Research and application of key technologies for dam safety monitoring based on LoRa

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Abstract. Aiming at the problems of high power consumption, weak scalability and short wireless transmission distance of dam safety monitoring system, the key technology of dam safety monitoring based on Lora is proposed. An intelligent monitoring terminal is designed based on ARM LPC1788 and Lora wireless communication module. The low-power relay mode with Lora and 4G transmission function is adopted, and the active loop calling process and threshold trigger early warning process are designed. The platform software automatically receives data to realize the intelligent collection, analysis and early warning of dam multi factor safety data. The engineering application effect is good.

1. Introduction
In the 1990s, China began to put into operation the reservoir and dam safety monitoring automation system. With the development of the economy and society, the relevant departments also deeply understand that reservoir and dam safety monitoring is an important factor that directly affects the function and role of water conservancy projects. Therefore, many reservoir dams have been reinforced and upgraded in recent years. Automatic monitoring of reservoir and dam safety refers to the installation of corresponding observation instruments in the reservoir and dam, and the automatic monitoring system is used to carry out on-site measurements and then obtain relevant data to judge and analyze the changes in the dam structure[1]. The research investigation found that the automated monitoring system has some problems: ① high cost of wiring, high power consumption and weak scalability; ② unattended remote measurement points; ③ corridor monitoring equipment in a complex and confined environment, the traditional wireless transmission distance is short, signal penetration is not strong, the system data operation is not stable.

LoRa has the advantages of long-distance transmission, strong penetration ability, strong anti-interference ability and ultra-low electric current consumption[2]. In this paper, we propose a technical method of intelligent safety monitoring system based on LoRa to achieve intelligent monitoring of reservoir and dam safety, stable and efficient data transmission, and help managers make accurate and fast disaster warning forecasts.

2. Key technology
According to the layering technology of IoT[3], the overall architecture of the reservoir and dam intelligent safety monitoring system is divided into sensing layer, transmission layer, platform layer and application layer. It consists of an intelligent monitoring terminal with integrated LoRa module, a low-power relay gateway with LoRa and 4G transparent transmissions, a cloud platform and a PC terminal.
2.1. Intelligent monitoring terminal

LoRa belongs to LPWAN communication technology[4], which is based on ultra-long-range low-power data transmission technology below 1 GHz (LoRa for short). There are several main features: ① long range: the communication distance can reach up to 20km; ② low power consumption: the battery life can reach 5 to 10 years; ③ low rate: the transmission rate is low, up to hundreds of kbps.

The wireless module adopts SX1278 device, using high spreading factor to transmit small capacity data out through a wide range of radio spectrum. It mainly operates in the free frequency band from 137433 to 525433 MHz, including 433 MHz, and the reception sensitivity can reach -148 dbm. The coverage can reach 15 km in open areas and more than 3 KM between buildings.

The intelligent monitoring terminal optimally integrates sensors, collectors, LoRa wireless communication module and power supply system, which is mainly responsible for the data acquisition of each monitoring station at the reservoir and dam site, and the hardware structure is shown in figure 1. Except for video surveillance, which is powered by utility power, all others are powered by lithium batteries. The MCU uses ARM LPC1788 processor with LoRa communication module. LPC1788 is a microcontroller with various advanced communication, high quality image display, and high integration. The peripheral components include 512kB Flash memory, 4kB EEROM memory, 5 UARTs, 3 I2C interfaces, an 8-channel 12-bit ADC, up to 165 general-purpose I/O pins, etc. The LPC 1788 chip integrates a rich set of on-chip peripherals. The LPC 1788 chip integrates a wealth of on-chip peripherals, and by writing control words to the corresponding registers, internal resources can be flexibly configured to the GPIO ports, which can well meet the needs of multi-element monitoring systems.

![Figure 1. Structure diagram of intelligent monitoring terminal](image)

The intelligent monitoring terminal collects and controls data such as surface deformation, internal deformation, infiltration line (seepage pressure), seepage volume, rainfall, reservoir water level, flow, temperature, water temperature and video images in real time. As the reservoir and dam safety monitoring is mostly fixed monitoring, the measurement frequency requirements are not very high, in order to achieve the goal of maximizing power saving usage time, the intelligent monitoring terminal adopts the working mode of regular measurement self-reporting by default. With 14.4V/19000mAh disposable lithium battery power supply, it can run stably for 1 year without external power supply,
which can fully ensure the smooth completion of the measurement and reporting work during the rainy season and flood season. However, when an unexpected event occurs, the terminal enters the working state for data collection, which is gathered to the LoRa relay gateway through LoRa wireless transmission and stored in the EEROM in the form of telegrams.

2.2. Smart Gateway

The reservoir dam monitoring points are scattered and large in number. In order to improve the stability of the system, the automated monitoring system needs lower power consumption and larger concurrent transmission volume to solve the problems of large coverage radius and difficult network construction in complex or field environments. In this paper, the RG-IBS6120(E)[5] of Ruijie Network is selected as the LoRa relay gateway, which is a low-power base station based on LoRa wide-area IoT communication for the whole bank scenario. And it supports the standard LoRaWAN protocol[6], which is fully compatible with LoRa wireless communication module.

RG-IBS6120(E) relay gateway mainly has several important features: long distance coverage, multi-terminal access, high concurrency, secure network, RF control, etc. It can support working in 470MHz~510MHz band and also support 4G transmission uplink mode.

RG-IBS6120(E) low-power gateway uses a star transmission structure. It adopts frequency hopping mechanism for different intelligent monitoring terminals, detects RF environment for adaptive algorithm, and selects different communication channels. The number of optional channels is up to 320 and the working frequency is from 470 to 510MHz. In addition, it is responsible for command issuance, data reception and upload, system detection and management, etc. It receives data uploaded by LoRa monitoring terminals in the region through the downlink, uploads the data to the reservoir and dam safety monitoring cloud platform through the uplink to 4G network, and sends acquisition and control commands to any LoRa monitoring terminal.

![Flow chart of active cycle call test](image-url)

Figure 2. Flow chart of active cycle call test
2.3. Active loop calling mode
The active cyclic call test working mode is to set each monitoring terminal with a fixed station number, and the RG-IBS6120(E) sends a call test command, that is, a wake-up signal. The intelligent terminal enters the working mode in response to the command and sends the collected data to the gateway according to the terminal serial number. After the gateway successfully receives the data, it sends a hibernation signal to the terminal. For example, if 16 stations send real-time data at 8:00 a.m. according to the serial number of terminals, the flow chart is shown in figure 2.

2.4. Threshold triggering mode
This mode is mainly applied in key monitoring areas to facilitate early warning and forecasting. The intelligent monitoring terminal is in the real-time listening state and the LoRa module is in the idle state. When one of the multiple listening data mutates beyond a preset threshold, the intelligent terminal immediately activates the communication module and transmits this mutated data to the remote cloud platform via LoRa and 4G WAN.

![Sample Diagram](image-url)

Figure 3. Threshold trigger work flow diagram

Figure 3 takes the temperature in environmental quantity monitoring as an example. The intelligent terminal monitors whether the ambient temperature exceeds the threshold value, and continues to judge whether the threshold value exceeds the plus reporting period. If it exceeds, the data is sent through the LoRa communication module. The data transmission adopts MODBUS protocol and parses the command through RG-IBS6120(E) relay gateway. RG-IBS6120(E) sends real-time monitoring commands downstream, and the corresponding monitoring terminal responds immediately. And it sends warning commands upstream, and transmits them to the cloud platform through 4G network to remind staff to take measures in time.

3. Engineering application
Conventional monitoring of reservoir dams is installed with monitoring instruments ranging from tens to hundreds, and the measurement points are distributed over a dozen to tens of kilometers[7]. In order to verify the stability and feasibility of the system, the ambient temperature in the environmental quantity monitoring is selected in this paper, and the monitoring points are distributed in three places, the arch dam base, the diversion cave and the power plant house. The data stability of different measurement points and the continuity of real-time data in 2019 are analyzed.

3.1. Data stability of different measurement points
The temperature comparison experiments were conducted at the base of the arch dam, at the entrance of the diversion cavern and outside the power plant room, respectively, from 10:00 to 11:00 a.m. on June
18, 2019. The experimental results are shown in Table 1. The received temperature of the three measurement points is consistent with the sent temperature, the number of received data entries is consistent with the sent entries, and the data reception completion rate is 100% in all cases, which indicates that the system has high data stability.

| Location | Base of arch dam | Diversion cave | Power plant house |
|----------|------------------|----------------|-------------------|
| Measuring point temperature value(℃) | 36.50 | 32.00 | 32.00 |
| Received temperature value(℃) | 36.50 | 32.00 | 32.00 |
| Number of data sent | 1000 | 1000 | 1000 |
| Number of received data | 1000 | 1000 | 1000 |
| Completion rate | 100% | 100% | 100% |

### 3.2. Continuity of annual data
This experiment counted the real-time temperature values of a dam in 2019 to verify the feasibility of the system. As can be seen from Table 2, the intelligent monitoring system is able to continuously reflect the monitoring data in real time. The highest annual temperature occurs in July to August with a temperature of 39℃. The annual minimum temperature occurs in January, with a minimum temperature of 0℃. And the annual average temperature is about 19.5℃, which is in line with the temperature variation of this reservoir area.

| Result | The minimum temperature | The maximum temperature |
|--------|-------------------------|-------------------------|
| Maximum value | Air temperature (℃) 28.0 | 39.0 |
| Date | 2019-06-20 | 2019-08-12 |
| Minimum value | Air temperature (℃) 0.0 | 1.0 |
| Date | 2019-01-01 | 2019-01-01 |
| Current value (2019/12/31) | Air temperature (℃) 3.0 | 11.0 |
| Annual change (℃) | 3.0 | 9.0 |

### 3.3. Analysis of the temperature monitoring data of dam concrete
Typical temperature time series curves as shown in Figure 4. From the analysis of concrete temperature monitoring results and temperature time series curve, it can be seen that the annual concrete temperature change is stable, and the concrete temperature change lags behind the air temperature and water temperature. The deeper the water is, the longer the lag time is. The variation of surface concrete temperature is larger than that of air temperature, and the variation of deep concrete temperature is smaller than that of temperature and water temperature. For the three thermometers installed on the same section, the temperature of the upstream side is lower than that of the middle part, and the temperature of the middle part is lower than that of the downstream side. The change of concrete temperature is positively related to the change of real-time air temperature. In general, the temperature tends to change periodically, and there is no obvious abnormality. The analysis results are consistent with the actual, and the data is reliable.
Figure 4. Temperature monitoring data of dam concrete

4. Conclusion
In the context of "Internet +", "artificial intelligence" and "5G" era, reservoir and dam safety monitoring should also adapt to the new normal. This paper introduces a new LoRa network technology with long-distance, low-power and massive access. This technology is flexible in site selection and can cover the underground for a long distance, which is very suitable for the special characteristics of reservoir dam safety monitoring. The combination of intelligent monitoring terminal, low-power relay gateway and cloud platform can improve the stability of data transmission and the feasibility of the system, which has good application value.

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