Outlook on the Application of "Beidou+5G" Fusion Technology in Slope Displacement Monitoring

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Abstract. Based on the analysis of the principles of BeiDou positioning and 5G positioning, this paper explores the "BeiDou+5G" fusion positioning technology. Based on the characteristics of slopes, the application of "Beidou+5G" fusion positioning technology in slope displacement positioning is elaborated, and a slope displacement monitoring system is constructed using this technology. Finally, the characteristics of the slope displacement monitoring system are explained and future development prospects are presented. This study solves the problem of accurate and reliable signal transmission for different slopes in complex wireless environments, and further improves the accuracy of slope displacement positioning. It improves and upgrades similar slope displacement monitoring systems, and has certain significance for monitoring other types of geological disasters.

Keywords: Beidou short message; Slope displacement monitoring; Beidou positioning; 5G; Fusion positioning

1 Introduction

Slope stability is one of the hot spots in civil engineering research. Due to the influence of slope structure, geological environment, typhoon rainstorm, earthquake, other engineering disturbances and other factors, the slope is prone to lose stability or deformation, which will lead to serious natural disasters and cause loss of personnel and property. Therefore, research on the survey, monitoring, protection and other aspects of slope disasters is of great significance. The country has always adhered to the principle of putting people at least and life first, and has done a good job in slope displacement prevention and management, as well as scientific research related to it, to promote sustainable social and economic development. Relevant departments have also issued documents related to slope monitoring and slope engineering, such as the announcement by the Ministry of Housing and Urban Rural Development in November 2013 on the release of the national standard "Technical Specifications for Building Slope Engineering", the announcement by the Ministry of Housing and Urban Rural Development in September 2019 on the release of the national standard "Construction Quality Acceptance Standards for Building Slope Engineering", and the notice by the National

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Mine Safety Supervision Bureau in August 2023 on the construction and networking of open-pit mine slope monitoring systems.

Due to the complexity of slope environment and the harmfulness of slopes, scholars have conducted research on the development characteristics of slope disasters, slope stability, slope monitoring, and factors related to slope disasters. Chen Xiaoxue (2008) summarized the current status of slope displacement monitoring; Liu Hongbo (2020) analyzed the development characteristics of highway slope collapse disaster bodies, such as slope type, slope, slope height, formation mechanism, etc; Wang Jianwei (2020) applied Beidou positioning technology to slope displacement monitoring and constructed a slope displacement monitoring system; Chen Siyu (2022) conducted research on the quality evaluation method of slope displacement measurement data to ensure the reliability and effectiveness of monitoring data; He Zhen (2021) analyzed the factors affecting slope stability and proposed corresponding prevention and control measures.

With the development of the social economy, slope problems are inevitably involved in the construction of roads, bridges, and other engineering projects. The mechanism of slope disasters is complex and variable. In the process of slope disaster prevention, it is necessary to timely discover slope hidden danger points, carry out corresponding protective engineering according to the characteristics of slope hidden danger points, and build a slope disaster monitoring system. Due to the fact that the Beidou Navigation and Positioning System is a self-developed global navigation and positioning system in China, which has the characteristics of high safety, high positioning accuracy, and wide coverage, it is widely used in slope displacement monitoring systems and other geological disaster monitoring. However, the wireless propagation environment in which the slope is located is complex, and some Beidou signals are obstructed, resulting in the inability to transmit monitoring data to the management backend. 5G has the characteristics of high bandwidth, low latency, and wide connectivity. More than 3.6 million base stations have been built, and 5G signal coverage is basically mature. The use of 5G to assist the Beidou system further enhances positioning accuracy and improves the timeliness and reliability of slope displacement monitoring data transmission. The article studies slope displacement monitoring technology from the perspective of "Beidou+5G", solves the reliability problem of slope displacement monitoring signal transmission, improves the accuracy of slope displacement monitoring, and expands its application field.

2 The Principle of Beidou+5G Fusion Positioning

2.1 Beidou Positioning Principle

The Beidou 2 or 3 satellite navigation and positioning system operates based on TOA estimation to determine the user's location. In theory, the spatial position (x, y, z) of the user observation station can be calculated using three Beidou-2 or 3 satellites. In practice, due to factors such as ionospheric refraction, tropospheric refraction, and clock errors, there is also a deviation between the satellite clock and the receiver clock. This error needs to be introduced as an unknown quantity into the equation system to construct at least four sets of equations in order to calculate the spatial position (x, y, z) of the user observation station, as shown in Figure 2 and Equation (1).

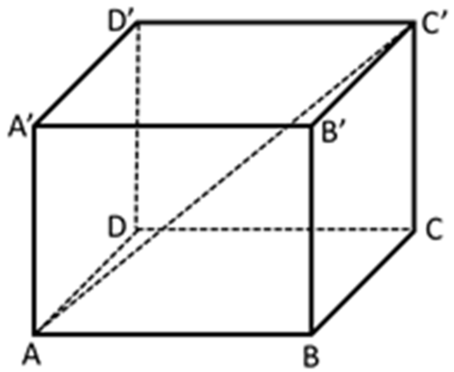

Fig. 1. Spatial three-dimensional geometric diagram

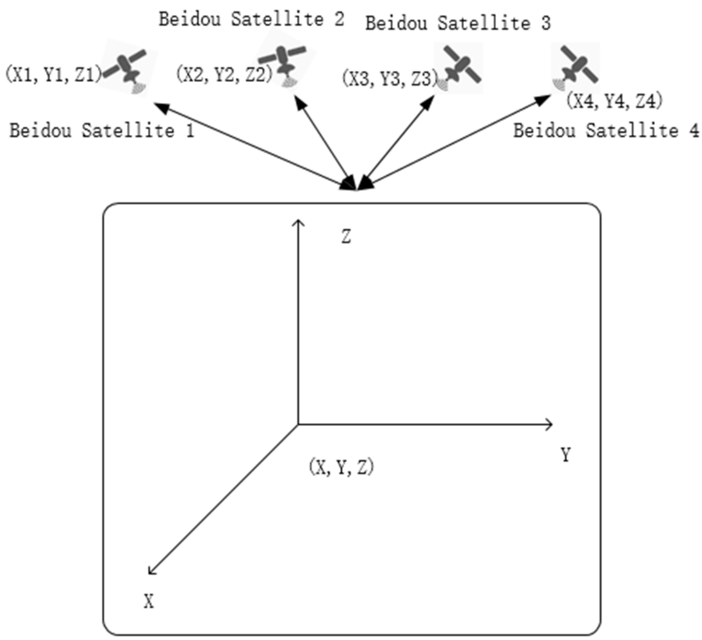

Fig. 2. Schematic diagram of RNSS satellite positioning principle

By using the Pythagorean theorem, the distance between two points A and C 'in space in Figure 1 can be calculated. If the three-dimensional coordinates of two points A and C' in space are A (x, y, z) and C '(x_1, y_1, z_1), then | AC' |=. If point A is the target positioning point, and C ', D', A ', and B' are the constellations of Beidou-3, representing satellite 1, satellite 2, satellite 3, and satellite 4 in Figure 2, with coordinates (x_i, y_i, z_i) (i=1, 2, 3, 4), the following equation system is construc

$$\begin{cases} \rho_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} - \delta \\ \rho_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2} - \delta \\ \rho_3 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2} - \delta \\ \rho_4 = \sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2} - \delta \end{cases} \tag{1}$$

Among them, (x_i, y_i, z_i) is the spatial coordinat *e* of the Beidou-3 satellite, and i is the observed satellite number; (x, y, z) is the spatial location of the user observation station; ρ i is the spatial pseudorange from the satellite to the receiver; Delta is the product of the error between the satellite's clock and the receiver's clock and the speed of light. By using the Newton iteration method to solve formula (1), the spatial position (x, y, z) of the user observation station can be obtained.

2.2 5G Positioning Principle

The R16 standard includes a series of positioning methods such as Enhanced Cell Identification (E-CID), Round Trip Time (RTT), Downlink Arrival Time Observation Difference (DL-TDOA), Uplink Arrival Time Observation Difference (UL-TDOA), and Uplink Arrival Angle (UL-AOA). DL-TDOA is the TDOA of the downlink PRS sent by two base stations measured by the terminal, using the hyperbolic principle to achieve positioning; UL-TDOA is a base station that measures the uplink TDOA, calculates the time difference between the terminal's uplink detection reference signal and different base stations, and uses the hyperbolic principle to achieve positioning [2].

UL-TDOA measures the time difference between signals sent by UE and reaching different base stations. It is greatly affected by UE transmission power in terms of coverage range, and has high requirements for network synchronization and timestamp technology. It is suitable for scenarios with specific requirements for UE energy consumption and network load. DL-TDOA measures the time difference between the signal sent by the base station and the UE, and then feeds back this time difference information to the network through the UE. It has a larger coverage range and stronger signal penetration ability, requiring the UE to have high-precision time measurement ability, suitable for scenarios that require larger coverage range and stronger penetration ability. According to the application scenario of slope displacement monitoring, the UL-TDOA method is proposed to be used for positioning.

The receiving terminal UE sends an SRS-Pos/SRS signal for uplink positioning. The base station measures the TDOA observation difference between the UE and the base station (including the reference base station) through the SRS-Pos/SRS signal, and reports it to the positioning solution platform. It uses the double differential positioning algorithm to obtain the UE position. As shown in Figure 3.

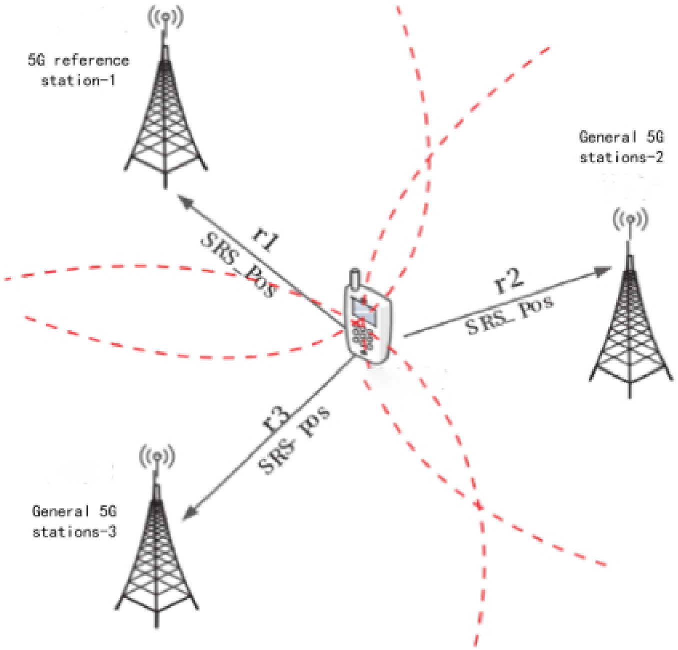

Fig. 3. Schematic diagram of UL-TDOA positioning principle[2]

Assuming base station 1 is a reference base station with coordinates (x_1, y_1) and terminal UE coordinates (x, y), if the signal arrival time between the receiving terminal and base station i is Δ t (i=1, 2, 3), then formula (2) and formula (3):

$$\begin{cases} r_2 - r_1 = c(\Delta t_2 - \Delta t_1) = d_{2,1} \\ r_3 - r_1 = c(\Delta t_3 - \Delta t_1) = d_{3,1} \end{cases} \tag{2}$$

$$\begin{cases} \sqrt{(x_2-x)^2+(y_2-y)^2} - \sqrt{(x_1-x)^2+(y_1-y)^2} = d_{2,1} \\ \sqrt{(x_3-x)^2+(y_3-y)^2} - \sqrt{(x_1-x)^2+(y_1-y)^2} = d_{3,1} \end{cases} \tag{3}$$

That is to say, then use CHAN algorithm, Taylor algorithm, etc. to solve the UE position.

2.3 Beidou+5G Fusion Positioning Principle [3]

GNSS is affected by factors such as ionospheric refraction, tropospheric refraction, clock errors, multipath effects, etc. during the positioning process, resulting in poor positioning accuracy and signal instability. The "5G+GNSS" will compensate for the shortcomings of global navigation satellite system positioning. The BeiDou satellite navigation and positioning system is a independently developed positioning technology in China. The BeiDou+5G fusion positioning can provide full coverage and high-precision positioning. As shown in Figure 4.

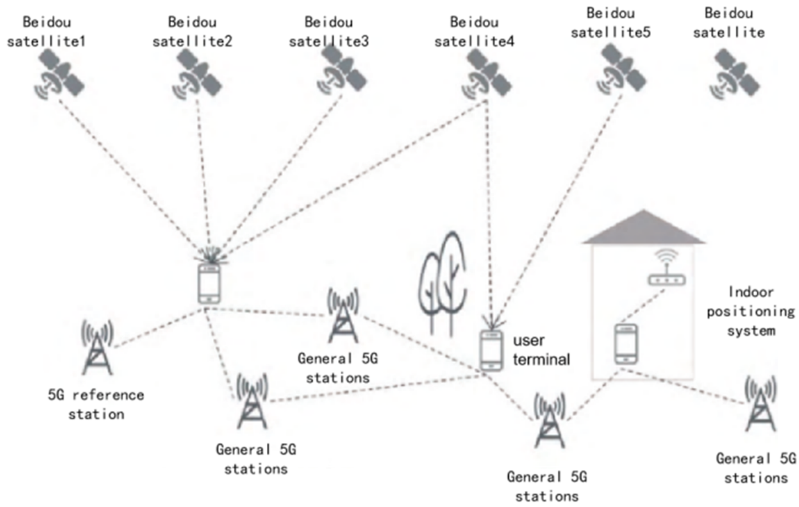

Fig. 4. Schematic diagram of Beidou+5G fusion positioning[1]

Assuming the coordinates of the positioning terminal are (x, y, z), the clock error variable is δ, and the coordinates of the Beidou satellite (Beidou 2 or Beidou 3) are (x_{z1}, y_{z1}, z_{z1}), (x_{z2}), y_{z2}, z_{z2}), …, (x_{zM}, y_{zM}, z_{zM}); 5G base station coordinates are (x_{b0}, y_{b0}, z_{b0}), (x_{b1}, y_{b1}, z_b1), …, (x_{bN}, y_{bN}, z_{bN}). Among them, (x_{b0}, y_{b0}, z_{b0}) is the reference base station coordinate, then the mathematical model of Beidou+5G fusion positioning is as follows formula (4).

$$\begin{cases} \rho_1 = \sqrt{(x_{z1}-x)^2+(y_{z1}-y)^2+(z_{z1}-z)^2}+\delta \\ \cdots \\ \rho_M = \sqrt{(x_{zM}-x)^2+(y_{zM}-y)^2+(z_{zM}-z)^2}+\delta \\ d_1 = \sqrt{(x_{b1}-x)^2+(y_{b1}-y)^2+(z_{b1}-z)^2}-\sqrt{(x_{b0}-x)^2+(y_{b0}-y)^2+(z_{b0}-z)^2} \\ \cdots \\ d_N = \sqrt{(x_{bN}-x)^2+(y_{bN}-y)^2+(z_{bN}-z)^2}-\sqrt{(x_{b0}-x)^2+(y_{b0}-y)^2+(z_{b0}-z)^2} \end{cases} \tag{4}$$

Use the Gauss Newton iterative algorithm in the least squares method to solve the above formula and determine the location of the positioning terminal.

3 Beidou+5G Fusion Positioning Slope Displacement

China has a mountainous, plateau, and hilly terrain, with uneven distribution of rainwater and complex geological conditions. Slope displacement often occurs due to earthquakes, rainwater, geological disasters, and other factors, and the impact is significant. Slope displacement monitoring is an important means to verify the effectiveness of slope geological hazard reinforcement, slope stability, and guide construction design. By using Beidou+5G fusion positioning technology, automatic monitoring of slope displacement is achieved, and the accuracy and breadth of slope displacement positioning are improved. Comprehensive analysis of satellite remote sensing image information, geological hazard risk point information provided by the Ministry of Land and Resources, and geological hazard risk points determined by geological hazard experts to locate slope displacement risk points, in preparation for the construction of subsequent slope displacement monitoring systems [4], as shown in Figure 5.

The Beidou+5G slope displacement monitoring and positioning system mainly consists of three parts: 5G base station network, time synchronization equipment, and Beidou+5G fusion positioning receiver. The 5G base station network consists of one reference base station and at least two ordinary base stations (depending on the 5G coverage range) [2]. If the positioning accuracy of Beidou is further improved, a Beidou enhancement system can also be constructed [5], as shown in Figure 7.

The "BeiDou+5G" positioning receiver obtains relevant positioning data, and the BeiDou receiver receives BeiDou satellite signals to obtain BeiDou satellite navigation messages (pseudorange, satellite coordinates, satellite clock deviation, various error parameters, etc.); The 5G receiver receives TDOA observation data (location coordinates, UL-TDOA time, etc.) from the 5G base station. According to section 1.3, the positioning terminal calculates the data of Beidou positioning and 5G positioning in the terminal to obtain location information (as shown in Figure 6). The positioning terminal can also transmit Beidou positioning and 5G positioning data to the integrated positioning service platform through the 5G communication network for data calculation (as shown in Figure 7), obtain terminal location information, and provide different positioning services for different terminals.

Fig. 5. Schematic diagram of slope displacement monitoring points

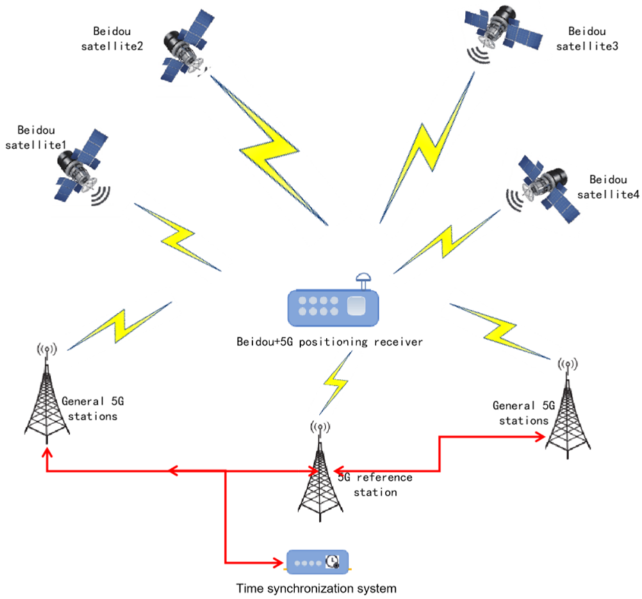

Fig. 6. Schematic diagram of the "Beidou+5G" slope displacement monitoring and positioning system

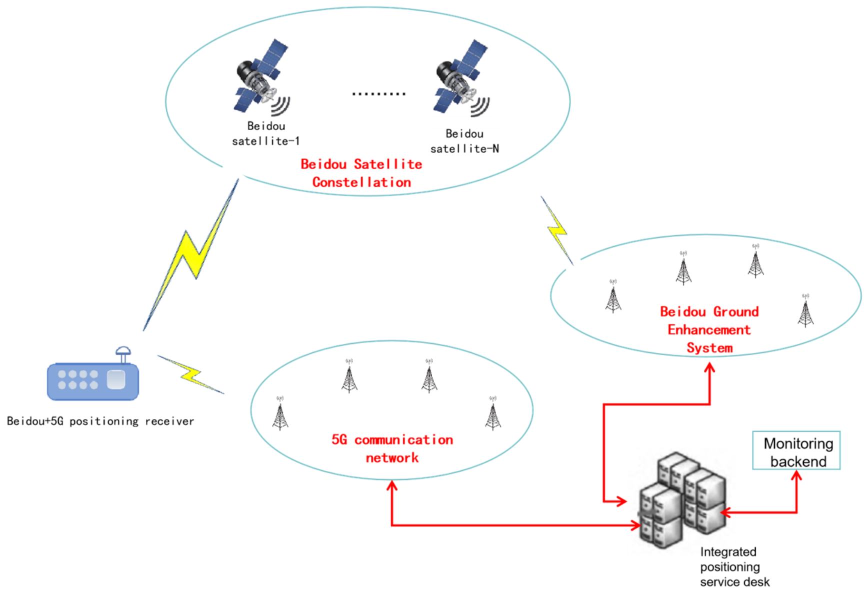

Fig. 7. Schematic diagram of the "Beidou+5G" slope displacement monitoring and positioning enhancement system

4 Construction of Slope Displacement Monitoring System

4.1 Building a Slope Displacement Monitoring System

The geographical environment in which the slope is located is characterized by complexity and diversity. Some are on the shoulders of highways, some are above the edges of villages, and some are on both sides of valley roads, making the wireless environment for the transmission of slope displacement positioning and monitoring signals more complex. In some places, the BeiDou signal is not strong enough to achieve positioning, while in some places, satellite signals are greatly affected by multipath effects. The BeiDou positioning accuracy is insufficient, and in some places, the 5G signal receiving positioning results is not strong enough, resulting in the inability to receive positioning information. Therefore, the construction of a slope displacement monitoring system cannot rely solely on the BeiDou short message communication system, nor can it rely solely on the 5G communication system for positioning data transmission. It is necessary to comprehensively use the BeiDou+5G fusion positioning technology to construct a slope displacement monitoring system, as shown in Figure 8.

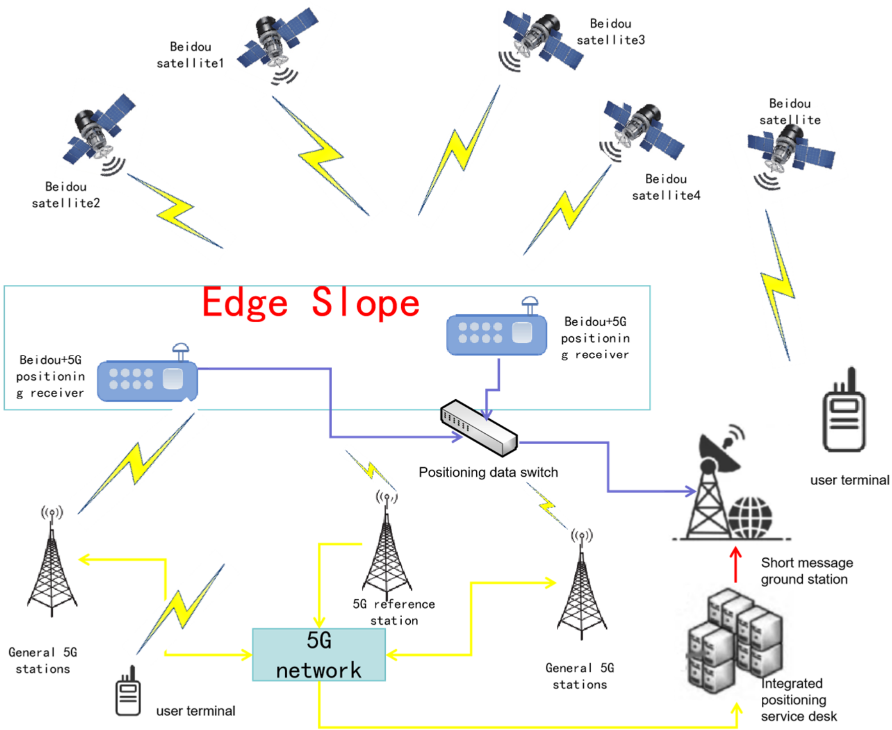

Fig. 8. Schematic diagram of slope displacement monitoring system

Determine the slope hazard points and levels through satellite remote sensing and other information data, and then design corresponding slope displacement monitoring systems based on the wireless propagation environment around the slope. Considering the complexity of the wireless propagation environment around the slope and the unknown wireless environment of the receiving and positioning data terminal, to ensure that the slope displacement monitoring data can be delivered to the receiving terminal in real-time and reliably in any environment, the "Beidou+5G" fusion positioning technology is used to construct the slope displacement monitoring system in Figure 8. Install a "Beidou+5G" receiver at the point of slope displacement disaster, receiving satellite signals from Beidou 2 and 3 as well as 5G signals. According to the principles in Section 1.3, calculate the position information of the slope. On the one hand, all positioning result data can be transmitted to the switch near the slope. The exchanged data can be directly delivered to the BeiDou Short Message Ground Center, or transmitted to the BeiDou Short Message Ground Center through 5G communication network and integrated positioning service platform. Then, it can be transmitted in real time to the slope displacement monitoring user terminal (BeiDou terminal) through BeiDou satellite; On the other hand, a 5G communication module is embedded in the positioning data switch, which directly transmits the slope displacement monitoring results in real-time to the slope displacement monitoring user terminal (5G terminal) through the 5G network.

4.2 Main Performance Analysis of Slope Displacement Monitoring System

The geological hazards caused by slope displacement are quite harmful and can cause significant losses to personnel and property. For example, in January 2024, a landslide in Zhenxiong, Yunnan poured into a village to bury houses, in April 2024, a road section in Mabian, Leshan, Sichuan hit a vehicle with rocks, resulting in 3 deaths and 1 injury, and in May 2024, the collapse of the Meida Expressway in Guangdong. The slope displacement monitoring system must be able to accurately and effectively deliver slope displacement monitoring information to the monitoring backend and surrounding users, reducing disaster losses. When constructing a slope displacement monitoring system, it is necessary to focus on the following system performance requirements.

(1) Slope displacement positioning accuracy: The monitoring system must have high-precision measurement capabilities and be able to accurately capture small displacement changes. Therefore, the "Beidou+5G" fusion positioning technology is adopted to improve the accuracy of slope displacement positioning.

(2) Real time and reliability of monitoring data: The system can provide real-time or near real-time monitoring data, and can accurately transmit monitoring data to timely detect abnormal slope behavior. Due to the transmission delay of BeiDou short message being about 0.5 seconds and 5G communication system being about 1 millisecond, and adapting to the complex wireless propagation environment around the slope, the BeiDou short message communication system and 5G communication system are used to transmit monitoring data, ensuring real-time and reliable monitoring.

(3) Monitoring data processing and storage capabilities: The monitoring system should have strong data processing capabilities and be able to quickly analyze and process a large amount of collected data. During system construction, ground equipment such as switches, ground data processing and storage were used to ensure rapid processing and long-term storage of monitoring data, ensuring data security.

(4) Automated remote monitoring: The system supports automated remote monitoring function, reduces manual intervention, improves monitoring efficiency and security, and allows management personnel to view monitoring data in real-time at different locations. 5G communication module and Beidou short message communication module have been installed on the corresponding equipment to ensure the automation and remote monitoring of the system.

4.3 Application Prospects of Slope Displacement Monitoring System

Slope types can be classified according to different criteria, such as genesis, formation lithology, rock structure, stability, height, etc. The main research object of this slope displacement monitoring system is soil slope, focusing on slope displacement positioning accuracy and slope displacement monitoring signal transmission. The slope displacement monitoring system built with the integrated positioning technology of Beidou navigation and positioning system and 5G communication system solves the complex wireless propagation problem around the slope well, and uses the Beidou 2 or 3 satellite signal system and 5G communication network for wireless transmission network disaster recovery backup, ensuring the effectiveness and reliability of wireless signal transmission around the slope. At the same time, because the slope displacement monitoring system adopts Beidou and 5G fusion positioning technology or Beidou + Beidou land-based enhancement system and 5G fusion positioning technology in positioning, 5G positioning assists the Beidou system to enhance positioning, improving the slope displacement positioning accuracy. If the monitoring system has high requirements for timeliness, reliability and positioning accuracy, the slope displacement monitoring system built with Beidou +5G fusion positioning technology will be widely used. Such as the following slope field.

1) Application of soil highway side slope displacement monitoring

With the rapid development of society and economy, roads are connected with money, and highways are the link between cities. The construction of highways is bound to encounter some geographical environments with complicated soil. Monitoring the displacement of highway side slopes can avoid the loss of human and money caused by traffic accidents caused by geological disasters.

This kind of soil road can be a general road, or a highway, etc., with the main characteristics of soft soil layer, more regional rain, large traffic flow, good 5G signal coverage, and a certain slope of the roadbed. When designing the slope displacement monitoring system, Beidou No. 2 or No. 3 system can be used for slope displacement positioning according to cost needs, and the slope displacement positioning results can be transmitted in real time through 5G communication network to build the Beidou positioning +5G signal transmission mode monitoring system to achieve effective monitoring, real-time and reliable transmission, and avoid excessive project construction costs.

However, due to the large highway traffic flow and different vehicle loads in this type of environment, minor vibration of the roadbed may be caused, leading to the problem of system monitoring false alarm. In monitoring data processing, it is necessary to conduct corresponding screening and eliminate "false" data to ensure the real and reliable monitoring results.

2) Mountain highway side slope displacement monitoring application

Some roads pass through the mountain col, and the side of the road is mostly soil slope with relatively large slope (such as the road in Sichuan and other mountainous areas). Under the influence of rain infiltration and earthquake, the slope stability deteriorates and serious geological disasters are induced. Meanwhile, the region has high forest coverage rate, small population distribution, imperfect 5G signal coverage and unstable Beidou signal. Therefore, when designing the slope displacement monitoring system, the "Beidou +5G" fusion technology can be used to achieve accurate positioning of slope displacement and reliable transmission of monitoring results, as shown in Figure 8. At the same time, 5G+ intelligent transportation is combined to achieve real-time warning of geological disaster risk. Once the slope displacement monitoring results are abnormal, the red light in front and rear of the risk slope is activated in real time, preventing passing vehicles from moving forward, avoiding major traffic accidents, and ensuring the safety of life and property.

3) Application of river side slope displacement monitoring

In the design of roads, due to the constraints of terrain, some roads have rivers on the side (such as mountainous roads in Tibet), which are prone to geological disasters caused by slope displacement induced by river scour in the rainy season. When designing the slope displacement monitoring system, appropriate monitoring systems can be selected according to the surrounding environment and cost requirements of the slope, such as Beidou positioning +5G transmission, "Beidou +5G" integration technology, etc. At the same time, the river flow monitoring system can also be added to the system. The slope displacement positioning results and river flow monitoring results are integrated together with 5G communication network, Beidou short message communication system, 5G communication + Beidou short message transmission to improve the efficiency of the monitoring system.

4) Village and house side slope displacement monitoring application

Due to the limitations of the living environment, some villages and residential houses are built in the soil layer with large slope slope, which is easy to induce large-scale slope displacement and serious natural disasters under the influence of earthquake, rain and human activities. When designing the slope displacement monitoring system, the "Beidou +5G" fusion technology (as shown in Figure 8) is applied to build the slope displacement monitoring system, and the application scenario of 5G massive Machine Type of Communication (mMTC) is combined. The early warning results will be communicated to the personnel near the slope to quickly leave the dangerous area through the 5G communication network in the form of voice broadcasting and short message mass sending, so as to ensure people's lives and financial safety.

Due to the scattered distribution of slope damage points and the complex surrounding environment of slope, on the one hand, a certain amount of slope displacement monitoring system needs to be constructed using Beidou +5G fusion technology, which increases the construction cost of the monitoring system. On the other hand, part of the slope is distributed in special areas such as expressways, and is affected by vibration such as cars, so the use of high-precision and high-sensitivity system may cause false alarm phenomenon. Based on this, in future applications, we can update technologies such as 6G technology, control costs, improve slope monitoring data processing algorithms, and eliminate false reporting. In addition, the system can also be applied to high-speed railway settlement deformation monitoring, pipeline geological disaster monitoring, environmental radiation monitoring and other fields.

5 Conclusion

Due to the positioning capabilities of both Beidou and 5G, 5G is used to assist Beidou in enhancing positioning accuracy. A slope displacement monitoring system is constructed by utilizing the wide coverage range of Beidou short message communication system and the short delay of 5G communication system. The system can timely detect abnormal slope behavior, provide real-time, effective, and reliable management data for management personnel, and provide early warning and management for slope disasters. By utilizing the "Beidou+5G" fusion technology, not only can slope displacement be located and monitored, but also the surrounding weather, rainfall, soil moisture content, etc. can be monitored. It can also monitor road settlement deformation, pipeline location disasters, etc. In the future, we will delve deeper into the integration technology of Beidou+5G to broaden its application scope and further enhance its application value.

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