Application and Research of GPS Digital Image Measurement Technology in Landslide Disaster Monitoring and Prediction

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Abstract. This article mainly uses GPS high-precision satellite positioning technology, using low-power, long-term maintenance-free power supply system monitoring equipment in the field, to establish a scalable and expandable landslide displacement deformation monitoring system. The system uses a combination of real-time monitoring, real-time processing, and timing processing to detect mountain deformation in time. Taking the monitoring of landslide accumulation area of a nuclear power plant as an example, through the monitoring data and the actual situation on the spot, the disease symptoms of the slope were discovered in time, and the development status of the disease was grasped. At the same time, preventive measures for related disease remediation were provided, especially when the climatic conditions changed the dynamic changes of the slope at the time, forecast the occurrence and development of the main diseases of high-risk slopes, analyze and predict the possibility of sudden diseases, do well in advance control, and reduce unnecessary losses.

1. Introduction

The phenomenon that part of the slope performs shear movement along one or several surfaces in the slope under the action of gravity is called landslide. As a common geological hazard, landslides are widely distributed and large in scope. In the northwest, southwest, north China, and hilly, loess plateau regions, there are many types of landslides, a wide distribution area, serious damage and great destructive power, causing huge economic losses every year, which seriously restricts the development of the national economy and threatens disaster-prone areas. The safety of people's lives and property. The main means of monitoring landslide disasters at home and abroad are: precision leveling, wire measurement, fiber optic sensors, global positioning system GPS, satellite remote sensing technology, close-range photogrammetry, ground laser scanning, etc. With its wide coverage, high resolution, all-weather and all-weather, high monitoring accuracy, spaceborne synthetic aperture radar interferometry technology is widely used in monitoring of surface deformation caused by earthquakes, volcanoes, glacier movement, groundwater extraction and underground mining.

In the real world, as the environment deteriorates, various geological disasters such as earthquakes, dam breaks, and landslides occur more and more frequently, causing huge losses to the country. Among them, landslides have caused the greatest harm to people's lives, property, and national economy. Therefore, it is very important to establish a safe and reliable landslide monitoring system. Landslide monitoring requires comprehensive methods. Landslide monitoring includes overall deformation monitoring of the landslide body, stress and strain monitoring within the landslide body, and external...
environment monitoring such as rainfall and groundwater monitoring. Deformation monitoring is an important part of it and an important basis for judging whether a landslide is dangerous [1].

2. GPS used in landslide deformation monitoring example

2.1. GPS monitoring network layout of landslide
The GPS monitoring network consists of a reference network and a deformation network. The primary network is the reference network of the monitoring system, and the secondary network is composed of landslide monitoring points. Under the control of the reference network, the stability of the landslide can be judged by comparing the coordinate difference between the observations of the landslide monitoring points in each period and the observations in the first period.

The landslide monitoring points are selected according to the characteristics of the landslide body. These points must reflect the overall direction and amount of deformation of the landslide body, as well as the deformation rate of the landslide body. At the same time, each point should also consider the situation of receiving satellite signals, and there should be no large-scale obstructions above the measuring point. To this end, according to the field survey of the site conditions, the GPS deformation monitoring network as shown in Figure 1 was deployed according to the principle of network layout.

Among them, ZG200–ZG201 are the reference points arranged on the stable bedrock outside the landslide body, and ZG250–ZG255 are the 6 monitoring points arranged on the body of the landslide. The average distance between points is 280.32 m, the longest distance is 558.562 m, and the shortest distance is 46.285 m. Observation piers are embedded on the reference point and the monitoring point and are equipped with a forced centering device.

2.2. Data processing
This data processing collects the GPS observation data of the sixth and seventh periods. Since the delay of the precision ephemeris is two weeks, it is obviously not conducive to the short-term prediction of landslides; while the delay of the fast precision ephemeris is two days, and the satellite The accuracy of the orbit, precision ephemeris and fast precision ephemeris are very close (no more than 5cm); the accuracy of the satellite clock difference, precision ephemeris and fast precision ephemeris are close (no more than 0.1ns), so first 3 reference points (II04, II05, II06) Joint measurement with known stations,

![Figure 1](image-url)
using Bernese software and fast precision ephemeris calculation, to obtain the accuracy and displacement of the reference point (see Table 1).

**Table 1.** Accuracy of measuring points in the coordinate direction

| Measuring point | Sixth period | Seventh | Displacement of Phase 6 and Phase 7 |
|-----------------|--------------|---------|-------------------------------------|
|                 | σx  | σy  | σz  | σx  | σy  | σz  |                             |
| H104            | 0.5mm| 0.5mm| 0.7mm| 0.5mm| 0.5mm| 0.9mm| 0.2mm                     |
| H105            | 0.9mm| 0.8mm| 1.3mm| 1.0mm| 0.9mm| 1.5mm| 0.3mm                     |
| H106            | 0.6mm| 0.5mm| 0.8mm| 0.5mm| 0.6mm| 0.9mm| 0.2mm                     |

It can be seen from Table 1 that the displacement of the reference point and the accuracy of the two phases are in the sub-millimeter level. The accuracy of the reference network is much greater than the change of the deformation observation, so that the deformation analysis for the next step reduces the source of error, and can ignore the reference network. Error and comparative analysis of deformation. After referring to the data of the previous 5 periods, it is known that the reference point is basically stable and meets the design requirements.

For the data processing of the monitoring network in each period, the random software TGO1.62 is used for calculation. In the process of data processing, the inspection of synchronous edge observation data: the baseline vector removal rate of the observation data of the two phases is within 4.5%, which meets the requirements of the specification; the residual plot generated according to the software is shown in Figure 2.

![Fig 2. Epochs](image)

It can be seen that the residuals in the carrier phase observation values are not more than 0.05 weeks, and the residual plot curve is basically smooth and continuous and the value is relatively small, indicating that the quality of the observation data is better and meets the requirements of high-precision GPS monitoring.

Table 2 lists the statistical table of point errors in the local coordinate system after coordinate conversion of each point after the adjustment of the observation network. From the table, the error in the unit weight of the observations in each period, the units of the sixth and seventh periods can be calculated. The weighted errors are 2.11mm and 2.32mm, respectively.

**Table 2.** Accuracy of measuring points in the coordinate direction

| Measuring point | Sixth period | Seventh |
|-----------------|--------------|---------|
|                 | σN  | σE  | σU  | σN  | σE  | σU  |
| H23             | 0.9mm| 0.8mm| 1.4mm| 0.9mm| 1.0mm| 1.6mm|
| H24             | 0.9mm| 0.8mm| 1.1mm| 0.9mm| 1.0mm| 1.4mm|
| H25             | 1.0mm| 0.8mm| 1.4mm| 0.8mm| 0.9mm| 1.5mm|
| H26             | 1.0mm| 1.0mm| 1.5mm| 0.9mm| 1.1mm| 1.7mm|
| H27             | 1.1mm| 0.9mm| 1.7mm| 0.9mm| 1.0mm| 1.9mm|
| H28             | 1.0mm| 0.9mm| 1.5mm| 1.1mm| 1.0mm| 1.6mm|
From the statistical results, the accuracy indicators of the two phases of the monitoring network observations of the monitoring network after unconstrained adjustment can reach the expected goal, and reach the three aspects of point accuracy, reliability, and confidence. In view of the expected design requirements, the GPS landslide monitoring network is qualified [2].

3. Detection of changes in ratio of images based on GPS intensity

For abrupt landslides, due to the rapid change rate, the deformation may exceed the deformation monitoring gradient of interferometric measurement, so you can use the method of change detection, by performing difference and ratio processing on the amplitude images before and after the change, to keep the intensity ratio too large or if the area is too small, detect and locate the landslide area to realize the deformation area extraction. The intensity ratio between the two SAR images is used to detect the area where the image changes, and the area that is too large or too small in the intensity ratio is retained to detect and locate the landslide area. The detection principle is as follows:

$$\text{Ratio} = \frac{pwr_1}{pwr_2} \geq 1$$  \hspace{1cm} (1)

$$\text{Ratio}$$ is the final deformation detection result. To perform change detection, first register the two scene images. The two-phase registration accuracy is less than 1/8 pixel. For accurately registered two time-phase images to detect changes, the most conventional method is image subtraction or ratio processing. Other processing methods, such as multi-temporal data classification and principal component changes, have been proven by optical remote sensing data processing experience to be less effective than image subtraction or ratio methods. The distribution of the ratio depends only on the relative change, so from the statistical model point of view, the ratio method is more suitable for change detection than the image subtraction method. In addition, since many radiation errors are multiplicative, the ratio method is more adaptable to the radiation errors. However, the SAR image difference information obtained by the difference method can also play an important supplementary role.

In the process of landslide monitoring, in order to obtain the relative position change of the monitoring point, it is necessary to accurately calculate the relative movement position of the measuring station relative to the base station, not its absolute position. So, this paper chooses the double difference solution model using relative positioning algorithm. According to the phase observation value obtained by a satellite observation antenna, the observation equation can be obtained as:

$$(N + \varphi) \lambda = R + c \tau + \sigma$$  \hspace{1cm} (2)

Where $$N$$ is the phase ambiguity, $$\varphi$$ is the fraction of the phase, $$\lambda$$ is the carrier wavelength, $$R$$ is the actual distance from the satellite observation antenna to the satellite, $$\tau$$ is the receiver clock difference, and $$\sigma$$ is the delay of the satellite signal through the troposphere and ionosphere Error correction. Satellite measurement antennas installed on the monitoring site For satellites far away from 20,000 kilometers, the path of the satellite signal to the two measurement points can be considered to be the same, that is, the delay of the same satellite signal to the ionosphere and troposphere at the two observation points is the same.

3.1. Algorithm flow

3.1.1. Method of extracting deformation. (1) Select the appropriate radar satellite, and then select the research time to obtain the corresponding radar data. (2) Perform accurate registration on the selected D-INSAR data, and then calculate the phase difference at the same point. (3) Filter the generated interferogram and remove the flat effect. (4) Unwrapping the interferogram to obtain the absolute phase change, and then using differential interference processing to obtain the differential interferogram. (5)
Finally, after further unwrapping the phase of the differential interferogram, the small deformation information of the surface is obtained.

3.1.2. **D-INSAR technology specific data processing.** The process is shown in Figure 3 for the specific data processing process (taking the traditional DEM dual-track method and the three-track method as examples).

![D-INSAR data processing flow](image)

**Fig 3.** D-INSAR data processing flow

The four-track method is basically the same as the three-track method. The only difference is that in image registration, two SAR images suitable for generating DEM are used, and two SAR images suitable for deformation are selected instead of the common image1.

3.2. **Algorithm application and defects**

The application of D-INSAR technology in landslide monitoring has good prospects and great potential, but due to the development of spaceborne SAR sensors and the characteristics of D-INSAR technology and landslide disasters, it also has certain limitations.

Loss of correlation is a more serious problem that limits the application of D-INSAR technology. In addition to the influence of atmospheric conditions, humidity and other factors caused by the time decorrelation of interference data and the propagation delay of electromagnetic waves in the atmosphere,
due to the length of the baseline and the orbit. Slight non-parallelism, excessive deformation movement, vegetation cover, and excessive landslide deformation during continuous data acquisition can all cause phase loss. In addition, because D-INSAR technology uses a unique space-time ratio related to the spatial resolution of the sensor and the image repetition period to draw the motion map, the only landslide activity that is currently suitable for monitoring is the displacement accuracy from mm to cm per month to mm to cm per year. Therefore, the current satellite SAR is not yet suitable for the application of concentrated small-area and steep mountain slopes and narrow valleys and other related rapid activity system monitoring, such as sudden landslides, debris flows, rock slides, and the fallout of gravel, etc. The best information is in the case of slower activities (rates less than a few centimeters per month) and large areas with scarce vegetation. In addition, phase unwrapping also directly affects the processing results of D-INSAR technology. Due to the complexity of the ground undulation and the difference in the quality of the interference image to the data itself, phase unwrapping is very difficult. At present, many industry researchers have conducted a lot of research on phase unwrapping and have proposed some new algorithms, such as branching Method (CB), instantaneous frequency algorithm (IFA), Kalman filter algorithm, and algorithm that automatically suppresses global diffusion error [3].

3.3. Solution

3.3.1. PS technology. PS technology is the permanent scattered technology. It selects those points that maintain high coherence from a set of time-series SAR images as PS points (such as artificial buildings, rocks, etc.). These PS points are often smaller than the resolution unit, and the scattering characteristics are compared. It is stable and less affected by time and space decoherence. Reliable phase information can be obtained on these discrete and sparse PS points, and then accurate surface deformation and DEM information can be reversed. PS technology was proposed by Ferretti et al in 1999, and was applied to landslide monitoring in 2003 in combination with D-INSAR technology, which achieved a theoretical accuracy of 1 mm and proved that the PS technology can be used to monitor plant coverage areas. Because the PS technology conforms to the characteristics of point-by-point stable reflection and the study of long-term series of interference data by performing a subset of image pixels, it can solve the phase loss correlation problem caused by atmospheric interference and vegetation coverage in the D-INSAR technology. And can study the single-phase stable radar target in the low consistency area, so that if there are enough reflectors, the interference differential technology can monitor the dense vegetation area. In some areas, due to the lack of artificial features and rocks, it is difficult to have permanent caterers, so some scholars have proposed a method of arranging corner reflectors, but because of the difficulty and cost of arranging corner reflectors, it is only suitable for monitoring a small surface area Stability, so PS technology is more suitable for application in urban areas.

3.3.2. SBAS technology. The SBAS technology is a small baseline subset differential interferometry technique, which combines the obtained long-term sequence SAR data into a small spatial baseline interference subset (the SAR image baseline distance within the collection is small, and the SAR image baseline distance between collections is large) Interferometric data set, and then use the SVD to combine the spatially small baseline subset data of different time baselines to form a time series, and then obtain the high-precision deformation field differential interferometry technology. The SBAS technology was proposed by Bernardino et al in 2002. It can solve the geometric decorrelation problem caused by the long baseline in the D-INSAR technology, and uses all the acquired data to improve the time resolution of the sampling and ensure the deformation. Time series analysis has a higher spatial density, and is also suitable for analyzing the temporal evolution of surface deformation fields in non-urban areas.

3.3.3. GPS technology. GPS positioning methods are divided into absolute positioning and relative positioning. Relative positioning is to accurately measure the relative change of the distance between two points. The positioning accuracy can reach 10-8 or higher accuracy. It can perform high-precision positioning and deformation monitoring, and Data can be repeatedly collected at short time intervals.
(tens of seconds to several hours), and these data can be used as constraints during D-INSAR data processing. Another application of GPS combined with D-INSAR is that it can calculate tropospheric delay and ionospheric delay, which is an important basis for correcting errors of D-INSAR data products and removing phase loss correlation caused by atmospheric conditions. Because the spatial resolution of GPS data collected is far less than that of remote sensing, and the interval between continuously operating stations is generally tens of kilometers, increasing the density of observation stations will be limited by factors such as geographic environment and operating costs. Low-cost observation points, the effect is still very limited. Therefore, GPS technology and D-INSAR technology are complementary. If the two data are combined, the distribution and change process of surface deformation can be described in more detail in spatial resolution and temporal resolution [4].

4. Design of landslide disaster system based on GPS digital measurement image

4.1. Overall system design

The embedded landslide monitoring system is mainly composed of ARM9 chip S3C2440, M87GPS data acquisition and processing terminal and GPRS data transmission terminal. Its system structure block diagram is shown in Figure 4. This system transmits the satellite signal received by GPS to the MCU. After the data is processed by the MCU, the data is transmitted by the GPRS module to the network with a specific IP address through the GPRS network. Finally, the remote monitoring PC receives the data by accessing the Internet [5].

![Block diagram of embedded landslide monitoring system](image)

**Fig 4.** Block diagram of embedded landslide monitoring system

4.1.1. GPS module. This system selects the HOLUX M87 GPS receiver chip and uses the ultra-small satellite receiver module designed by low power consumption MTK GPS, which can achieve the purpose of GPS navigation and positioning. M87 provides excellent sensitivity up to -159 dBm for navigation applications and fast first positioning time. It can search up to 32 satellite channels. It has the advantages of fast position correction and continuous operation in harsh environments. The CMOS level output by the GPS module can directly drive the S3C2440 chip. Therefore, when the system is integrated, the serial port of the GPS module can be directly connected to the serial port of the S3C2440 without level conversion.

4.1.2. GPRS communication module. SIM300 is a GSM/GPRS dual-frequency module launched by SIMCOM. It supports TCP/IP protocol, tri-band/quad-band/GSM/GPRS, supports short message
transmission in PDU mode and text mode, and supports high-speed transmission of data and fax information. More convenient and flexible. SIM300 module is mainly composed of 5 parts: baseband processor, power supply module, FLASH module, ZIF connector antenna interface and GSM radio frequency module. In this design, the interface signals RXD and TXD of the GPRS module are connected to the TXD0 and RXD0 of the S3C2440. When the system and the GPRS module are started, the MCU directly sends AT commands to the GPRS module through the serial port to access the GPRS network and set the parameters. Its contents include baud rate, gateway, GPRS module type, testing whether GPRS service is activated, etc. [6].

4.2. Hardware design of landslide monitoring system

4.2.1. Power supply circuit. The power supply circuit is the foundation of the entire system, and the working characteristics of the power supply directly affect the stability of the system. In the design process of the power supply, the following factors are considered: input voltage and current; power supply protection; output voltage, current, and power; electromagnetic compatibility and electromagnetic interference; and volume restrictions. Due to the high speed, low consumption, low power consumption and other characteristics of the ARM9 chip, its noise margin is low, and higher requirements are imposed on the transient response, reliability, and clock stability of the power supply. The power supply of the landslide monitoring system is 220 V to 5 V. The 5 V power supply mainly supplies power to the serial port RS232 and other peripheral chips. The 3.3 V power supply mainly supplies power to I/O, Nand-Flash, SDRAM, reset chip, etc. The 1.25 V power supply uses MAXIM’s low-power linear power supply chip MAX8860EUA18 to provide the core voltage for S3C2440.

4.2.2. System clock circuit. S3C2440 requires two external crystal oscillator circuits: one way to make CPU clock; the other way to provide clock to RTC. The clock circuit is shown in Figure 5.

Fig 5. System clock circuit

4.2.3. JTAG debug interface design. The Joint Test Action Group (JTAG) is an international standard test protocol, which is mainly used for in-chip test and simulation and debugging of the system. Most of the more complex devices currently support the JTAG protocol. The standard 5-wire JTAG includes TCK, TMS, TDI, TDO and TRST. The JTAG circuit is shown in Figure 6.
4.3. Platform demonstration

This system can accurately output positioning information through the GPS receiving module, first determine the reference position: such as $GPRMC, 020534.000, A, 3746.9012, N, 11233.5839, E, 0.00, 96.40, 101210, A*50, information Data collection terminal output after collection and processing: 10:05:34.3746.9012, N, 11233.5839, E2010.12.10. Collected every one minute, this experiment collected twice, offset position: such as $GPRMC, 020634.000, A, 3746.8643, N, 11233.5916, E, 0.00, 96.40, 101210, A*50, information via data the output of the collection terminal after collection processing: 10:06:34.3786.8643, N, 11233.5916, E 2010.12.10. It is transmitted to the host computer via GPRS for data comparison and processing, and then the offset of this collection is calculated to obtain whether a landslide and debris flow hazard may occur, as shown in Figure 7.

Fig 7. Monitoring system software
5. Conclusion
This paper verifies through examples that GPS can replace conventional geodetic monitoring methods and meet the requirements of landslide displacement monitoring. Because GPS has the characteristics of all-weather, real-time, continuous three-dimensional displacement high-precision monitoring, there is no need to see through between the stations, the operation efficiency is high, and the labor intensity is low, which is very suitable for mountain landslide monitoring. The use of GPS static measurement technology, through correct scheme design and precise data processing, can meet the requirements of landslide deformation measurement under a larger range and poor operating conditions.

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