

An Secure Design of Zigbee-based Wireless Forest Air Quality Monitoring

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Abstract:

Under the background of aggravated global warming caused by the accelerated worldwide industrialization process, all countries are pursuing carbon neutrality and carbon peak. Meanwhile, considering that the tree growth is subject to concentrations of oxygen and carbon dioxide in forest areas^[1], and people's daily life is closely related to the content of all kinds of gases in urban air, an outdoor air quality monitoring device is designed based on Zigbee wireless transmission. By taking the STM32F103ZET6 embedded processor as the core controller, this device applies high-precision AO-03 oxygen sensors and M702-A seven-in-one air quality sensors to collect the concentration of various gases in the air. Then, relevant data, after being read and processed by the micro-processor, is transmitted to a computer terminal through the DL-22 module so as to evaluate whether the gas concentrations have reached alarm thresholds, thereby initiating corresponding procedures if so. According to the results of comparison between data collected in different environments and the real-time data from the China National Environmental Monitoring Center, the designed monitoring system offers higher measurement accuracy, and features better energy efficiency as well as longer battery life.

Keywords: STM32; Sensor Array; Wireless Communication; Environmental Monitoring; Air Quality Monitoring

Introduction

In today's society with the increasingly significant environmental changes, people become more concerned about the monitoring of harmful airborne emissions as these gases pose a serious threat to our health and life quality. Under this circumstance, gas monitoring has gained wide recognition in the marketplace^[2]. At the same time, since various countries pursue carbon neutrality and carbon peak, and people attach importance to health issues, not only CO₂ emissions and uptake are getting more attentions, but also the outdoor air quality is highly emphasized, of which PM_{2.5} and PM_{1.0} levels are closely related to people's travel plans, and O₂ as well as CO₂ concentrations in forest areas also affect the growth of trees. However, most of China's traditional indoor air quality monitoring instruments can only monitor the concentration of specific gases or certain environmental indicators with a single function, and its effectiveness is seriously vulnerable to poor battery life and natural environment when being used outdoor. Besides, it is still quite difficult to put the existing Internet of Things (IoT) wireless monitoring system into service because there is no design of the corresponding housing^[3]. In view of the complicated forest environment and ecological protection demands, unmanned wireless monitoring has become a mainstream thanks to the rapid advancement of Internet of Things (IoT) technology. With the purpose to settle the above difficulties, a forest air monitoring device integrating multiple gas sensors is designed in this project, which has a special sealed housing with multiple protections such as insect-proof, rain-proof and snow-proof, provides stronger endurance, and achieves wireless data transmission to the computer terminal, thus greatly saving labor and monitoring costs.

1. Overall Design of System

Based on the STM32 platform, a forest environment gas monitoring system is designed and constructed through comprehensively considering the factors of timeliness, accuracy and economy, with the system structure shown in Fig.1.

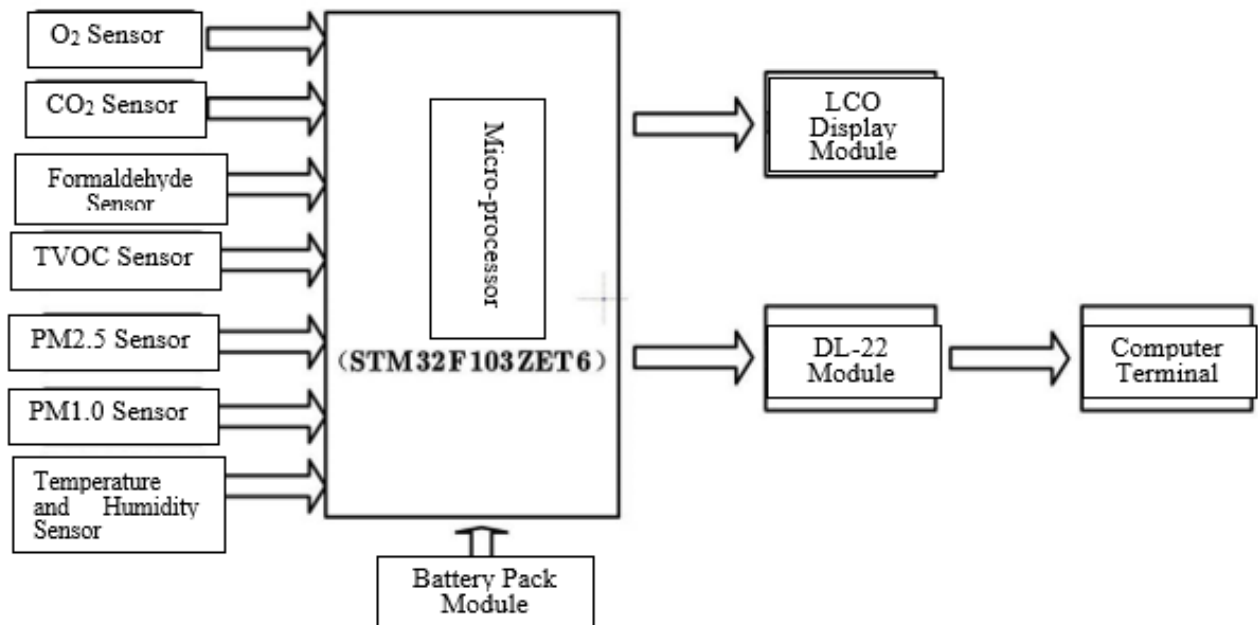


Figure 1: System Structure Diagram

The environmental monitoring system contains the modules of sensor, MCU, display and communication. Started with the design concept, the appropriate sensor modules are firstly selected to match the monitored gas and the environmental target; then the pins and software are reasonably configured in response to the communication mode and parameters of each sensor. In this way, the sensor output information can be instantly displayed on the LCD screen or transmitted to the computer monitoring terminal. Moreover, the forest air quality parameters acquired by gas sensors are further processed by the micro-controller and sent to the computer terminal through the DL-22 wireless module, so that users can remotely check the forest environmental conditions via the host computer, while the monitoring terminal will issue a real-time alarm once the value of a parameter in the forest exceeds the alarm threshold. On the basis of this system, a special housing is added to realize the actual deployment of the system in forest areas.

2. Design of System Software

The software design comprises the systems of sensor data acquisition, and terminal data threshold evaluation and alarm, with the framework shown in Fig.2.

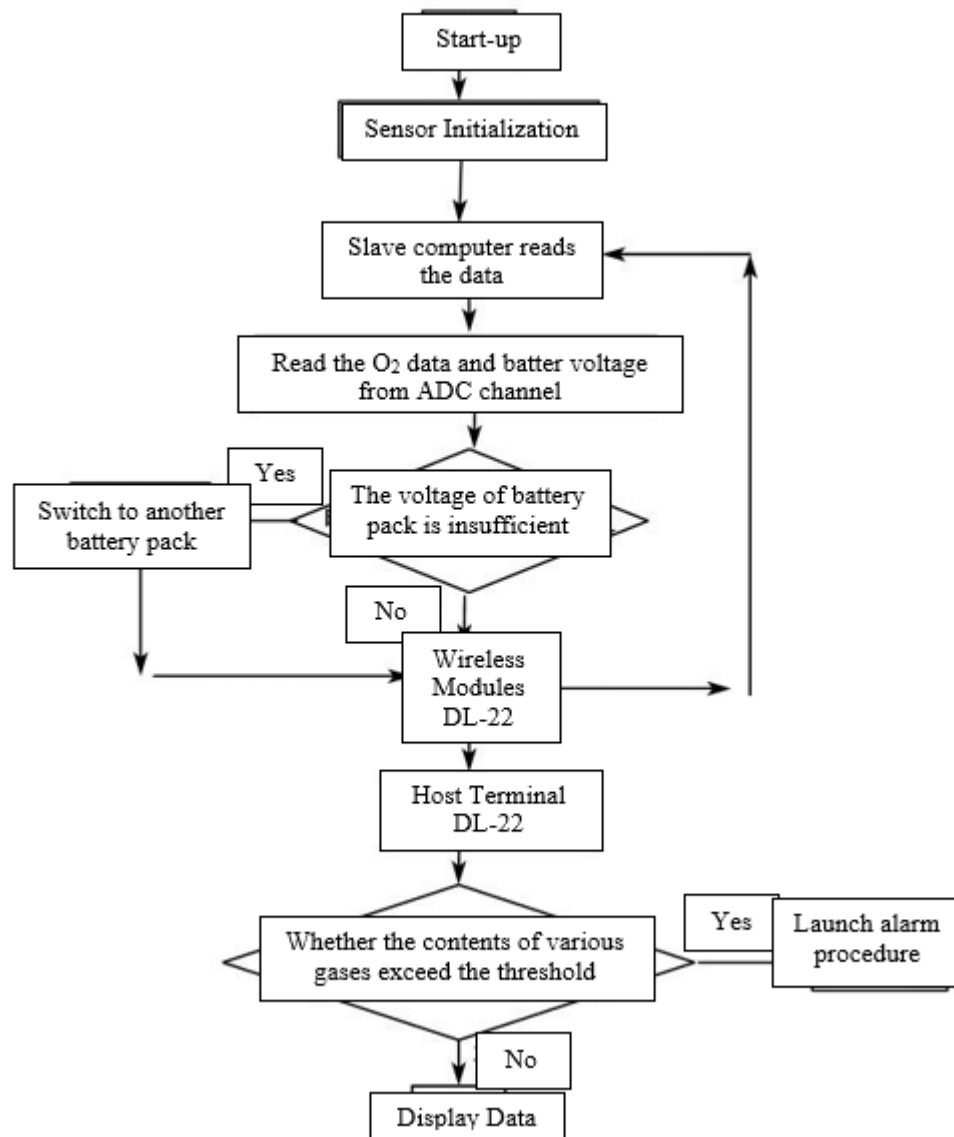


Figure 2: Design of System Software

2.1 Software Design of Sensor Data Acquisition System

The data acquisition system is composed of STM32F1 modules, sensors, LCD display, DL-22 wireless modules and battery pack switching modules, in which the software consists of the acquisition environment construction of the slave computer (STM32F1), LCD display program design, battery pack voltage acquisition program and computer terminal display program.

2.2 Software Design of Information Processing Evaluation

The information processing evaluation system contains the battery voltage evaluation program, fan intermittent start program, gas concentration threshold evaluation and alarm program.

As soon as powering on the slave computer, the serial port and ADC acquisition initialization program are started; then after the initialization is completed, the slave computer intermittently orders the fan to rotate for two seconds in every ten seconds to ensure the air circulation inside the monitoring device while measuring the voltage of battery pack simultaneously. In the case of insufficient voltage, the relay is driven to switch the battery pack, and when the backup battery pack lacks voltage, the DL-22 module sends a message to the computer terminal, prompting the replacement of battery pack. In this condition, the sensors start to collect and transmit data to the slave computer, which transmits the data to the computer terminal through the DL-22 module, thereby achieving real-time viewing of

the data and battery usage on the computer APP. In the meantime, the APP triggers an alarm and graphical prompt interface if the concentration of a certain gas reaches the threshold value.

3 Design of System Hardware

For this system, totally seven types of sensors are selected to form a sensor array, which include temperature and humidity sensor, O₂ sensor, methane sensor, CO₂ sensor, PM2.5 sensor, PM1.0 sensor, and TVOC sensor. The selection of appropriate sensors shall consider several factors such as sensitivity, response time, selectivity, stability and cost; while the design of sensor array needs to mainly focus on the ability to comprehensively as well as thoroughly monitor the gas concentrations and environmental parameters in forest areas. By utilizing electrochemical electrodes as sensitive elements, electrochemical sensor measures gas concentrations under the control of sampling circuits with good stability and selectivity. Equipped with high-precision amplification and de-noise processing, and also calibrated with standard gas, the catalytic combustion methane sensor is able to ensure accurate output of usable gas concentration information. The AO-03O₂ sensor outputs an analog voltage proportional to the measured dust concentration, the temperature and humidity sensor is a digitally integrated device, while the CO₂ sensor is a semiconductor-oxide chemical sensor adopting solid electrolyte cell principle for CO monitoring. A low-power fan with intermittent start-up is installed in the housing to ensure gas circulation and to make the measurement values more real-time. In the power supply module, two batteries are connected to one relay module and also to an RC charging and discharging circuit in parallel, which realizes follow current at the moment of switching battery pack.

4. Sealed Housing Design

The device is subject to weather and natural factors in the actual forest application, such as rain, snow, wind, sand and insects, etc. For the sake of accurate data monitoring, a stable and safe environment is necessary, so a housing specifically for monitoring in forest areas is designed accordingly. The physical appearance is shown in Fig.3.



Figure 3: Physical Appearance

Designed based on a rectangular body, the back panel of the housing is changed to a rounded shape so as to make the device better fit tree trunk when being deployed in the forest areas. With five oval openings each on left and right sides, similar in shape to the shutters, a tilted baffle is added upper on each opening, holding an angle of 30° with the direction of the plumb bob and an area of $\frac{\sqrt{3}}{2}$ times to the openings. In this manner, the device ensures less than 0.3% of water penetration in snowy and rainy weathers but good interior ventilation, thus achieving waterproofing purposes. Meanwhile, there are same openings at the bottom of the housing to guarantee timely discharge of a small amount of water from the device. In the inner side of all the openings, a layer of gauze is pasted to isolate the external insects and other objects possibly enter the device without affecting the inner air circulation. The device also comes with a fan, which is turned on regularly by the slave computer to assure instant renewal of air inside the device. The front side is protected by a removable acrylic plate, facilitating immediate readings and maintenance inside the device.

5. Design of Ultra-long-life Battery Pack

Given the ecological protection, human resources and safety considerations under the complicated forest

ecological environment, the endurance of the monitoring device is quite crucial. Due to the relatively scarce wind and light resources in forest areas, and after the comparison between the geothermal power generation^[4] and branch vibration power generation, an additional set of batteries is finally installed on top of the existing battery pack for the sake of the device portability and sealing. However, there is about 0.2 seconds of power failure time when the relay switches batteries, leading to repeated restart of the slave computer and program jamming. Therefore, in order to maintain follow current to the host computer and ensure normal switching of the battery packs, an RC circuit is connected in parallel with the power supply of the two battery packs, as shown in Fig.4.

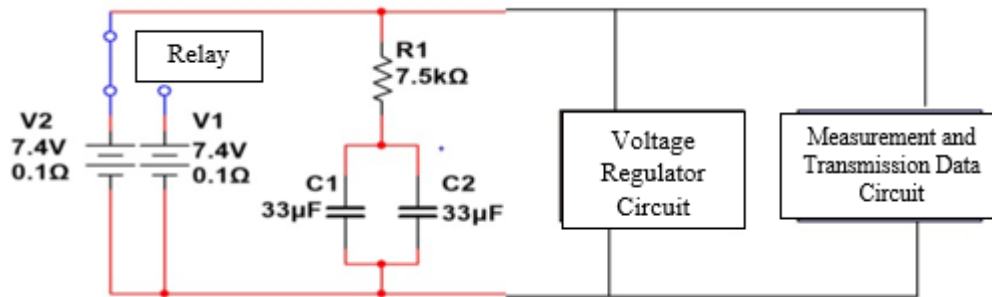


Figure 4: RC Circuit

As can be calculated from the RC circuit charge/discharge equation,

$$(C1 + C2) \times R = \tau$$

it takes about 0.5 seconds for charging and discharging, which meets the requirements of the renewal time. The two battery packs use a total of 4 sections of 26650 batteries, each with rated capacity of 5000mAh, and the experimental measurement of this program shows a single continuous power supply for more than 10 days.

6. Experimental Data Test

For the purpose of testing the device accuracy in practical application, measurements were taken at indoor Northeast Forestry University (NFU) in urban Harbin, at the recently completed renovated main building of NFU, and at the forest area within the urban NFU. Also, the measured data for each gas were compared, as shown in Fig.5. It can be seen that the PM1.0 and PM2.5 levels are higher in the recently completed indoors and forest area than in the normal indoor area, and that there are significantly more O₂ contents in the forest area in the early morning with lower temperatures and higher humidity. In contrast, the humidity in the renovated indoor area is also higher than that in the normal indoor area. This experimental data supports to prove the accuracy of the measured data.

Measurement Item	Normal Indoor Data	Data of Completed Renovated Indoor Area	Data of Outdoor Forest Area
CO2/ppm	421	425	428
CH2O/ug·m ⁻³	1	2	2
TVOC/ug·m ⁻³	12	14	16
PM2.5/ug·m ⁻³	17	56	63
PM1.0/ug·m ⁻³	21	69	78
Temperature /°C	23.03	23.01	15.0
Humidity/%	34.06	39.07	52.04
O2/%	20.11	20.56	24.02

Table 1: Test Data

7. Conclusions

In this paper, a zigbee-based air quality monitoring device is designed for forest areas, which can timely monitor the various gas concentrations, surrounding temperature and humidity with simple system, portable structure, small size, accurate measurement, and strong endurance. Through monitoring gas contents in various indoors and outdoors, the designed device supports to alleviate the impaired plant growth caused by the abnormal concentration of CO₂, provides an indicator of air pollutants for the public on their daily trips, effectively reduces the potential threat of environmental pollution to human health, and improves people's life quality. It is not only suitable for field air testing in forest areas, but also applicable to various indoor scenarios so as to provide real-time environmental gas data.

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