Research on Safety Monitoring System of Tailings Dam Based on Internet of Things

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Abstract. The paper designed and implemented the safety monitoring system of tailings dam based on Internet of things, completed the hardware and software design of sensor nodes, routing nodes and coordinator node by using ZigBee wireless sensor chip CC2630 and 3G/4G data transmission module, developed the software platform integrated with geographic information system. The paper achieved real-time monitoring and data collection of tailings dam dam deformation, seepage line, water level and rainfall for all-weather, the stability of tailings dam based on the Internet of things monitoring is analyzed, and realized intelligent and scientific management of tailings dam under the guidance of the remote expert system.

1. Introduction

The tailings dam is ore beneficiation discharge stockpiling place of metal mines or nonmetallic mines, it is a man-made debris flow hazard with high potential energy, should be strictly standardized management in daily operation and after closed. Once the tailings dam collapsed, it is likely to cause serious accidents and disasters[1-2]. The tailings dam is usually built in complicated geological environment. According to different dam construction techniques, it can be divided into upstream method, middle line method and downstream method and so on. The tailings dam often built with tailings directly, but face many challenges of external loads such as seasonal rainfall, water level changes and seismic disturbance, it is easy to destroy the original stable state so as to cause the dam deformation and even collapse[3-4]. So it’s necessary to make these external disturbances and the dam running state under monitoring, damage can be avoided by measures taken in good time. Therefore, in the face of extreme weather conditions such as typhoon, rainstorm, earthquake and other strong external disturbance, put forward higher requirements on safety management of tailings dam, and urgent need to take effective technology as a new means of support.

The Internet of things is regarded as another wave of information industry after the computer, Internet and mobile communication network[5-6]. The traditional field bus network architecture is commonly used in tailings dam safety monitoring system, monitoring data and information transmitted along the communication cables, the shortness include monitoring data is limited, low robustness and scalability, so it can’t meet the actual needs practical necessity of the tailings dam safety running under the uncertainty, complexity or extremely external disturbance environment. Therefore, the paper construct the tailings dam safety online monitoring system based on IoT technology, the system can sense the factors that affect the safe operation of tailings dam intelligently, and timely feedback to the
safety manager, so the people can take effective remedial measures in advance, reduced the probability of disasters occurrence and minimized the incidental loss, thereby improving the security level of tailings dam and its surrounding facilities [7-9].

2. System design
The paper designed the tailings safety monitoring system based on Internet of things, the system can intelligently sensing the tailing dam deformation, seepage line, water level, rainfall and other key safety parameters of tailings dam operation, make format conversion and pre recognition processing on the collected information and data, and transmits the outcome to the tailings dam safety monitoring center. The network architecture of the system is divided into three layers (Figure 1), the bottom is the perception layer based on ZigBee wireless sensor network, the middle layer is the network layer with 3G/4G network as the backbone transmission network, the upper layer is the tailings dam safety monitoring center as the application layer.

2.1. perception layer (ZigBee wireless sensor network layer)
The ZigBee wireless sensor network used by the system consists of three kinds of node: sensor terminal node, router node and network coordinator node. Communication between nodes follows ZigBee protocol. The sensor terminal nodes arranged at monitoring area around the tailings dam, these terminal nodes connecting the monitoring sensors included deformation monitoring (internal displacement and surface displacement), saturation line monitoring, the length of dry beach monitoring, water level monitoring, rainfall monitoring and seepage flow monitoring, etc..Router nodes communicate followed the ZigBee protocol, transmitted the data through wireless multi hop ad hoc network, responsible for data receiving and forwarding from the sensor nodes, and eventually gather the data to the network coordinator; network coordinator node is the center node of the whole network, responsible for the network establishment, network maintenance, network management and network address assignment.

The sensor nodes deployed in the monitoring area around the tailings dam as star topology or mesh topology to form ZigBee wireless monitoring network, real-time monitoring and intelligently percept the mass data information, upload the tailings dam monitoring data through the ZigBee network to the router node and network coordinator node, then the network coordinator node sent the data to acquisition host through the 3G/4G network. From the functional perspective, the terminal sensor nodes responsible for data acquisition, not transmit information from other nodes; the router is a kind of support related equipment, it can realize the functions of forwarding messages for other nodes; the coordinator is responsible for organizing the network, responsible for network maintenance and management, with the highest network authority.
2.2. network layer (3G/4G network transport layer)
The tailings dam safety monitoring data from the bottom perception layer uploaded to the network coordinator node through the router node, then connected to the 3G/4G communications network after the signal conversion through a dedicated interface circuit, finally completed the wireless connection with Internet Wan, realized the remote data transmission from the monitoring position to the tailings dam safety monitoring center.

2.3. application layer (tailings dam safety monitoring center)
The application layer was composed by computer hardware and a series of application software. The software system used B/S architecture, using SQL Server database as the data storage warehouse, developed the data processing, analysis and publishing module of the software platform, obtained the monitoring information from the corresponding nodes, completed a series of basic functions like monitoring data analysis, data processing and storage, data query and statistics, process curve and chart drawing and monitoring information web publishing, integrated with geographic information system and decision-support expert system, make an intelligent and networking safety monitoring system of tailings dam.

3. Hardware system design
The hardware circuit design of the system including the hardware circuit design of sensor terminal node, router node and coordinator node. Because the tailings dam safety online monitoring includes internal displacement, surface displacement, saturation line, dry beach length, reservoir water level, rainfall, seepage and other safety factors, need to adopt different forms of sensor signals, such as vibrating string type osmometer, voltage displacement meter, GNSS receiver, the ultrasonic water level gauge, weir meter gauge, etc.. The signals of these sensors are analog and digital, and some sensors, such as vibrating string gauges, need to exert external excitation signals. The signal interface unit converts the analog signals produced by the sensors into voltage signals by sampling, amplifying and filtering, and then connects to the A/D input of the CC2630. Digital sensor interface includes RS485 half duplex digital serial bus, RS232 duplex digital serial bus, SPI three wire serial bus, etc.. The digital sensor is connected to the digital I/O interface through the CC2630 bus interface circuit.

The design of the sensor terminal node structure is shown in Figure 2.

![Figure 2. Structural design of hardware of sensor node](image)

The hardware structure design of the network coordinator node is shown in Figure 3. It mainly includes 3G/4G module, CC2630 chip module, RS232 interface conversion circuit and power management circuit. The coordinator realizes the function of network and routing organization, and the sensor terminal node communicates with the external network through coordinator.
4. Software system design

4.1. Lower computer software
The design of the lower computer software includes the wireless sensor network data acquisition, network organization, data upload, instruction management, etc. After the network initialization, the system will distribute network address for each sensor terminal node in advance, terminal nodes work by the self-starting mode, when the network is initializing, the terminal nodes will call the default function to find the network, load the PAN network successfully by loading, and send the address to the coordinator; After receiving the instructions sent by the coordinator, the terminal node analyzes the instructions and collects the data, and returns the collected data to the coordinator node. After the initialization of the network, the router node receives the data and forwards the data by querying the routing table. As the center of the whole wireless sensor network, the coordinator node not only in addition to network establishment, management and maintenance, but also connect with the 3G/4G module through the RS232 interface circuit, access the collected monitoring data to the public network, communicating with the host computer.

4.2. Host computer software
The host computer software was designed based on Windows Server operating system and SQL Server database system, online real-time monitoring and multi thread programming are adopted, integrated the safety monitoring system of with the geographic information system and decision support expert system, developed the tailings online monitoring software platform, main functions included port monitoring, data receiving, data processing, data storage and processing the client connection requests. The software platform structure of the safety monitoring system of tailings dam is shown in Figure 4, including the following 3 main functional modules:

(1) Data management module. The data receiving and processing program is written using the visual programming tools Visual Basic and Socket technology, can monitor the server communication port, capture the data sent from the terminal nodes by 3G/4G network module, analysis in accordance

**Figure 3.** Structural design of hardware of coordinator node

**Figure 4.** Software structure of online monitoring system for safety of tailings dam
with the custom data frame protocol and save it to the database, to achieve real-time monitoring data reception, data analysis, data storage, data processing and other functions.

(2) Remote connection management module. By requesting the connection of remote clients, the functions of monitoring data transmission, data real-time display, data query and hydrograph drawing, data network publishing and remote parameter setting are realized. The module can provide real-time monitoring, data browsing, historical data query and generate data reports for mining users.

(3) System management module. The module integrates system login, password settings, authority management, system maintenance, system settings and many other management functions.

5. Engineering application

At present, the on-line safety monitoring system of tailings dam based on Internet of things has been applied in a tailings dam of Dexing copper mine, China. The project is based on the IoT technology, integrated the Zigbee function module in the osmometer, displacement meter, water level meter and other types of monitoring sensors, an intelligent wireless sensor network has been formed, which covers the key points of safe operation of the tailings dam, and has the advantages of Ad Hoc network, high flexibility and easy construction.

The monitoring system consists of 6 kinds of monitoring items, 53 sensor terminal nodes, 12 router nodes and 1 network coordinator node. Based on the Internet of things, the sensor node configuration of the safety monitoring system of tailings dam is shown in table 1. The sensor terminal node is a micro embedded system with data acquisition and transmission functions. It is designed for low power consumption and powered by small solar cells. The sensor terminal node layout in the key areas of safe operation of tailings dam according to the engineering design, the terminal nodes constitute wireless sensor network through self-organizing way, data collected by the sensor terminal node transmitted to the network coordinator node through the router node and then transferred to the tailings safety monitoring center through the 3G/4G wireless network module integrated in the coordinator node, on the monitoring software platform in the tailings dam safety monitoring center, data processing, data analysis, data storage and remote publication are carried out, online users can obtain real-time monitoring data, historical data, drawing hydrographs, query data report, combined with remote decision support expert system, can also be further access to the safe operation of the tailing pond analysis report, It strongly supported the fine, intelligent and safe management of tailings dam.

| Monitoring item          | Sensor terminal node type | Sensor signal form | Number of sensor nodes | Router node type | Number of router nodes |
|--------------------------|---------------------------|-------------------|------------------------|-----------------|-----------------------|
| surface displacement monitoring | GNSS receiver | digital signal (RS232) | 16 | displacement router | 3 |
| Internal displacement monitoring | in-place inclinometer | voltage | 20 | displacement router | 4 |
| saturation line monitoring | osmometer | vibrating string | 12 | interstitial flow router | 2 |
| water level monitoring | Ultrasonic | current | 1 | water level router | 1 |
| seepage flow monitoring | measuring weir | vibrating string | 3 | water level router | 1 |
| rainfall monitoring | pluviometer | digital pulse | 1 | rainfall router | 1 |

When the monitoring data of tailings dam changes, monitoring system can quickly and accurately capture the abnormal signal, and sent it to software analysis module as an abnormal event to identify if
it was the valid data, then generate the corresponding diagnostic results in real-time, as shown in Figure 5. The diagnostic results can tell the tailings dam safety manager where the hidden danger located and how to deal with it, the system can also generate a report, record the current exception alarm event information, as the basis of risk management.

![Figure 5. Seepage analysis and safety diagnosis of tailings dam](image)

6. Conclusion
The system improved information acquisition and transmission mode distinguish from the traditional monitoring, realized the key operation parameters such as tailings dam deformation, seepage, water level, rainfall monitored, collected and controlled in all-weather and real-time, compared with the traditional monitoring methods, this system has the following 4 characteristic:

(1) The system fully adopted the intelligent, high flexibility, low power consumption and other advantages of IoT technology, combined the ZigBee wireless sensor network with 3G/4G wireless network to achieve the highly reliable remote data transmission, reduced the monitoring system construction cost, enhanced the reliability and stability of the system under extreme conditions;

(2) A software platform for safety monitoring of tailings dam based on Internet of things has been developed, which changed the traditional mode of information collection and transmission, and realized the digitalization and micro power consumption of the monitoring system;

(3) Through the integration of geographic information system, the visualization of the safety monitoring data of the tailings dam is realized in the geographical space, which is convenient for rapid warning and dispatching command;

(4) The expert decision support system has been integrated so that the hidden trouble of the tailings dam can be well controlled, and the intelligent, networking and fine management of the tailings dam safety have been realized.

However, the research on the tailings dam safety parameter threshold, the emergency command and decision still need to be carried out.

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