Construction of Open-pit Mine Environmental Monitoring System Based on Wireless Sensor Network

Yuanrong He¹, Dewei Nie¹, *, Qianjin Wan², Lu Hang¹

¹Big Data Institute of Digital Natural Disaster Monitoring in Fujian, Xiamen University of Technology, Xiamen, China
²Fujian Yunshang Qingtian Planning and Design Co., Ltd: Xiamen, China

*Corresponding author: 2634776905@qq.com

Abstract. Green mining in mines should be combined with the emerging new technologies and methods to collect, store and display mine environmental data, so as to achieve the balance between mine economic benefits and environmental protection. In this paper, low power sensor nodes are deployed on a large scale in mines, which is based on LoRaWAN protocol wireless sensor network to build mine environment monitoring system of internet of things. Energy collection, energy management and storage of monitoring nodes are designed to realize self-sufficiency of power supply of monitoring nodes. The single chip microcomputer of the monitoring node reads the sensor data and sends it to the gateway and server, and then the client application program realizes data storage and display of mine monitoring node position, rainfall, PM2.5, temperature and humidity in two dimensions of time and space.

Keywords: mine, WSN, environmental monitoring, LoRaWAN, energy collection, low power consumption.

1. Introduction

Mineral resources are the "food" and "blood" of China's industry and an important material basis for national economic and social development [1]. The mining of mineral resources will inevitably have an impact on the ecological environment of the mining area, and the monitoring of the ecological environment of the mine is an inevitable trend of development [2, 3]. A large number of scholars at home and abroad have been studied mine environmental monitoring. Zhao Ting and others monitored and evaluated the environment of Dexing Copper Mine in Jiangxi Province based on remote sensing and GIS technology, and obtained the environmental monitoring results quickly and conveniently. Zhou Chunlan and others used the "3S" technology to monitor the mine ecological environment of Baoding Coal Mine in Panzhihua, which can extract the mine ecological environment information in real time and provide important basis for mine environment control. Li Baiming designed ZigBee wireless sensor network monitoring system to monitor mine environment, which accumulated some experience for improving wireless monitoring technology of mine environment with complex environment.

However, the mining environment is mostly mountainous and hilly, with large undulating and complex terrain [4]. The location of the mine is always remoting and opening, the population density...
of mine is small, and there are not many energy supply facilities such as electricity, it is very difficult to build a wired sensor network geological monitoring system for the whole mining area [5]. Wireless sensor networks have advantages that other traditional environmental monitoring systems do not have, so they are very suitable for mine environmental monitoring [6, 7]. The application of wireless sensor networks not only enhances the environmental detection effect, but also ensures the environmental governance quality [8]. Traditional network connection methods (WiFi, Bluetooth, ZigBee, etc.) can not meet the needs of large-scale and long-term mine environmental monitoring. LoRa technology has the characteristics of long distance, low power consumption [9], large network capacity and supporting parallel processing of multi-channel and multi-data rate, which is exactly what the field of mine environmental monitoring expects. Therefore, LoRaWAN low power wide area network technology is chosen to build the mine Internet of Things environmental monitoring system.

This article uses LoRa wireless communication technology and energy acquisition, battery energy storage, single-chip low-power sensor data acquisition technology to achieve the design of mine data acquisition nodes. Then through the establishment of LoRaWAN gateway, LoRaWAN server and client application design, the system finally realizes the collection, storage and display of data in the mining environment.

2. System architecture
The data acquisition node of mine environmental monitoring system is designed, which uses solar energy acquisition and power management to realize the field power supply of the node. The low-power MCU is selected to collect the data of mine environmental monitoring sensor, and Beidou module is added to obtain the geographical location information of the acquisition node, finally, the data packet conforming to LoRaWAN protocol is sent to the gateway by lora wireless module. The gateway module is mainly responsible for collecting the information uploaded by the nodes and sending it to the LoRa server, it also needs to complete the hardware construction and software design. The LoRaWAN network server is deployed based on the open source LoRa Server. Finally, the mine environment monitoring system client is designed based on the C# language, and the sensor data is obtained from the MQTT agent of the server and stored in the database. The main functions of the client interface of the mine environment monitoring system include real-time display of node locations on the map, data display and historical data viewing functions. The LoRaWAN network architecture is shown in Figure 1.

![Figure 1. LoRaWAN network architecture.](image)

3. Module design
The main modules of the system are divided into three modules: node design, gateway and server design, and client application design. Node design includes three parts: power supply design, data acquisition and wireless transmission. The energy of nodes determines the life cycle of the monitoring system, once the power supply is exhausted and not replenished in time, the monitoring system will not work. Therefore, in this paper, energy collection, storage, battery capacity estimation and other technologies are combined with low-power MCU sensor data collection and wireless module data transmission, so that outdoor collection nodes do not need to replace batteries. The gateway is responsible for receiving data from the node and transmitting it to the server. LoRa server encapsulates
and parses the data gathered by gateway, LoRa server also includes MQTT subscription/publishing service and database storage service. The client application program design is divided into several parts: the node location is displayed on the map, the mssql database is used to store data, the node data is displayed, and the line graph displays historical data. The System structure diagram is shown in Figure 2.

![System structure diagram](image)

**Figure 2.** System structure diagram.

### 3.1 End Node design

End Node is widely deployed in mines, and the node is designed by combining energy acquisition system, single chip microcomputer, various sensors and wireless transmission module, and collects mine environmental data. Nodes mainly realize node functions from energy collection, energy storage, low-power design of nodes, sensor data collection, and data transmission by wireless modules. The Node frame diagram is shown in Figure 3.

![Node frame diagram](image)

**Figure 3.** Node frame diagram

#### 3.1.1 Design the power supply part of mine monitoring node.

Because mining areas are generally located in remote mountainous areas and the terrain is complex, it is not convenient to replace the battery when it runs out. The battery power poses a threat to the long-lasting use of the system.

The mining area is located in the field to facilitate solar energy collection, so the system is powered...
by solar cells [10]. The power supply module consists of three modules: solar charging module, lithium battery electric energy storage module and lithium battery management module. The solar panel converts solar energy into electric energy for output, the lithium battery pack is charged and optimized by the maximum power of the solar charging module with MPPT(Maximum Power Point Tracking) charging algorithm, and the lithium battery pack is connected in parallel with the lithium battery management module to realize battery pack voltage protection, Current protection, over-temperature protection and other functions. The lithium battery management module is connected with a DC-DC converter to supply power for the MCU, sensors, wireless modules, etc. The MCU reads data such as battery capacity and sends the battery data to Lora gateway.

1) The solar MPPT charging circuit is designed, and LTC4020 chip is selected as the control chip to realize the maximum power collection of solar energy.

The charger principle based on Ltc4020 chip is based on synchronous buck-boost converter, which can charge lithium battery pack with wide voltage and large current. Buck-boost switching regulator charger can work when the input voltage is higher, lower or equal to the output voltage. Ltc4020 solar panel at the input end of lithium battery charger charges lithium batteries in a constant current/constant voltage charging mode. The maximum power voltage of the solar panel has a relatively fixed value, and the working voltage of the solar panel can be adjusted by adjusting the charging current of the solar panel, so that the solar panel can be charged to the lithium battery pack at approximately the maximum power. Ltc4020 judges the charging current by measuring the voltage across the current sampling resistor, thereby performing current protection. the current overcurrent threshold is set by the resistance of the Ilimit pin of the chip.

2) Design the management circuit of lithium battery, so as to realize measuring state of charge and state of health for lithium battery packs, and the protection of the lithium battery.

In order to realize the collection and transmission of mine environmental data even under conditions of insufficient sunlight such as night and cloudy days, it is necessary to use battery fuel gauge to make a more accurate estimation of the state of charge. The single-chip microcomputer will determine the times of sensor data collection and wireless transmission according to state of charge, so as to realize the rational use of electric energy.

Lithium battery management circuit board uses bq40z50 battery management chip of Texas Instruments as control chip, which can manage lithium battery packs from 1s to 4s. The chip and its peripheral circuits collect the cell voltage, total voltage, charge and discharge current and battery temperature of the battery packs. The control chip analyze and process the collected data, When the battery pack has over-charge, over-current, under-voltage, over-voltage, over-temperature and other faults, it turns off the charge and discharge MOSFET in time to cut off the charge and discharge circuit. The equalization circuit balances the battery, eliminates the uneven charging and discharging phenomenon of the battery pack and improves the capacity utilization rate. The chip uses Impedance track power estimation method to estimate the capacity. The MCU communicates with BQ40Z50 by using SMBUS interface.

3) Design DCDC conversion circuit.

In this part of the main circuit, the output power of the battery pack is converted into DC 3.3V to supply power to the modules such as MCU and sensors. The DCDC power chip used in the design is mp1584. The input voltage is 4.5-28V, the output voltage is adjustable, the maximum output current is 3.5A, the programmable switching frequency is from 100Khz to 1.5Mhz, and the output current can reach 3A. And high-efficiency voltage conversion is realized.

4) Design sensor power supply switch circuit.

This part of the circuit is the power supply switch circuit of the sensor module, The circuit uses a controllable switch network structure composed of P-channel mos tube and NPN triode, which can realize the switching control of large current power supply, and has the characteristics of low leakage, stability and reliability. The power supply circuit can be controlled by a single chip microcomputer, and the power supply is turned off when the sensor is idle, thereby reducing the power consumption of the whole system.
3.1.2 MCU of mine monitoring node acquires sensor data. The MCU used in node design is STM8L chip of stmicroelectronics Company. The microcontroller has many kinds of ultra-low power consumption modes [11]. In this paper, the lowest power consumption of single-chip microcomputer is realized by selecting the internal low-speed clock as the system clock and turning off idle peripheral devices. The sensor data is read regularly, and when the sensor data is not read, the sensor is powered off or configured to enter sleep mode to reduce the power consumption of the sensor. The MCU has UART, IIC, SPI and several analog pins to read various sensor data. The raindrop sensor is connected with the analog pin of the MCU to obtain the analog quantity of rainfall. The chip sht20 is selected as temperature and humidity sensor, and the MCU communicates with sht20 by IIC.

The accurate positioning of mine monitoring can be realized based on Beidou satellite navigation system [12], the satellite locator ATGM336H supporting Beidou navigation is selected as the monitoring node positioning module, and the GPS global positioning module transmits the position information to the MCU in the form of message through serial port [13]. GP2Y1014AUOF optical dust sensor is selected as PM2.5 data acquisition sensor. In the sensor, an infrared detection transceiver tube is arranged at the diagonal position inside, which can detect the dust in the measured gas [14]. The sensor has low power consumption, and the output voltage is an analog voltage proportional to the measured dust concentration, and the sensitivity is 0.5V/0.1mg/m3, which connects analog quantity to the analog pin of MCU in hardware connection.

3.1.3 Lora wireless module sends data. The unique modulation technology of LoRa achieves lower power consumption and a longer communication distance. SX1278 is selected as the radio frequency chip, which can obtain high sensitivity exceeding -148dBm by using 20ppm crystal and low-cost materials [15, 16]. The sleep current of SX1278 RF chip is less than 0.2uA, the current is 1.6mA when idle, the current is 9.9mA when receiving, and the current is 120mA when transmitting. Outside of receiving mode and sending mode, the microcontroller sets the SX1278 chip to a sleep mode with ultra-low power consumption. The single-chip microcomputer of the mine data acquisition node communicates with the LoRa module through the SPI bus to configure the chip's transmission power consumption, working mode and other parameters. After the single-chip microcomputer reads the sensor data, it transmits the data packet to the LoRa gateway through the LoRa wireless module, and the transmitted data packet follows the LoRaWAN protocol.

3.1.4 Node program flow design. In LoRaWAN protocol, the terminal has three working modes: two-way terminal equipment (Class A), two-way terminal equipment with definite receiving time slot (Class B) and two-way terminal equipment with maximum receiving time slot (Class C). Class A
mode is the most power-saving mode, and the terminal only receives the downlink data sent by the gateway after sending the uplink data. The whole terminal operation flow is shown in Figure 4. The MCU reads the power several times every 100ms. When the power increases, it is considered that the solar energy is charging the battery. When the battery is charging and the power is sufficient, it reads the data from the sensor and sends the data to the gateway by the wireless module. When the power is no longer increased, the chip and peripheral circuit will continue to sleep or the peripheral module will be cut off from power supply. If no data is collected for ten consecutive minutes, MCU read the sensor data and send it.

3.2 The establishment of gateway and cloud server
The gateway and server framework is shown in Figure 5.

![Gateway and server framework](image)

**Figure 5. Gateway and server framework**

3.2.1 Packet forwarder software runs on lora gateway to encapsulate and pass the collected node data: UDP is forwarded to LoRa Gateway Bridge on internet; LoRa Gateway hardware consists of Raspberry Pi and gateway module, and the gateway module adopts LoRaWAN gateway chip SX1301. Raspberry Pi is a microcomputer motherboard based on ARM. TF card is used for memory hard disk and open source Linux system is used for operating system. LoRaWAN gateway runs packet forwarder software, which converts LoRa RF data packets into UDP data packets and uploads them to LoRa Gateway Bridge of LoRaWAN server [17].

3.2.2 LoRa Gateway Bridge packages the received data into JSON format data packets, and then broadcasts them to the MQTT proxy service through MQTT: LoRa Gateway Bridge reads data from lora gateway through UDP protocol, gateway bridge receives packet forwarder data packet and converts it into JSON format data packets, and uses MQTT protocol for data transmission, MQTT broadcast service transmits gateway bridge data to LoRa Serve.

3.2.3 LoRa Server subscribes to the message of LoRa Gateway Bridge through MQTT, processes the data packet in real time, stores and notifies LoRa App Server: LoRa Server is mainly responsible for verifying the integrity of upstream and downstream data packets and de-duplicating data packets received by gateway. LoRa App Server and LoRa Server access each other through gRPC interface. Open source structured database PostgreSQL is used as the data storage database of LoRa Server and LoRa App Server.

3.2.4 LoRa App Server reads the information of LoRa Server through gRPC or receives the push from Server, and exposes it to users through HTTP interface and MQTT broadcast: LoRa App Server is used to process the upstream load messages and downstream message queues of node devices, and is mainly responsible for the network access activation of OTAA equipment, decryption and encryption
of messages, etc. LoRa App Server provides gRPC/http RESTful interface for node information, gateway information and other server configuration, and exposes the real-time message interface of MQTT format of each node to MQTT broker, so applications can be written according to the interface.

3.3 Application/CustomerServer

The monitoring data is obtained from the MQTT agent, stored in the database, and finally displayed on the management platform based on the client monitoring system. The Application/CustomerServer calls the HTTP interface of LoRa App Server (information operation, downlink sending) and subscribes MQTT (message monitoring, downlink sending) to complete the message acquisition. The MQTT protocol mainly includes the message Publish, the message Subscribe and the message Broker. The main job of message publishers and message subscribers is to publish messages and subscribe to messages, so they exist in the form of clients, and message agents exist in the form of servers as "intermediaries" of messages. In this paper, the client application is designed to subscribe to MQTT to complete the message acquisition and realize the mine environmental data display. The data obtained by subscribing to MQTT needs to be analyzed according to the type, length and size of different sensor data. The analyzed data frame contains rainfall data, temperature data, humidity data, latitude and longitude data and pm2.5 data, each of which occupies four bytes.

Create a data table to store the data of the node. The Sql Server database is used to manage the data, and the sensor data containing the geographic location information of the acquisition terminal is stored in the database in combination with the arrival time information of each data frame to realize the real-time storage, query and display of the data [18].

Table 1. Data Sheet.

| field        | data type | empty | describe          |
|--------------|-----------|-------|-------------------|
| ID           | int       | no    | node number       |
| Temperature  | nchar(20) | no    | temperature       |
| humidity     | nchar(20) | no    | humidity          |
| Pm2.5        | nchar(20) | no    | Pm2.5             |
| rainfall     | nchar(20) | no    | rainfall          |
| longitude    | nchar(20) | no    | Longitude of node |
| latitude     | nchar(20) | no    | Latitude of node  |
| time         | datetime  | no    | time              |

GMAP control realizes the position display of mine monitoring nodes on the map. GMap.NET is great and Powerful, Free, cross platform, open source NET control. Enable use routing, geocoding, directions and maps from Google, Yahoo!, Bing, OpenStreetMap, ArcGIS, Pergo, SigPac in Windows Forms, supports caching and runs on windows mobile [19, 20].

![Gmap add overlay](image)
GMAP can be add multiple Overlay by adding customizations on the GMAP control, as shown in Figure 6. In this paper, the mine geofence Overlay is added to the GMAP control, and the mine monitoring node GMap markers is added. The mine monitoring node GMap marker realizes the visual display of abstract longitude and latitude on the map, and uses different colors to represent different environmental pollution levels, as shown in Figure 7. Among them, red marker means high pollution, green means less pollution and no pollution, and yellow means moderate pollution. The response of clicking the marker event is added to the MapControl, when the marker of the node is clicked, the event is triggered and the node information is displayed.

**Figure 7.** Mine node map display interface

4. Organization of the Text

In this paper, five terminal nodes are arranged outdoors to collect environmental data, and the information of the five terminal nodes is summarized through the gateway. Finally, the data is displayed by the client. The main interface of client program displays the latest mine environmental data monitored by end nodes, as shown in Figure 8.

**Figure 8.** Display diagram of information and location of all nodes

Click the node marker to view the historical data of the node, and the program can store and display the historical data in a line chart, as shown in Figure 9. Click Alarm Log button to view the data records of the monitoring node that exceed the high pollution threshold.
Finally, this paper tests the relationship between communication distance between gateway and node and packet loss rate, received signal strength indication and signal noise ratio. The test results are shown in Table 2. After testing, it can be concluded that in the open field, the transmission distance is within 5.5 kilometers, and the nodes and gateways can work stably, normally and reliably during system operation.

| Distance | Packet loss rate | Gateway_rx_rssi | Gateway_rx_snr |
|----------|------------------|-----------------|----------------|
| 1500m    | 0%               | -120dBm         | 3.5dB          |
| 3000m    | 0%               | -111dBm         | -2.2dB         |
| 4000m    | 0%               | -123dBm         | 2dB            |
| 5000m    | <5%              | -130dBm         | -16dB          |
| 5500m    | <20%             | -115dBm         | -11.5dB        |
| 6000m    | <47%             | -129dBm         | -12dB          |

5. Conclusions
The mine environmental monitoring system realizes the storage and display of mine environmental data from time dimension and space dimension, and provides data support for mine green development. By testing the function of the whole system, the system has achieved the expected results in communication distance, node power consumption and sensor accuracy. The test shows that the mine environmental monitoring system can run stably for a long time, realize multi-source collection and long-distance transmission of mine environmental parameters, and the system has strong reliability and applicability.

Acknowledgments
This work was financially supported by Fujian Province Natural Fund Project (grant nos.2020J01263), Shanxi Key Laboratory of Resources, Environment and Disaster Monitoring (grant nos.2019-02), Fujian Construction Science and technology research and development project (2020-k-60), Xiamen
science and technology plan project (3502z20203060).

References

[1] He Yuanrong. Study on the Method and Application of High Resolution Remote Sensing Monitoring of Mining Environment and Development and Utilization of Information Resources [D]. Central South University, 2011.
[2] Zhang Huiting, Nie Wenjie, Zhang Weiguo. The application of "3S" technology in mine environmental monitoring [J], scientific and technological innovation and application, 2018(08):152-153.
[3] Liang Hongbo, The role and measures of mine environmental monitoring in air pollution control [J], Resource Conservation and Environmental Protection, 2020(05):43.
[4] Guo Peng. Study on dynamic monitoring and evaluation system of mine environment based on wireless sensor network [D], Hebei Normal University, 2011.
[5] Wang Kun, Zhang Wei. Design of mine environmental monitoring system based on new technology of wireless sensor network [J]. China Manganese Industry, 2018, v.36; No.161 (04):213-216.
[6] He Xuewen, Li Baiming, Huang Guoping, Xiao Yong. Research on Wireless Sensor Networks for Mine Environmental Monitoring [J], Metal Mines, 2010(07):103-107.
[7] Liu Zhiqiang. Research on Application of Wireless Sensor Network in Mine Environmental Monitoring [J]. Computer Products and Circulation, 2019(12):55-55.
[8] Battambang, Feng Min. Research on Application of Wireless Sensor Network in Mine Environmental Monitoring [J]. China New Communication, 2020, 022(006):93.
[9] Li Baiming. Overall design of wireless sensor network nodes for mine environmental monitoring [J], Sensor World, 2010, 16(01):37-38.
[10] Zhou Lijun. Application of Wireless Sensor Network in Mine Environmental Monitoring [D], Anhui University of Science and Technology, 2016.
[11] Zhang Qin, Dai Yang, Yang Shenglong, Zhang Heng, Cui Xuesen. Design of low-power aquaculture water quality monitoring system based on LoRa [J], Sensors and Microsystems, 2019, 38(11):96-99.
[12] Yang Guoqing, YANG Guoqiang, WANG Chengan, et al. Study on Dynamic Monitoring System of Mine Geological Environment Based on Beidou Satellite Navigation System Technology [C]// China Satellite Navigation Annual Meeting. Organizing Committee of China Satellite Navigation Academic Annual Meeting, 2019.
[13] Wei Jingxin, Jin Wentao, Li Guan. Remote monitoring system of open pit mine disaster and environment [J], Coal Mine Safety, 2017, 48(05):123-126.
[14] Wang Shen. Design of PM2.5 detector based on GP2Y1010AU0F sensor [J], Industrial Heating, 2020, 49(02):61-63+68.
[15] Zhao Wenju. Research and Application of LoRa System with Low Power Consumption and Wide Coverage [D], Beijing University of Posts and Telecommunications, 2019.
[16] Zhang Kun. Research on Intelligent Control System of Urban Street Lamp Based on LoRa Communication [D], Shandong University, 2018.
[17] Xiao Yang. The application of LoRaWAN protocol in ship environmental monitoring [D], south China University, 2020.
[18] Hu Ying. Design and Research of Landslide Monitoring and Early Warning System Based on Wireless Sensor Network [D], Chongqing University, 2011.
[19] Yang Weiqiang, A remote location background client based on WinForm and GMAP [J], Electronic World, 2019(16):105.
[20] Wang Fuhai, Li Weifeng. Design and implementation of underwater sound source explosion marking and recording system based on Gmap.NET [J], Software Engineering, 2017, 20(06):17-20.