Exploring the Application of Remote Sensing Technology in Natural Disaster Monitoring

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Abstract. The frequency of natural disasters is increasing annually, posing a significant threat to the social economy. Traditional methods of monitoring natural disasters are inefficient and can no longer meet monitoring needs. Remote sensing is economical, rapid, and data-rich. It has gradually been applied in natural disaster monitoring and has yielded positive results. This article explores the application of LiDAR and InSAR remote sensing technologies in three natural disasters: earthquakes, landslides, and floods. It concludes that in practical applications, selecting appropriate remote sensing technology methods or broadening the scope of remote sensing technology applications is necessary. Secondly, researchers should improve remote sensing data sharing, optimize algorithms, and develop better data processing systems and platforms. Finally, researchers can achieve better observation results only by improving observation accuracy. This paper aims to provide the public with relevant knowledge on the application of remote sensing in natural disaster monitoring. It also highlights flaws and deficiencies to provide references and ideas for related research.

Keywords: Remote sensing, natural disasters, LiDAR, InSAR.

1. Introduction

Natural disasters are inevitable on Earth, causing significant losses to human production and life. As cities expand and population density increases, the threats and challenges posed by natural disasters to the socio-economy become more severe. The frequency of natural disasters has been increasing year by year. In the year 2023, 15,600 earthquakes were recorded on the Quantectum website, 19 of which were measured at 7.0 or higher on the Richter scale. According to the Natural Disaster Loss Record Report, the global losses caused by natural disasters in 2023 amounted to approximately $250 billion. The number of deaths from natural disasters in 2023 was about 74,000 people, significantly higher than the average of 10,000 over the past five years. The severity of natural disasters is evident in the Libyan floods of early September, which claimed nearly 4,000 lives and left more than 9,000 people missing.

Additionally, the earthquake disaster killed some 63,000 people, surpassing the previous record set in 2010 [1]. Countries worldwide are utilizing scientific and technological methods to reduce the impact of disasters, including advanced technologies such as the Internet of Things, artificial intelligence, life detectors, and drones. Remote sensing technology has shown great potential in natural disaster monitoring and has achieved significant domestic and international success.

Satellites and drones can acquire high-resolution image data of disaster situations on a wide scale and in real time. The use of remote sensing technology in natural disaster monitoring provides precise information for understanding the development of disaster situations, assessing disasters, post-disaster reconstruction, and rescue efforts, thus effectively reducing the losses and casualties caused by natural disasters. For instance, analyzing post-earthquake surface changes through remote sensing data can yield a normalized digital surface model that detects damaged buildings [2]. This saves time in post-earthquake building monitoring and helps direct rescue teams to the right place quickly. Fu Xiaodi used optical remote sensing images of the avalanche and landslide disaster in Bijie City as the data source [3]. She established a dataset for avalanche and landslide disasters and improved the model to identify the scope of damage caused by such disasters intelligently. Zou Yang et al. used a multi-view photographic camera to rapidly acquire high-precision geological image data of the Longmengou mudslide disaster area [4]. They then used refined reconstruction technology to produce high-precision orthophotos and realistic three-dimensional models. Finally, the researchers identified landslides, avalanches, rock piles, and sources of hazardous rockfall material in the mudslide disaster area. Additionally, remote sensing technology can be combined with geographic information systems and other technical tools to integrate various disciplines and achieve the analysis and prediction of natural disasters, effectively reducing disaster losses.

This paper explores the application of remote sensing technology in monitoring natural disasters. It introduces commonly used remote sensing technology in natural disaster monitoring and summarizes the methods and principles of remote sensing technology in monitoring earthquakes, landslides, and floods. The text analyzes the application of remote sensing technologies and identifies current shortcomings in natural disaster monitoring. It also provides future research directions for remote sensing in natural disaster monitoring.

2. Overview of Remote Sensing Methods Commonly Used in Disaster Monitoring

The main remote sensing methods used for natural disasters include optical remote sensing, Synthetic Aperture Radar (SAR), Light Detection and Ranging (LiDAR), and Interferometric Synthetic Aperture Radar (InSAR). Optical remote sensing is intuitive in displaying images but is more affected by high vegetation cover and weather conditions in mountainous areas. SAR generates radar images that can show specific features of the ground surface. SAR generates radar images, which can show particular features of the ground surface. It is mainly used in agriculture, urban planning and other fields. However, SAR's construction and maintenance costs are relatively high, requiring more complex data processing methods. LiDAR is a laser radar that can penetrate vegetation and monitor terrain conditions in mountainous areas. InSAR monitors small ground surface deformations, making it advantageous for crustal movement applications. This paper focuses on exploring the use of LiDAR and InSAR.

2.1. LiDAR

LiDAR is a technology for detecting the distance of an object, which scans the terrain by emitting a laser beam to measure the distance from the object to the scanner [5]. The weather and light conditions do not limit it. LiDAR can generate high-density point cloud data, provide high-precision three-dimensional terrain models and monitor the centimeter-level terrain undulation. Also, the data has a high resolution. These advantages make LiDAR widely used in agriculture, forestry, disaster monitoring and other fields.

Acquiring remote sensing data using LiDAR usually involves the following steps: The flow diagram of the specific steps is shown in Fig. 1.

1) Data acquisition is typically done by flying a vehicle (e.g., a drone or fixed-wing aircraft) with a LiDAR device on board, which performs a laser scan of the target area. Raw point cloud data is then collected.

2) Data preprocessing is the process of cleaning and organizing the raw data that has been collected to remove noise and outliers. It ensures the accuracy and reliability of the data.

3) Data filtering and analysis is to further filter and analyze the preprocessed data according to the research purpose, such as classification, segmentation, feature extraction, etc., to extract practical information related to the research.

4) Generating derived products is based on the filtered and analyzed data to construct 3D terrain models or related models. It provides the basis for subsequent disaster monitoring and analysis.

5) Application and interpretation refers to the generated models being applied to specific disaster monitoring tasks, such as landslide identification, crack detection, etc. The models can also be combined with other data and information for parsing and judgment.

6) Data visualization and output is the visual presentation and output of monitoring results in graphs, charts, or reports that decision-makers and researchers can easily understand and use.

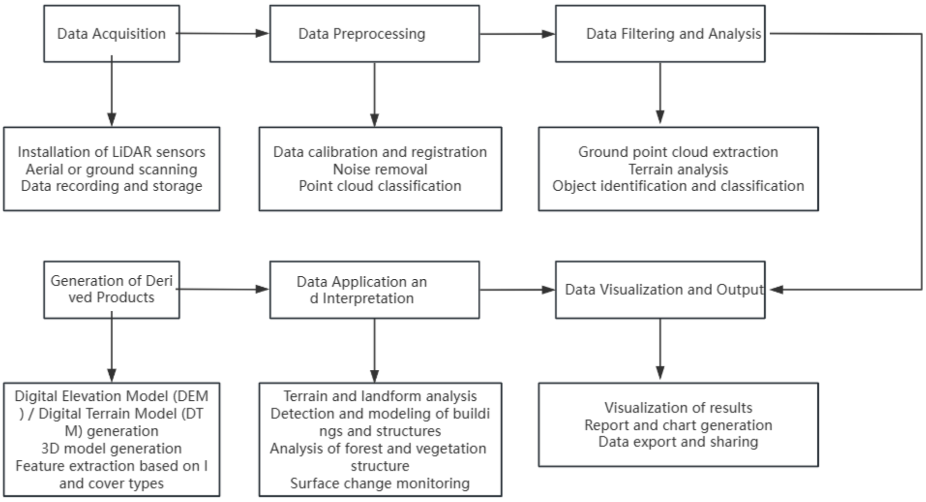

Figure 1. Workflow diagram of LiDAR

2.2. InSAR

InSAR uses multiple synthetic aperture radar images of the same area to extract topography and deformation patterns [6]. It is mainly used to monitor crustal deformation and volcanic activities by analyzing the phase difference of the radar signals to extract the surface variance changes. Compared to LiDAR, InSAR has the ability of vegetation penetration and can be applied to vegetation-covered areas.

Acquiring remote sensing data using InSAR usually involves the following steps: The flow diagram of the specific steps is shown in Fig. 2.

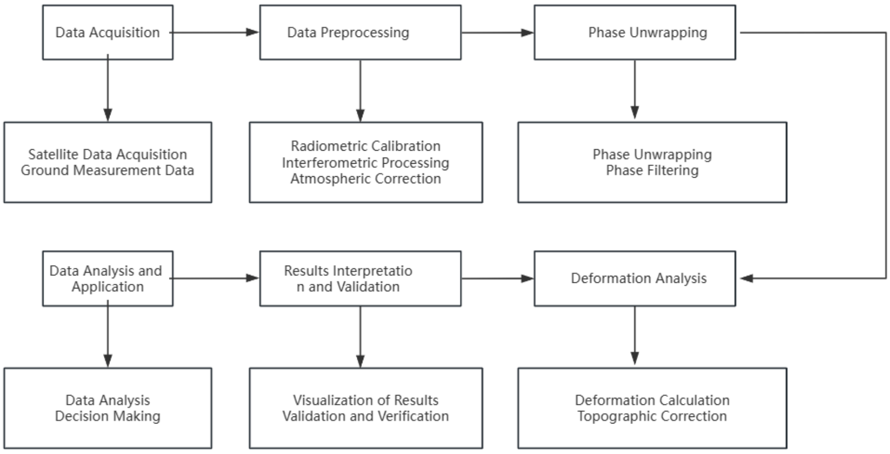

Figure 2. Workflow diagram of InSAR

1) Data acquisition is selecting appropriate satellite data, usually satellites with radar sensors, such as ESA's Sentinel-1, ERS, ENVISAT, and so on. Ground measurement tools can be used to obtain some basic topographic and geomorphologic information for subsequent processing.

2) Data preprocessing is the radiometric calibration of satellite data to convert the raw data to surface reflectivity. It utilizes the phase difference between two radar wave propagations for interferometric processing to obtain an interferometric image. Atmospheric effects are then removed as much as possible by atmospheric correction methods.

3) Phase unwrapping is processing phase information in an interferometric image, unwrapping the phase and obtaining a phase image. The phase image is then filtered to remove the noise.

4) Deformation analysis is the calculation of surface deformation using phase information. This includes changes in surface subsidence, elevation, etc., taking into account the topography of the Earth's surface and making corrections to enhance the accuracy of the deformation results.

5) Results interpretation and validation is the verification of InSAR results using ground measurements, other remotely sensed data, or field surveys. The deformation results are visualized for intuitive understanding.

6) Data analysis and application is the use of InSAR results for more in-depth data analysis, e.g., monitoring of geohazards, urban subsidence, etc. The results of the analysis are then applied to decision-making, such as in urban planning and resource management.

3. Applications of Remote Sensing in Natural Disaster Monitoring

3.1. Earthquake

Earthquakes result from a sudden release of internal stress in the earth's crust, which can trigger secondary disasters and cause significant damage. In the past, access to disaster information was limited to on-site investigations, which could not provide a wide range of information promptly, making rescue work more difficult. Remote sensing has several advantages, such as unmanned maneuvering and rapid data acquisition. It can be combined with algorithms to quickly investigate the scope of an earthquake and provide real-time conditions, which is crucial for earthquake disaster monitoring.

On September 21, 1999, at 01:47:12.6 GMT, an earthquake of magnitude 7.6 on the Richter scale and with a depth of 7.0 km occurred in Chi-Chi Township, Nantou County, Taiwan, resulting in the deaths of over 2,500 people. The InSAR technique generates interferograms by selecting appropriate input data and then unwraps the phase to obtain surface deformation before and after an earthquake, providing crucial data for earthquake disaster monitoring [7]. In Fig. 3, the InSAR technique is used to show pre-seismic and co-seismic deformations, which can be modeled to determine the crustal deformation rate.

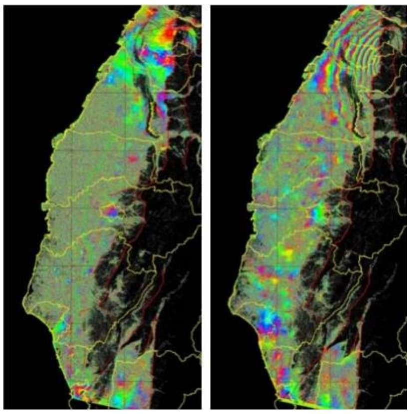

Figure 3. Crustal deformation related to the Chi-Chi earthquake in western Taiwan [7]

The technique of Pixel Offset Tracking (POT) is frequently utilized to track the position of a target in consecutive image frames. Therefore, this technique can be combined with remote sensing imagery to infer the target's trajectory. POT acquires the co-seismic deformation field of an earthquake and combines it with SAR imagery to obtain high-precision offsets. For instance, on February 6, 2023, at 4:17 p.m. local time, an earthquake measuring 7.8 on the Richter scale with a depth of 20 km struck Turkey. The surface rupture zones' location and the earthquake's deformation magnitude in Turkey can be quickly obtained by using the POT calculation with the LandTrack-1 (LT-1 SAR) satellite data before and after the earthquake [8]. This method accurately portrays the location and spatial coverage of the surface rupture zone of medium-strength earthquakes while overcoming the shortcomings of large-scale deformation that results in sizeable interferometric phase gradients in existing InSAR monitoring techniques.

3.2. Landslide

Landslides are a common hazard in mountainous areas and can cause significant damage to buildings and utilities. Optical remote sensing can be used to acquire images of landslide areas and estimate their extent. However, due to the dense vegetation in mountainous regions, optical remote sensing cannot penetrate the vegetation. Therefore, LiDAR can be used to determine the image of landslides under the vegetation. In addition, InSAR can monitor ground deformation with high accuracy. Liang Feng used InSAR to discover the landslide potential within the second group of Pawan Village, Leng Moraine Town [9].

LiDAR and InSAR can have slightly different results in landslide area boundary identification [10]. For example, Fig. 4 shows the boundary identification of a landslide in Danba; the red area is the landslide area identified by LiDAR, and the black area is the landslide area identified by InSAR.

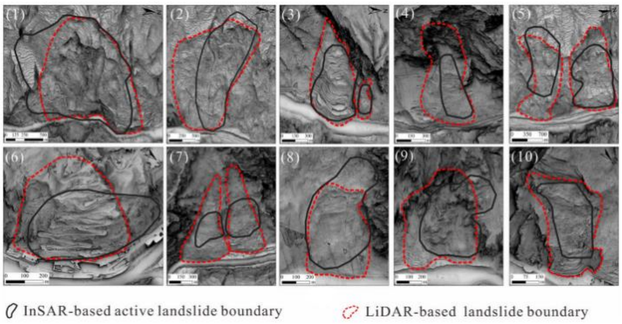

Figure 4. Comparison of InSAR and LiDAR boundary detection on the same landslide [10]

LiDAR and InSAR can be effectively combined to identify landslide hazards. While InSAR can detect millimeter-scale deformation, it may also include surface deformation unrelated to landslides [10]. In cases where slope deformation is not significant, InSAR may be unable to detect it. For instance, when detecting a landslide site in Mao County, it was found to be a landslide deformation area after on-site verification, despite the lack of obvious signs of deformation within the time range of InSAR interpretation [9].

Overall, LiDAR and InSAR are two distinct but complementary remote sensing technologies. Choosing the appropriate technology or combining the two can provide more comprehensive surface information based on specific application needs and research purposes.

3.3. Flood

Due to global warming and the increasing frequency of extreme weather, flooding caused by heavy rainfall and typhoons is becoming more common. Floods can inundate cities and farmland, greatly affecting production and life and even triggering secondary disasters such as mudslides and landslides. Remote sensing imagery can quickly determine the extent of flooding after it occurs, allowing for the development of accurate disaster relief strategies.

Jiang Mang utilized Sentinel-2 optical remote sensing images as a data source and employed remote sensing classification and inversion to conduct a remote sensing monitoring test of flood-affected areas [11]. However, during flood occurrences, clouds often obstruct traditional optical remote sensing images, rendering them ineffective and more weather-dependent.

SAR sensors can improve accuracy by penetrating clouds and imaging at night. The Sentinel-1 remote sensing satellite, launched by the European Space Agency, provides SAR images with high spatial and temporal resolution. Deep learning, which recognizes objects in an image by learning many samples, is commonly used in remote sensing technology to improve the speed and accuracy of remote sensing image interpretation. Dong Zhen utilized Sentinel-1 remote sensing satellite data. He applied deep learning algorithms to high-resolution remote sensing images to monitor the flooding in the Poyang Lake area during the summer of 2020 [12]. The deep learning method effectively removed speckle noise in the SAR image and accurately identified the water body area in the image. Finally, by combining the land cover type data, one can analyze the inundation area of each type of land, calculate the economic loss of flood disasters, and provide effective data support for post-disaster reconstruction.

3.4. Issues and Recommendations

Remote sensing technology has several advantages in monitoring natural disasters; however, it also has some limitations. Firstly, no single remote sensing method currently applies to all types of natural disasters. Therefore, researchers need to assess disasters before selecting the appropriate remote sensing method for monitoring. In the future, it is necessary to broaden the scope of the application of remote sensing techniques or combine multiple remote sensing data for analysis. Additionally, international cooperation should be strengthened to share remote sensing data and images, as not all countries have their remote sensing satellites. This will allow remote sensing technology to participate in natural disaster monitoring and reduce disaster losses fully. Simultaneously, improving systems and platforms is crucial for effective disaster management decisions. In the future, an increased number of sensors will be utilized, and it will be necessary to comprehensively analyze all types of data, process the data, and optimize the algorithm. Additionally, current disaster monitoring still faces low resolution and atmospheric interference issues. Multiple data with varying resolutions, orbits, and sources can be utilized to obtain more accurate monitoring data.

4. Conclusion

As modern society has developed, natural disasters have become more widespread and difficult to manage. Traditional methods have limitations in exploring geological disasters, as they are greatly affected by the environment and progress slowly. On the other hand, remote sensing technology has a large monitoring area and quick response, providing powerful technical support for efficient and systematic monitoring of natural disasters. It has made many achievements and has a broad application prospect, which guarantees the development of the social economy. This paper introduces common types of remote sensing technology for natural disaster monitoring, explores their applications, and discusses current challenges and prospects.

LiDAR and InSAR are two standard remote sensing methods for monitoring natural disasters. LiDAR is a ranging technology that emits a laser beam to measure the distance from an object to the sensor and collect point cloud data. The data is denoised, filtered, and analyzed by the researchers. Then, an interferometric image is obtained using InSAR by processing the phase difference between the propagation of two radar waves. Finally, the deformation of the ground surface can be calculated by processing the interferometric image to construct a terrain model. In seismic monitoring, InSAR can be employed to observe the pre-seismic and co-seismic crustal deformation, and the location of the surface rupture zone and the deformation magnitude can be obtained by POT calculation with SAR data. LiDAR can compensate for the limitations of optical remote sensing in landslide monitoring, as it can penetrate vegetation. InSAR can also be used to observe landslides, but its results may differ slightly from LiDAR's. Therefore, a combination of the two can be beneficial in practical applications. In flood observation, optical remote sensing can serve as a data source, but it is highly dependent on weather conditions. On the other hand, SAR can effectively overcome the influence of clouds and fog.

However, the implementation of remote sensing technology in natural disasters still has problems that need improvement. These challenges include the limited scope of single remote sensing technology, difficulty obtaining and processing remote sensing data, and low accuracy. This paper provides corresponding suggestions for addressing these issues, which may also serve as future research directions for remote sensing in the field of natural disasters.

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