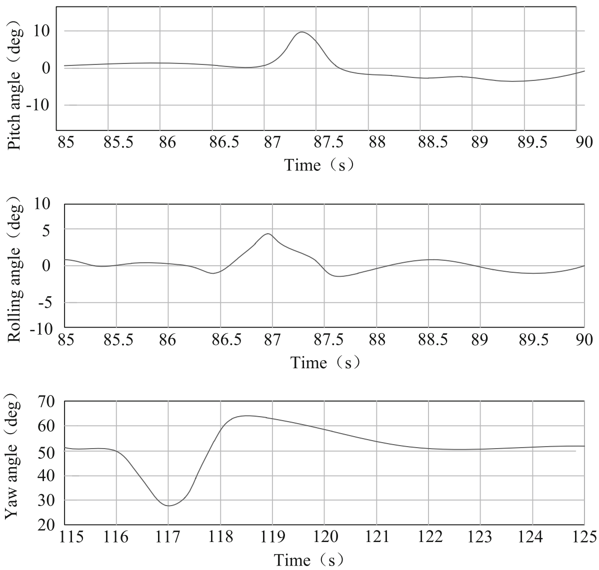


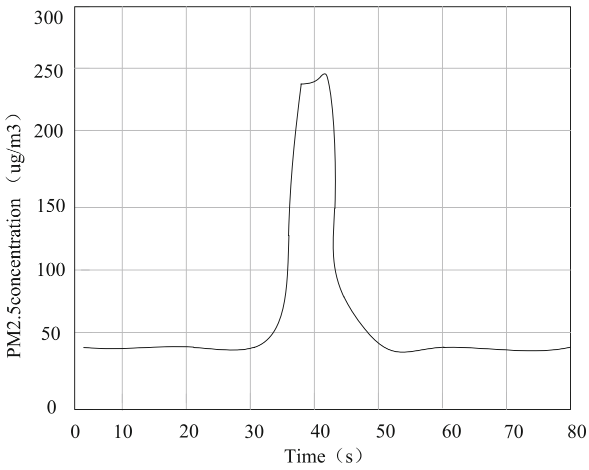
Fig. 3. Anti-jamming attitude angle response curve

generated, and the overshoot is too large. After the analysis, the integral action is too large, and the integral parameter can be further optimized and controlled.

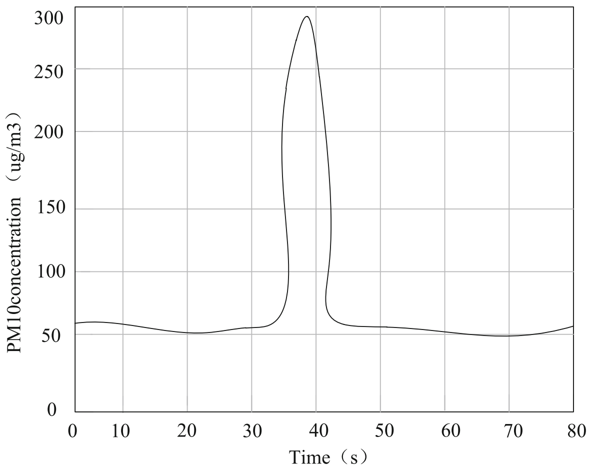
4.2 Air Quality Data Acquisition System Debugging

The air quality data acquisition system is designed based on the STM32F103 minimum system module. After completing the hardware platform construction and software design, the function of each sensor module is debugged. First, the dust particle detection sensor, carbon monoxide sensor, temperature and humidity sensor are tested through the serial port debugging assistant. It can work normally, and the standard monitoring instrument is used to compare and calibrate the collected data to ensure the accuracy of the collected data. After the data of each sensor is tested normally, the air quality data acquisition module is mounted on the drone platform and jointly debugged with the ground monitoring terminal.

Firstly, in the indoor environment, when the drone is in a static state, the indoor air quality is detected, and the sensitivity of the system is tested by means of artificially manufacturing pollution. The ground monitoring terminal displays and records each concentration data, and sets the data to be updated once in 1 s. The air pollution was simulated by igniting the wooden block. After the system was powered on, it was detected without any interference. The burning wood block was approached to the four-rotor atmospheric environment monitoring system, and then the wooden block was immediately removed. The test results are shown in Fig. 4.



(a) PM2.5 concentrations



(b) PM10 concentrations

Fig. 4. Concentration variation curves of PM2.5 and PM10

According to Fig. 4, at the beginning of detection, the concentration of PM2.5 and PM10 was kept at about 46 ug/m and 53 ug/m respectively. When the burning block was brought close to the aircraft for about 32 s, the concentration of PM2.5 detection instantly reached 232 ug/m, while the concentration of PM10 detection rose to 289 ug/m. When the block was removed and the fire source was extinguished, the monitoring data gradually returned to normal. It can be seen from the curve in Fig. 4 that the air quality data acquisition system designed has a high sensitivity.

5 Conclusion

This study designed an urban air quality monitoring system based on big data and unmanned aerial vehicles, and proved its effectiveness through experimental results. However, due to the limitations of research time and experimental resources, the system still has some deficiencies, such as high energy consumption and slow start-up speed. Therefore, in the following research, the focus will be on improving the start-up speed of the system and reducing the system energy consumption.

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