Design and implementation of real-time monitoring system for atmospheric particles based on a cloud platform

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Abstract: In order to reduce the cost of data acquisition and arrange the data acquisition nodes flexibly to meet the requirements of mobile pollution sources and unfixed data collection points, a real-time monitoring system for atmospheric particles based on a cloud platform is proposed here. The movable data acquisition nodes for atmospheric particles are designed to collect the particle concentration data, which are uploaded to the cloud platform through the general packet radio service (GPRS) network. The android application gets the atmospheric particle concentration data from the cloud platform in real time. Data acquisition nodes can be flexibly added to the system. It greatly improves the sharing of atmospheric particle concentration data. The test results show that the system has stable performance and low error rate.

1. Introduction

The rapid development of the economy and society has accelerated the process of urbanization, and increased industrial pollution sources. In recent years, frequent occurrences of large-scale haze weather in various regions have seriously affected the air quality and dramatically increased the concentration of atmospheric particles. Atmospheric particles have become the top atmospheric pollutants in China, and the people's attention to PM2.5 has also been increased [1]. The environmental air quality standards (GB3095-2012) added monitoring indicators of fine particulate matter (PM2.5) and set a daily concentration data or sampling time of at least 20 h. Moreover, it tightened the validity of monitoring data, including increasing the ratio of effective data by 25%. For atmospheric particle monitoring, China has also built atmospheric particle monitoring systems based on cloud platforms [2]. There are only a few monitoring stations in the range of several hundred square kilometres, so the collected data is not comprehensive [3, 4], which cannot be applied to mobile pollution sources or occasions where the monitoring points are not fixed.

Therefore, at present, the automatic monitoring system of atmospheric particles is a hot topic in the field of air quality monitoring [5]. For indoor air quality monitoring, there are some research results [6, 7]. In recent years, technologies such as zigbee and GPRS have been applied to the collection of environmental information, and have achieved good application effects [8–10]. With the continuous development of the Internet of Things (IoT) and cloud service technologies, a new direction to atmospheric particle monitoring is provided [11–14]. IoT cloud system provides a way for accessing IoT resources and capabilities in defined application programming interface, which can effectively reduce the cost of information storage and acquisition [15]. A real-time monitoring system for atmospheric particles based on cloud platform is designed in this paper.

2. System architecture

The structure of the real-time monitoring system for atmospheric particles based on cloud platform is shown in Fig. 1. It consists of three parts: the perception layer, the transport layer and the application layer [16]. The perception layer includes data acquisition nodes deployed at data acquisition points, which periodically collect the particle concentration data (PM2.5, PM1.0, PM10), geographic location data (latitude and longitude coordinates), temperature and humidity data and node fault information and send them to the cloud platform. The network layer uses GPRS wireless communication network for data transmission. The application layer includes android applications. The administrator can also send system setting commands to data acquisition nodes through the cloud platform, such as data acquisition modes and node work modes. The ordinary users can view and acquire the particle concentration data of interesting areas in real time through the mobile application.

3 Design of data acquisition nodes

The hardware structure of the movable data acquisition nodes is shown in Fig. 2, which is composed of embedded microcontroller STC12C5A60S2, particulate matter sensor, temperature and humidity sensor, global positioning system (GPS) + GPRS module, light emitting diode (LED) indicator and key switch. The embedded microcontroller STC12C5A60S2 is used to collect the particle concentration data, temperature and humidity data and geographical location data at regular intervals, which are sent to the cloud platform through GPRS module after processing and analysing. The LED indicator is used to display the working status of the data acquisition node. The LED indicator is on when the node is in normal operation, and the LED indicator flashes when the node is in bad function. The key switch is used to open and close the power supply. There are two serial ports, which are serial port 1 and serial port 2.

3.1 Circuit for data acquisition module

The data acquisition circuit is used to obtain the concentration data of PM2.5, PM1.0, PM10 as well as temperature and humidity. The system uses the digital universal particle concentration sensor PMS1003 to obtain the number and quality of suspended particles in the air per unit volume. The PMS1003 is based on the principle.
of laser scattering. The scattering occurs when the laser irradiates the suspended particles in the air. When the scattered light is collected at a certain angle, the curve of the scattering intensity over time is obtained. By using the algorithm based on the MIE theory, the equivalent particle size and the number of particles with different particle sizes in unit volume were obtained. The measuring range is 0.3–10 μm. The digital temperature and humidity module AM2305 are used as temperature and humidity sensor with calibrated digital signal output, high reliability and excellent long-term stability.

The AM2305 is connected to the embedded microcontroller STC12C5A60S2 through the single-bus synchronous data adapter (SDA). The embedded microcontroller STC12C5A60S2 sends the start signal to the AM2305 and receives the response signal from the AM2305 through the single-bus SDA. The AM2305 sends the byte data to the embedded microcontroller STC12C5A60S2 through the single-bus SDA. The PMS1003 is connected to the embedded microcontroller STC12C5A60S2 through the serial port 1, and the data is transmitted through the serial port, as shown in Fig. 3.

3.2 Circuit for data upload module

The Yi Tong Xing Yun M260 module is mainly composed of A8900 main control chip, which integrates a GPRS communication module and a GPS positioning module. The Yi Tong Xing Yun M260 module is connected to the embedded microcontroller STC12C5A60S2 through the serial port 2, as shown in Fig. 4. The data collected by the STC12C5A60S2 is uploaded to the ET-iLink cloud platform through the GPRS chip integrated in Yi Tong Xing Yun M260 module.

4 Software design

4.1 Software design of data acquisition

Data acquisition software is mainly divided into temperature and humidity data acquisition program, particle concentration data acquisition program and data upload program.

4.1.1 Temperature and humidity data acquisition program: The length of temperature and humidity data is 40 bytes, and the data format is: high 8-bit humidity data + low 8-bit humidity data + high 8-bit temperature data + low 8-bit temperature data + check bits. The following are the steps of the temperature and humidity data acquisition program.

(i) Setting the SDA to low level and lasting for 2 ms.
(ii) Setting the SDA to high level and lasting for 30 μs.
(iii) Determining whether the SDA has a low-level response signal of 80 μs. If yes, proceeding to the next step, otherwise jumping out.
(iv) Determining whether the SDA has a high level of 80 μs. If yes, entering data receiving state, otherwise jumping out.
(v) Receive and verify the data.

4.1.2 Particle concentration data acquisition program: The start bits of the particle concentration data are 0x4d and 0x40. First, the serial port 1 of the embedded microcontroller STC12C5A60S2 is initialised and the baud rate is set to 9600. Then the high 8-bit data and low 8-bit data are merged by the right shift operation when the start bits are received. Finally, the result is converted to a three decimal number and saved.

4.1.3 Data upload program: The procedure for data upload program is as follows:

(i) Initialising the serial port 2 of the embedded microcontroller STC12C5A60S2 and setting its baud rate to 115,200.
(ii) Setting the data transmission format to 1xxx2xxxx3xxxx4xxxx5xxx.
(iii) Sending the data collected by the sensor to the M260 module.

In step (ii), ‘1xxx2xxx3xxx4xxx5xxx’ means ‘1 + 3-bit temperature data + 2 + 3-bit humidity data + 3 + 3-bit PM2.5'.
concentration data + 4 + 3-bit PM1.0 concentration data + 5 + 3-bit PM10 concentration data’. For example: 10252052306041005020.

These data are verified on the android side by character length and special characters.

4.2 Software design of the client application

The client application software registers the new user with the ET-iLink cloud platform by ‘register’ method and obtains the user identification of the user. The ‘connectSvrs’ method is called to connect to the cloud platform, and the particle concentration data are obtained from the cloud platform after the successful connection. The Gaode map SDK [17] and the android positioning SDK are used to realise the real-time positioning of the data acquisition nodes [18]. At last, the positions of the data acquisition nodes and the atmospheric particle concentration are displayed on the map.

The detailed steps are as follows. The system uses the ‘IMService’ class to monitor and receive the positioning information in real time. After the server is successfully connected, the subscription message is monitored in real time by calling back ‘setContextCallback’ method. The topic ‘information’ can be further divided into GPS themes, analog-to-digital converter theme, general purpose input output theme and universal asynchronous receiver/transmitter (UART) theme. The system only processes the GPS information [19] and UART information. The flowchart of GPS and UART information processing programs is shown in Figs. 5 and 6. The UART information processing mainly includes processing the sensor data sent by the M260 module, in which the parameter values are obtained by judging the special data bits.

5 System testing

The picture of the movable data acquisition nodes is shown in Fig. 7. In the following section, the data acquisition function, data receiving function and data display function are tested.

5.1 Testing of data acquisition function

The data acquisition function of the data acquisition node is verified by changing the temperature and humidity values near the temperature and humidity sensor and shielding the particle sensor from the air inlet to observe the changes of the data. The testing results are shown in Table 1. Through comparison, changes in data are consistent with the expectation, indicating that the data acquisition function of the data acquisition nodes is normal.

5.2 Testing of data receiving function

First, the method of displaying UART information is added to the android application software, and then the received data is displayed in the main interface, as shown in Fig. 8. The data received is shown as ‘10642167308642835320’, which is consistent with the uploaded data format specified in the data acquisition program. Therefore, the data receiving function is normal.

5.3 Testing of data display function

The android mobile devices log on the real-time monitoring system for atmospheric particles, as shown in Fig. 9. When data acquisition nodes are powered on, the monitoring system begins to work. When a data acquisition point is selected on the map, the interface is shown in Fig. 10. It can be seen from the figure that the current data acquisition point is located in Wushan Road, Qilihe District, Lanzhou City, Gansu Province, which is close to Lanzhou Institute of Technology, the particle concentration data are: PM2.5:
141 μg/; PM10: 196 μg/; PM1.0: 356 μg/. The temperature data is 27.3°C. The humidity data is 32.5% RH. The data is constantly changing indicating that the data receiving and displaying functions are normal.

### 6 Conclusions

The atmospheric particle monitoring system proposed in this paper was successfully tested in Lanzhou City, China. The data from monitoring points are uploaded to the cloud platform through the GPRS network. Therefore, data sharing is realised conveniently. Users only need to use the APP on mobile devices to look through the atmospheric particle concentration data at the monitoring point.

Compared with other studies and commercial products, the contributions of this study to this research area are as follows:

(i) Data acquisition nodes can be flexibly added to the system and be easily added to the cloud platform to realise the data sharing of atmospheric particles, which can be an effective supplement to existing large-scale monitoring stations.

(ii) The data acquisition nodes can be moved and applied to mobile pollution sources or where the monitoring points are not fixed.

(iii) The administrator can send data acquisition control commands to the data acquisition node through the cloud platform to

| Table 1  | Sensitivity testing for data acquisition |
|----------|-----------------------------------------|
| Testing methods | Data before testing | Appearance | Data after testing |
| raise the temperature near the temperature sensor | temperature:20.3°C | humidity:45.2% | temperature:28.1°C | humidity:73.0% |
| increase the humidity near the temperature and humidity sensor | PM1.0:123 μg/m³ | PM1.0:51 μg/m³ |
| shielding the particulate sensor from the air inlet | PM2.5:70 μg/m³ | PM2.5:34 μg/m³ |
| | PM10:101 μg/m³ | PM10:56 μg/m³ |

| Table 2  | Temperature test analysis |
|----------|----------------------------|
| Data acquisition time | Temperature measured by the system, °C | The actual temperature, °C | Error rate |
| 2018.5.18 8:15  | 19.1 | 19.1 | 0 |
| 2018.5.18 8:20  | 19.3 | 19.1 | 0.01 |
| 2018.5.18 8:25  | 19.4 | 19.5 | 0.005 |
| 2018.5.18 8:30  | 19.5 | 19.6 | 0.005 |
| 2018.5.18 8:35  | 19.7 | 19.7 | 0 |
| 2018.5.18 8:40  | 20.0 | 20.0 | 0 |

Fig. 8 Data received through the serial port

Fig. 9 Client login interface

Fig. 10 Particle concentration

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implement remote control and management of the data acquisition nodes.

Since the present study is still in the stage of prototype development, they deserve further exploration in the future, such as realising a more user-friendly interface.

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