Landslide Monitoring and Early Warning System based on Edge Computing

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Abstract. With the advancement of modern sensing technology and network communication, the geological disaster monitoring and early warning technology is changing toward intelligence, continuity, and real-time monitoring. The most effective way to improve real-time monitoring and early warning is to conduct front-end analysis in the field of geological disasters. With the application of the Internet of Things technology in geological disasters, field data collection and field-level data strategies belong to the edge computing gateway for execution. According to the latest research trend of landslide on-site monitoring and early warning, edge computing gateways usually use thresholds for monitoring and early warning. On the basis of the empirical model of simple statistics or the theoretical model of landslide deformation early warning, key early warning indicators and weights are proposed to judge the stage of landslide evolution or disaster level. This study starts with a comprehensive analysis of the temporal and spatial evolution of the surface deformation area in the field of geological disaster monitoring. Then, an edge computing smart gateway is designed on the basis of the Linux operating system. The Long Range Radio field wireless sensor network is used to develop an automated monitoring system for slopes of displacement monitoring points, rainfall, and soil moisture content-inducing factors. Subsequently, the effective methods of obtaining multilevel topographic data of slopes are investigated using field information, such as the velocity and acceleration of surface displacement data. The slope multielement trigger modeling method with multiple induced element coupling modes is explored to realize the front-end edge computing strategy method of slope monitoring and early warning. The analysis results can be sent to high-level data analysis servers, such as the software deployed on the Local Area Network and cloud servers of the relevant department for secondary use. This research overcomes the problems of regular collection of existing on-site monitoring instruments, loss of catastrophic information, and low effective data rate. Compared with traditional working modes, such as uploading the original monitoring data to a server for data extraction and analysis and then feedback to control the field equipment, using front-end edge computing is more efficient in realizing the first data processing utilization and adaptive monitoring processing. It can also provide more effective and reliable data for disaster monitoring and early warning. In conclusion, this research is of great significance in effectively capturing the laws of early evolution, improving real-time early warning capabilities, and promoting the industrialization of national geological disaster monitoring and early warning technology and equipment.
1. Introduction

For a long time, the monitoring of geological hazards in China has been based on mass monitoring and prevention, supplemented by professional monitoring. As monitoring data collection and transmission methods are mostly backward, problems exist such as untimely information acquisition, unstable transmission network, and insufficient coverage. Specifically, when geological disasters occur, a risk of damage to the ground transmission network may occur, which makes the monitoring points scattered around the geological disasters unable to transmit monitoring data in a timely and effective manner, which can directly affect the monitoring and early warning of geological disasters. Therefore, a single ground transmission network and a point-to-point transmission method cannot meet the needs of the rapid early warning of geological disasters and emergency response to sudden disasters. Establishing a safe, stable, and an efficient real-time transmission network of monitoring information is an important part of the current geological hazard monitoring and early warning work.

The dynamic information transmission network is the key technical support for the development of intelligent, scientific, real-time standardization and visualization of geological disaster monitoring and early warning technology. The network transmission layer serves as a bridge connecting on-site intelligent sensing and early warning information platforms. GPRS, 4G network, Beidou short message, and other communication technologies have been gradually promoted in the field of geological disasters, with the rapid development of network information transmission technology. However, the characteristics and applicability of different communication networks vary. At present, the geological disaster monitoring information network mainly uses a combination of multiple communication methods: supporting GPRS, CDMA, WCDMA, EVDO, LTE, and Narrowband-Internet of Things (NB-IoT) as the main transmission channels, whereas Beidou, satellite, PSTN, ultrashort wave, microwave, ZigBee, Long Range Radio (LoRa), and other communication methods are optional.

In recent years, automatic monitoring and early warning technologies for landslide geological disasters at home and abroad have been rapidly developed, and they have become an important technical support for the research breakthroughs in the cause mechanism of landslide geological disasters and monitoring and early warning. The evolution process of landslide geological disasters has a certain degree of concealment and suddenness. Existing automatic monitoring and early warning technologies for landslide geological disasters have insufficient research on intelligent perception, multi-information fusion, early warning theory, and instability criteria in the catastrophic process, all of which belong to the worldwide problem of “difficulty in monitoring and early warning.” Existing technologies for the automatic monitoring and early warning of landslide geological hazards have insufficient research on the intelligent perception of the catastrophic process, multi-information fusion, early warning theory, and instability criteria, all of which still belong to the worldwide problem of “difficulty in monitoring and early warning.” In view of the urgent needs and technical bottlenecks of intelligent monitoring and early warning of landslides in China’s complex mountainous environment, studying the automatic and intelligent monitoring and early warning equipment of the landslide disaster process with the free combination of multiple sensors is urgent.

2. System design

The hardware design of the intelligent monitoring system for geological disasters is shown in Figure 1. The intelligent converged transmission gateway uses ARM chip as the core processor and is equipped with multiple communication interfaces, such as UART, USB, and SDIO. Peripheral modules support remote communication methods, such as Beidou, 4G, and NB-IoT. The core processor establishes the control of multiple transmission modes and the switching connection of multiple transmission modules. The gateway collects data from the displacement sensor node through the wireless connection of LoRa and transmits the data to the Internet of Things (IoT) server remotely after the primary processing of the data. The intelligent converged transmission gateway supports online upgrades or on-site program upgrades via WiFi.
2.1. Circuit design
The intelligent converged transmission gateway uses the chip MCIMX6Y2 as the CPU main controller. The chip uses the ARM Cortex-A7 core, 800 MHz main frequency, external expansion DDR512MB, and an external eMMC memory chip with a storage capacity of 8 GB. The main controller drives the LoRa communication module through the UART serial port and controls the LoRa transmission mode through M0 and M1. The LoRa module communicates with the collection node wirelessly according to the transmission protocol. In terms of long-distance transmission, the main controller drives the 4G module through the USB interface or drives the NB-IoT and Beidou short message transmission through the UART for remote data transmission.

2.2. Multimode converged transmission
The characteristics and applicability of commonly used transmission methods for geological disaster monitoring equipment communication, such as 4G, NB-IoT, and LoRa, are presented in Table 1. Through the analysis and comparison of the characteristics and advantages of multiple communication technologies, such as 4G, NB-IoT, LoRa, and Beidou satellite communications, the intelligent fusion transmission gateway proposes a way of fusion of remote transmission and local wireless network, according to the characteristics of different field environments of geological disasters. Compatible with the conversion among different network protocols, the interconnection of WAN and LAN is realized, and the best technical solution for terrestrial communication gateways is proposed.
Table 1. Comparison of the characteristics and applicability of common transmission

| Transfer method    | Transmission mode                  | Monitoring suitability                                                                 |
|--------------------|------------------------------------|--------------------------------------------------------------------------------------------|
| GPRS               | 56~115Kbps, data stream.           | Remote and mountainous areas have poor signal coverage and unstable transmission             |
| CDMA               | 56~115Kbps, data stream.           | Remote and mountainous areas have poor signal coverage and unstable transmission             |
| 3G, 4G             | 144Kbps~100Mbps, data Stream.      | Remote and mountainous areas have poor signal coverage and unstable transmission             |
| Beidou satellite   | Short message.                     | Stable, wide signal coverage                                                                 |
| NB-IoT             | <100kbps, multiplexing of existing cellular base stations. | Remote and mountainous areas have poor signal coverage and unstable transmission             |
| LoRa               | 0.3-50kbps, independent network construction. | Limited transmission distance, private ownership, good scalability                           |

2.3. Software programming
(1) Host control program
To improve the reliability and environmental adaptability of monitoring information transmission, the multimode converged transmission gateway software adopts the design of multi-communication mode switching function, and the host data flow control diagram is illustrated in Figure 3. The standby sleep mode is adopted to reduce the energy consumption of field installation and application and to ensure the long-term safe operation of the smart gateway as a whole. Through the single communication mode control subroutine, transmission modes, such as LoRa, 4G, Beidou, NB-IoT, and other methods, are completed. The fusion transmission function is completed through functional designs, such as adaptive mode switching control program design and signal strength analysis. According to environmental conditions, network signals, equipment energy consumption, and other conditions, the device performs adaptive multimode complementary backup. In this way, the normal operation of the multi-communication mode switching function is ensured, and the data backup channel is selected at the same time to ensure that the data are not lost.
Figure 3. Host data flow control diagram

(2) LoRa transmission subroutine
In the design of the LoRa transmission subroutine, when the set data collection time is reached or a wake-up signal is received, the intelligent transmission gateway turns on the LoRa module through the wake-up command. The LoRa module collects sensor data from each LoRa terminal node and completes data sorting and storage. It continues to judge whether the data transmission of all the LoRa nodes in the network is completed, if not, it continues to wait. Until all the data transmission is completed, the effective sensor data of all communication nodes are stored in the memory. Finally, they are packaged and sent to the server through the remote transmission module. After sending the data, the LoRa module enters the sleep mode again and waits for the next LoRa data transmission.
3. Multiparameter intelligent trigger algorithm

By summarizing the disaster-inducing factors and disaster-causing conditions of slope displacement and deformation in different environments, a multiparameter linkage triggering intelligent superposition algorithm is designed. On the basis of the hardware design of the smart gateway, the Linux operating system is embedded. In simulating different application scenarios, the intelligent overlay trigger monitoring algorithm based on multifactor coupling uses parameters such as multipoint displacement, rainfall, and soil moisture content, and starts encrypted collection according to the initial judgment conditions and threshold settings. In this way, the trend of data changes during the catastrophic process is fully captured, and the effective acquisition of on-site data is guaranteed. The scene application environment of the simulated landslide disaster is illustrated in Figure 5.
3.1. Multiparameter trigger intelligent superposition algorithm

By summarizing the disaster-inducing factors and disaster-causing conditions of slope displacement and deformation under different environments, this study selects parameters such as rainfall, soil moisture content, rope displacement, and deformation speed, and designs a superimposed monitoring model on the basis of multifactor coupling. The algorithm model design includes three parts: initial judgment triggered by encryption, multifactor superimposition effect, and the highest level of encryption acquisition. In the model: Rain is the rainfall; Rain_F is the rainfall threshold; time domain reflectometry (TDR) is the soil moisture content; TDR_F is the soil moisture content threshold; S is the displacement value of the rope displacement sensor; S_F is the displacement threshold of the rope displacement sensor; V_t is the displacement and deformation speed of the rope displacement sensor; V_F is the displacement and deformation speed threshold of the rope displacement sensor; A is the displacement acceleration of the rope displacement sensor; A_f is the acceleration threshold of the rope displacement sensor; Sample represents the sampling period.

(1) Initial judgment triggered by encryption
Rain > Rain_F
TDR > TDR_F
S > S_F
V_t > 0
Sample = Sample/2

In the algorithm model, four initial judgment conditions for encrypted collection are designed. When rainfall, soil moisture content, and displacement slip are greater than the corresponding threshold and the displacement slip speed changes, encrypted collection begins. The sampling frequency increases, and the trend of data changes during the acquisition process is fully captured. The displacement sliding speed change has priority, and no threshold is set. As long as the displacement speed changes, the sampling frequency will be increased immediately.
(2) Multifactor superimposition effect
Rain > Rain_F AND S > S_F
TDR > TDR_F AND S > S_F
Rain > Rain_F AND TDR > TDR_F
V_t > V_F
A > 0
Sample=Sample/4

The algorithm model has designed five application scenarios for the multifactor superimposition effect, and through the two-by-two combination, the simulation of the multifactor multi-superposition of the model is increased. For example, in the case of continuous rainfall, the amount of displacement slip continues to increase, and the sampling frequency is immediately doubled on the basis of the increase in frequency \((2 \times 2 = 4)\). Encrypted to 4 times the normal monitoring frequency to ensure the comprehensive judgment of multi-factor monitoring, to ensure the integrity of the monitoring process, and to avoid missing item monitoring in the process of increasing danger.

(3) Highest level of encryption acquisition
Rain > Rain_F AND V_t > V_F
A > A_f
Sample=Sample(MAX)

The highest level of encrypted collection sets two start conditions in the model design. One is that under the condition of continuous rainfall, the displacement and slippage continue to intensify. The other is the displacement and sliding acceleration continuous. The maximum collection frequency of the collector is set to accelerate the encrypted collection of the monitoring process in the deformation stage for ensuring that the monitoring data are complete and continuous. At the same time, combining different factors and setting the priority level realize the early warning of the slope displacement trend.

Table 2. Overlay trigger model and priority

| Model judgement factors | Encrypted monitoring mode | Priority |
|-------------------------|---------------------------|----------|
| 1 | Rain > Rain_F | Sample=Sample/2 | Elementary |
| 2 | TDR > TDR_F | | |
| 3 | S > S_F | | |
| 4 | V_t > V_F | | |
| 5 | Rain > Rain_F AND S > S_F | | |
| 6 | TDR > TDR_F AND S > S_F | | |
| 7 | Rain > Rain_F AND TDR > TDR_F | Sample=Sample/4 | Intermediate |
| 8 | V_t > V_F | | |
| 9 | A > 0 | | |
| 10 | Rain > Rain_F AND V_t > V_F | Sample=Sample(MAX)(100Hz)(10ms) | Advanced |
| 11 | A > A_f | | |
3.2. Trigger mode of slope displacement encrypted monitoring based on rainfall factor
Based on the slope deformation characteristics of rainstorm-causing factors and rainfall as the triggering condition of geological disaster monitoring, a rainfall-based slope surface displacement monitoring technology model is designed. This model scans and monitors the rainfall sensor every one second and uses every one hour as the data recording benchmark. During the scanning monitoring process, when the rainfall exceeds the predetermined threshold, that is, when Rain > Rain_F (set 0.1 mm), the counter is triggered. The data collection of rainfall and slope surface displacement is double encrypted, and real-time data are saved in the database. To ensure the test effect, the indoor test adopts 20 seconds as the data sampling period benchmark. In the case of no change in the displacement sensor (displacement is constant), the encrypted collection process is demonstrated by introducing a sudden rainfall signal. As displayed in Figure 6 (the red curve represents the change in rainfall, and the blue curve represents the change in the displacement of the rope displacement sensor).

![Figure 6. Encrypted collection data curve under rainfall disturbance](image)

Figure 6 illustrates that the system is in a working state with a data sampling period of 20 seconds when no one is simulating the rainfall. When the rainfall is disturbed, the sampling period of the system is continuously encrypted to ensure the continuity of data acquisition. When the rainfall disturbance is removed, the sampling period of the system quickly returns to 20 seconds. When the rainfall is added again to increase the rainfall disturbance, the system enters the encrypted sampling state again. It shows that the system has good dynamic performance and can adapt to changes in external conditions in time and take countermeasures.

3.3. Slope displacement encrypted monitoring trigger mode based on the water content of the sliding surface (water level) as the trigger condition
With reference to the characteristics of slope deformation caused by factors such as rainwater infiltration and reservoir water level rise, a slope surface deformation monitoring model based on the TDR test water level is designed, with soil moisture content and sliding surface water level as the monitoring trigger conditions.
This model scans the TDR sensor feedback information every one second and uses every one hour as the data recording benchmark. When the soil moisture content exceeds the predetermined threshold during the scanning and monitoring process, that is, TDR > TDR_F (set 30%), the counter is triggered. The encryption of TDR sensor information and slope surface displacement data collection is multiplied, and the real-time data are saved to the database.

To ensure the test effect, the indoor test adopts 20 seconds as the data sampling period benchmark. In the case of no change in the displacement sensor (displacement is constant), the encryption acquisition process is demonstrated by introducing a sudden change signal of soil moisture content. The laboratory uses buckets as the water level of the sliding surface and tests the water level of the sliding surface in different periods by lifting and lowering the TDR sensor. The specific data curve is shown in Figure 7 (the red curve represents the water level of the sliding surface measured by the TDR sensor, the blue curve represents the displacement change of the rope displacement sensor, and the yellow is the threshold line).

**Figure 7.** Encrypted data collection curve under the disturbance of soil moisture content

Figure 7 indicates that when the test water level is below the threshold set by the TDR sensor and the sensor is in a static state, the system is in an undisturbed state, and the system sampling period is 20 seconds. When the water volume of the bucket is continuously increased and the water volume measured by the TDR sensor exceeds the preset threshold, the system sampling period starts to be encrypted, which ensures the continuity of data acquisition. When the TDR sensor is lifted and the water level is lower than the sensor depth below the set threshold, the system sampling period quickly recovers to 20 seconds. When the TDR sensor is lowered and the water level disturbance is applied again, the system enters the encrypted sampling state again. After repeated tests, the dynamic performance of the system is verified.

4. Conclusion
(1) In this work, an embedded technology is used to complete the development of a convergent transmission intelligent gateway, which supports communication modes, such as LoRa, NB-IoT, 4G, and Beidou. According to the comparison of different transmission methods, a solution of fusion transmission of remote communication and local area network is proposed to ensure the effective transmission of data collected from geological disasters under different environmental conditions.
(2) The disaster-inducing factors and disaster-causing conditions of slope displacement and deformation under different environments are summarized. The embedded technology is used to develop a multiparameter joint triggering intelligent algorithm, and an intelligent superimposed triggering monitoring model is designed on the basis of multifactor coupling. This study commits to solving the lack of an effective capture of ground disaster monitoring data in different disaster processes and different spaces. It also provides a strong guarantee for the effective, comprehensive, reliable, and consistent acquisition of ground disaster monitoring information.

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