Methods for Measuring Landslides

Subjects: Remote Sensing

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Landslides are among the most destructive geo-disasters, causing substantial property damage and safety problems worldwide. Defined as the gravitational movement of mass down a slope, they can result from various events such as severe precipitation, earthquakes, volcanic activity, and human activities.

point cloud deformation analysis laser scanning surveying lidar geodesy

1. Introduction

Landslides are among the most destructive geo-disasters, causing substantial property damage and safety problems worldwide. Defined as the gravitational movement of mass down a slope [1], they can result from various events such as severe precipitation, earthquakes, volcanic activity, and human activities. These natural phenomena pose significant risks to infrastructure, including roads and buildings, and to human life. According to the World Health Organization, landslides affected an estimated 4.8 million people and caused more than 18,000 deaths between 1998 and 2017 [2].

Understanding and predicting landslides is pivotal for scientific inquiry. Researchers focus on studying their causes, mechanisms, and potential impacts to develop effective landslide prediction and early warning systems (LEWS) [3][4][5][6][7]. These systems are crucial for landslide management and risk mitigation. As we progress towards more technologically advanced methods of monitoring, high spatial resolution techniques have gained prominence. The following sections will delve into the significance and applications of these methods in contemporary landslide research.

One of the common approaches for landslide prediction and early warning is using numerical modeling and simulations, which allow for predicting the behavior of the landslide under different scenarios. This method is widely used to evaluate slopes' stability and identify the critical factors that control landslide behavior [8][9][10][11].

This part of the research presents a comprehensive literature research of various methods for measuring landslides, including the Global Navigation Satellite System (GNSS), image-based monitoring, and TLS. Each method has its advantages and limitations, which will be discussed in detail.

2. Global Navigation Satellite System (GNSS)

GNSS sensors are one of the beneficial ways of monitoring landslides [12][13][14][15][16]. The GNSS technology has proved to be one of the most flexible and practical tools for monitoring purposes. These instruments enable precision at the centimeter level or even lower in static mode and lengthy observation times [17]. GNSS can offer precise and accurate data regarding the location and movement of landslides. By putting permanent GNSS receivers at strategic points on a landslide or in an area prone to landslides, it is possible to measure small-scale ground surface motions with high temporal resolution. GNSS may also be used to measure the velocity and acceleration of a landslide, which can provide important information about the landslide's dynamics and possible risks and threats. The advances in GNSS technology have created new low-cost sensors that can provide continuous monitoring with medium to high precision, accuracy, and limited costs [17][18][19]. In this case, the precision of measuring is enough, but using these sensors for measuring the landslide provides low spatial resolution. Therefore, it is necessary to combine these sensors with other area-based methods to increase spatial resolution. It is possible to obtain a more comprehensive picture of a landslide and its development over time by combining GNSS data with the results of other remote sensing techniques, such as terrestrial laser scanning (TLS) and satellite images.

GNSS offers high precision in monitoring landslides, providing valuable data on location and movement. Its ability to measure velocities and accelerations is crucial for understanding landslide dynamics. However, its low spatial resolution necessitates integration with other methods for a comprehensive analysis.

3. Image-Based Monitoring

In addition to the accuracy needed to assess, with a given probability, the magnitude of the expected displacement and the number of other issues influence the choice of the best monitoring system to use. For instance, the size of the area to be controlled, the frequency of data gathering, the time it takes to provide the results, the stability of the reference system, and the impact of atmospheric conditions on measurement accuracy or operation [20].

Emerging Unmanned Aerial Vehicles (UAVs) are used for many purposes, including monitoring landslides. UAVs can provide high resolution compared to the first method. Furthermore, gathering data with them would be easier for large areas and regions that need to be monitored frequently during a short period. In most cases, UAVs use a camera to capture the images and make a 3D model from the area in each epoch [21][22][23][24][25]. With appropriate ground control, accuracies in the range of 3–10 cm in 3D can be expected, making UAV photogrammetry extremely appealing for monitoring applications [20][26]. Although most image-based methods in this field use airborne photogrammetry, some image-based research uses terrestrial systems [27][28][29]. Recent advancements in image-based methods have seen the rise of UAV-based Geographic Object-Based Image Analysis (GeoOBIA). This technique, utilizing high-resolution imagery from UAVs, allows for more detailed and frequent landslide assessments. A notable study in this area is the GeoBIA-based semi-automated landslide detection using UAV data [30], which demonstrates the potential of UAVs in enhancing spatial resolution and detection capabilities.

Satellite images are also used for monitoring landslides. Detecting and monitoring landslides can be accomplished in several different ways with the help of remote sensing methods, particularly satellite images. These methods have the potential to offer information regarding the location, extent, and movement of landslides, in addition to information regarding the dynamics and causes of landslides [31][32][33][34]. For instance, multispectral imagery, such as Landsat, can be applied to identify changes in vegetation cover and soil moisture, which can indicate the presence of a landslide, and radar imagery, such as that from the European Space Agency's Sentinel-1 satellite, can be used to detect changes in the elevation of the ground surface caused by a landslide. There are also some disadvantages to this method when compared to point-based methods, and one of the primary concerns is the accuracy of the image-based method for landslide detection. As reported in [35], the accuracy ranged from 5 to 15 cm in several projects using different types of UAVs and cameras. In cases where landslides occur at a rate of several millimeters per year, the image-based method faces some serious challenges.

Image-based monitoring, bolstered by methods like UAV-based GeoOBIA, offers a unique perspective in landslide analysis, especially in identifying surface changes. While it faces challenges in accuracy, especially for slow-moving landslides, its integration with other methods can significantly improve overall monitoring effectiveness.

4. Terrestrial Laser Scanners

A fixed sensor known as a terrestrial laser scanner (TLS) automatically captures the range and angles in equally spaced scanning steps [36]. They use the laser's flight time to compute distances to objects. Traditional measurement techniques do not have the advantages of three-dimensional laser scanning technology. It has high measurement accuracy and quick monitoring speed, can reflect the entire deformation trend of the landslide body, and can quickly produce high-precision, high-density three-dimensional point cloud data. It also does not need to touch the landslide body [37]. Consequently, numerous studies these days focus on using TLS for monitoring landslides [38][39][40][41][42][43]. However, this method also has some disadvantages, including a high volume of generated point clouds, especially for large areas, and the problem of accurately registering these point clouds. Based on this, there is some research about the reliability and accuracy of using TLS for monitoring [44][45]. In recent years, TLS and UAV photogrammetry have been used together to cover the disadvantages of using one of the methods alone [46][47][48][49][50].

The point clouds produced by laser scanners in two or more epochs are registered using different algorithms, such as ICP (Iterative closest point) [51] and M3C2 (multiscale model-to-model cloud comparison) [52], as well as their improved versions [53][54]. Feature matching is another method for matching the point clouds obtained from different epochs. This method is robust to noise in challenging conditions such as large-scale differences, and it can be used to register point clouds with a high degree of accuracy. This information can be used to monitor and evaluate the stability of places prone to landslides. Point cloud processing can provide vital information regarding potential landslide hazards, such as slope angles, surface roughness, and elevation changes, by examining the shape and structure of the terrain. This data can be used to construct detailed 3D models of the landscape and detect instability areas, which can aid in predicting and preventing landslides. In addition, point cloud analysis can be used to monitor changes in the terrain over time, which can aid in detecting early warning signals of landslides and tracking their advancement once they have occurred.

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