Application of BDS/GPS Fusion Relative Positioning in Slope Deformation Monitoring

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ABSTRACT

Given the difficulties faced in real-time monitoring of slope deformation and the low degree of automation of the traditional monitoring methods, a BDS/GPS based geological deformation monitoring system was designed. This system uses carrier phase differential technology to achieve BDS/GPS high-precision positioning, transmits data through the NB-IoT wireless network, and transmits slope deformation monitoring data and environmental-based data to a cloud server, achieving automatic and real-time data collection and transmission. In order to study the function and accuracy of the BDS / GPS integrated system in deformation monitoring, experiments are designed to test the stability of the system and collected environmental factors. The feasibility of BDS / GPS in deformation monitoring is analyzed from the constellation distribution and satellite system. The test results show that long-term continuous observation is the prerequisite for obtaining high-precision positioning data. Under the same conditions, the BDS / GPS integrated system's measured accuracy is better than that of the BDS single system.

CCS CONCEPTS

•Hardware~Communication hardware, interfaces, and storage~Sensor devices and platforms

KEYWORDS

Beidou satellite, NB-IoT, deformation monitoring, geological disasters, Relative Positioning

1.Introduction

Recently, in the context of the rapid increase in the construction of global transportation infrastructure, frequent climate changes, and the continuous expansion of engineering construction, the contradiction between land resource utilization and natural disasters such as landslides, collapses, and mudslides have intensified. The side slope is a slope formed artificially during the construction processes. When the side slope loses stability, it is easy to cause disasters such as landslides and mudslides, which could be hugely destructive. At present, the monitoring of landslides and other geological disasters mainly adopts methods such as the macro-geological observation methods, simple observation methods, instrument observation methods, and automatic telemetry methods. A common problem with these methods is that data needs to be collected manually regularly in the field.

Since the development of the Global Positioning System (GPS), it has been used in many fields. Since 1990, there have been many studies of GPS applications in deformation monitoring. At present, GPS has become an essential GNSS system in deformation monitoring [1]. The Beidou Satellite Navigation System (BDS) is a satellite navigation system independently constructed and operated by China. The Beidou Global System (BDS-3) began construction in 2016. The BDS-3 constellation consisted of 3 GEO satellites, 3 IGSO, and 24 MEO satellites. Composition[2]. At present, the last Beidou-3 satellite has been launched in June 2020, marking the successful completion of the deployment of the basic system constellation of the Beidou3 system. The deformation monitoring based on the principle of satellite positioning can achieve a one-time installation and all-weather automatic monitoring. Therefore, this paper proposes a geological deformation monitoring system based on the BDS / GPS integrated system.

2.Monitoring System Design And Implementation

2.1 Monitoring System Architecture

The geological deformation monitoring system based on BDS/GPS can achieve real-time monitoring of displacement deformation. The monitoring system consists of three parts: hardware, data transmission layer, and software. The hardware end is divided into two parts: a reference station and a monitoring station. The following figure shows the overall architecture of the monitoring system.

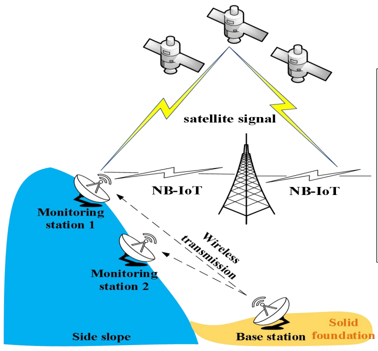

Figure 1. The overall architecture of the monitoring system[3]

2.2 Monitoring System Implementation

The picture below shows the monitoring station on the hardware side. The monitoring station and the reference station are slightly different in sensor selection. The monitoring station mainly consists of waterproof boxes, solar panels, Beidou boards, satellite antennas, temperature and humidity sensors, rain gauges, and soil humidity sensors.

Satellite antennas are used to receive satellite positioning signals. The solar panel provides a stable power supply for the entire equipment by solar energy. The solar panels are placed above the waterproof box. There is a battery in the waterproof box and an OEM628E Beidou board. The OEM628E board can receive all currently built GNSS constellation and satellite signals. It can realize not only single system positioning, but also realize combined integrated system positioning. The data transmission layer uses the SIM7020C NB-IoT module for wireless transmission. The software terminal is composed of

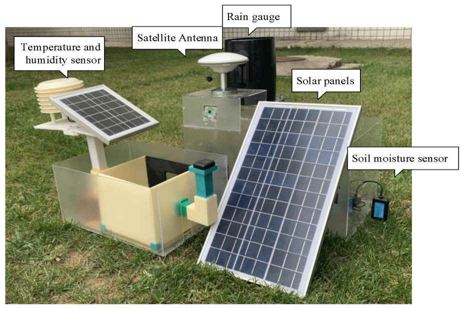

Figure 2. Monitoring station

a web terminal and a mobile APP, combined with charts to realize the data visualization function. Users can intuitively evaluate the displacement deformation of the monitoring point and the changing trend of the environmental factors through the visual charts and make decisions and discriminations.

3.Experimental Results and Analysis

3.1 Relative Positioning

Relative Positioning [4] refers to using two or more satellite positioning devices for long-term, continuous simultaneous positioning. In the relative positioning, the reference station and the monitoring station are two indispensable parts. The reference station provides a reference for relative positioning. It is often set up in a place with stable terrain and a wide field of view. The monitoring station is set up in the monitoring area to collect data. Single satellite positioning often contains positioning errors. The sources of positioning errors are intricate and sometimes related to the satellite itself, such as satellite clock errors, satellite orbit errors, etc. Sometimes errors come from the signal transmission process, such as ionospheric refraction errors and tropospheric refraction errors, etc., the occurrence of the above errors makes the observation results fluctuate. In relative positioning, long-term, continuous positioning can reduce fluctuations caused by errors, thereby improving positioning accuracy.

3.2 Unification of BDS/GPS Time and Space Datum

The Beidou satellite navigation system uses the CGCS2000 coordinate system, and the GPS satellite navigation system uses the WGS-84 coordinate system. When the two systems are combined for positioning, a unified reference is required. The current system difference between the latest WGS-84 and CGCS2000 is theoretically within the range of 0~0.015mm, which can be ignored entirely for short-distance relative Positioning [5]。 In our experiments, the test method is a short baseline, so we assume that the coordinate data is that of the WGS-84 coordinate system. Because the start time of the GPS system is different from that of the Beidou satellite navigation system, we need to perform the conversion when using combined, integrated positioning systems. The conversion relationship is as follows:

$$GPST=BDST+14 \qquad (1)$$

In this simulation experiment, we unified the time base under GPST.

3.3 Test Purposes

Compared with absolute positioning, relative positioning has higher accuracy. Therefore, in this experiment, we also use relative positioning to test the BDS/GPS combined system's deformation monitoring accuracy. In relative positioning, the observed value at each moment fluctuates around the actual value under random errors, so the observed value is a statistical value with a confidence interval of 68%. The reference station needs to send a reference information to the monitoring station for the different operations in the test. Therefore, a wireless communication link is needed to establish communication between the reference station and the monitoring station. This system uses the Lora module to establish a communication link between the reference station and the monitoring station to start the data transfer.

In order to verify the actual effect of BDS/GPS based geological deformation monitoring system and relative positioning technology in deformation monitoring, this simulation experiment was designed to compare and analyze the relationship between the relative positioning precision of BDS/GPS combined system, the BDS single system and the DOP (Dilution of Precision) value, positioning time, number of satellites, and other factors are considered. In the slope deformation monitoring, horizontal monitoring data is more reliable [6]. Therefore, this paper only tests the BDS/GPS combined system's deformation monitoring accuracy in the horizontal direction.

3.4 Deformation Test Environment

During satellite positioning, at least four satellites need to be searched to calculate location information. The positioning signal sent by satellite will be interfered with or even blocked by mountains, buildings, trees, etc. The positioning module can search for more satellite signals in a barrier-free environment, and the received signals will be relatively stable, thereby obtaining relatively high positioning accuracy. The experiment was carried out on the top platform of the Telecom Building of Lanzhou Jiaotong University, as shown in Figure 3.

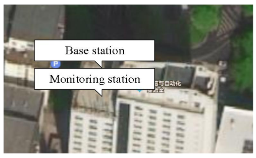

Figure 3. Test environment

3.5 Deformation Test Program

During the experiment, the base station receiver antenna remained stationary to provide a benchmark for the experimental data. The monitoring station and the reference station are on the same horizontal line, 1m away from the reference station, that is, it is in a short baseline state. There are two mutually perpendicular guide rails under the monitoring station. The monitoring station can move on the guide rails. In this experiment, the displacement is generated by the artificial mobile monitoring station. To simulate the deformation, and the high-precision straightedge was used to measure the actual displacement as the real value.

The BDS single system's accuracy and BDS/GPS dual system in deformation monitoring are obtained by comparing and analyzing the shape variables measured by the Relative Positioning of satellite with actual displacement.

The specific steps of the experiment are as follows:

(1) Fix the base station and place the monitoring station on the guide rail.

(2) Use the BDS/GPS system (BDS system) relative positioning time t (=10min), and record the scale with a ruler.

(3) Move the monitoring station with a distance of 2 cm, use a tape measure to record the actual displacement as the real value.

(4) Repeat the steps (2) and (3) ten times to complete the test.

3.6 Test Results

The dilution of precision reflects the spatial geometry of the available satellites. It is one of the main factors to obtain high-precision positioning results. It mainly includes PDOP, HDOP, VDOP, etc. As the DOP value decreases, higher positioning value can be gained. Simultaneously, the change in the number of satellites also affects the change in the DOP value. The conversion relationship between the three is as follows:

$$\mathrm{HDOP}^2+\mathrm{VDOP}^2=\mathrm{PDOP}^2 \quad (2)$$

Here, we first analyzed the data of BDS single system then BDS / GPS integrated system reference stations in the observation period to analyze, and the results are as follows:

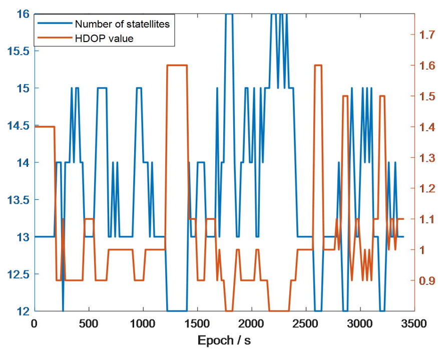

Figure 4. BDS System

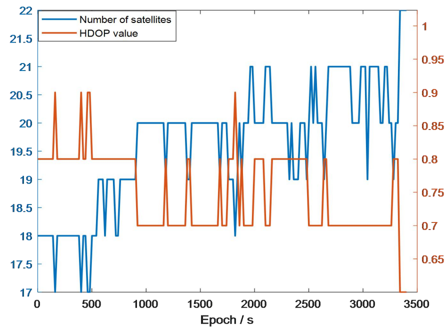

Figure 5. BDS/GPS System

From the above picture, we can get:

(1) During the observation period, the number of visible satellites in the BDS/GPS combined system is greater than the number of visible satellites in the BDS single system. The number of visible satellites in the BDS/GPS integrated system fluctuates around 20, and the number of visible satellites in the BDS single system remains at around 14.

(2) Under the same epoch, the BDS/GPS combined system's DOP value is lower than that of the BDS single system. After one hour of continuous observation, the HDOP is less than one, indicating that the BDS/GPS combined system has higher positioning accuracy in the horizontal direction.

(3) As the positioning time increases, the DOP value and the number of visible satellites of the BDS/GPS integrated system and the BDS single system tend to stabilize, and the fluctuation range of the positioning data of the BDS/GPS integrated system is lower than that of the BDS single system. More obviously, it can be seen that the positioning accuracy of the BDS/GPS integrated system is better than that of the BDS single system when using static relative positioning technology for long-term, continuous observation.

Figure 6 shows the relative positioning of the BDS/GPS combined system and the BDS single system. In the figure, the horizontal axis represents the test time; the vertical axis is the displacement value

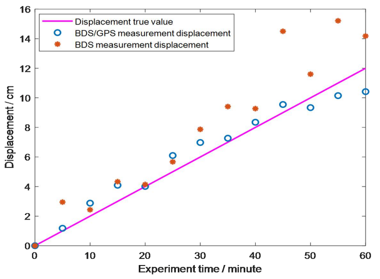

Figure 6. relative positioning accuracy test results

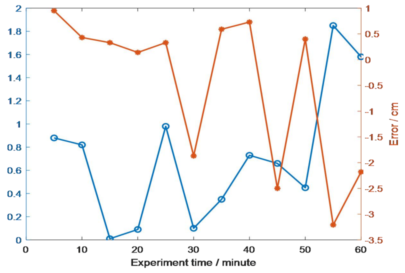

Figure 7. relative positioning error result

measured by the satellite system, and the straight line is the real value (ideal value) of the displacement measured by the tape measure. From Figure 6, the measured value of the satellite system fluctuates around the real value. Moreover, in the same time interval (10min), the longer the positioning time, the closer the satellite system measurement value to the real value measured by the tape measure, indicating that extending the positioning time can achieve higher accuracy. Simultaneously, compared with the BDS/GPS integrated system, the BDS single system's measured value fluctuates wildly. Compared with Figures 4 and 5, the reason is that the BDS single system has a smaller number of satellites, an immense HDOP value, and frequent fluctuations. From Figure 7, it can be obtained that the average error of the BDS/GPS combined system is ±0.708 cm. The BDS single system's average error is ±1.138 cm, so it is more reliable to use the BDS/GPS combined system for deformation monitoring.

4. Conclusion

This paper proposes a geological deformation monitoring system based on the BDS/GPS combined system. The system combines relative positioning and carrier phase difference technology to realize centimeter-level deformation monitoring in the horizontal direction. At the same time, web and mobile apps have been developed to facilitate users to view slope monitoring data in real-time. Finally, the design experiment proved that long-term continuous observation is the prerequisite for obtaining high-precision positioning data. Under the same conditions, the BDS/GPS combined system's measurement accuracy is better than that of the BDS single system.

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