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A Review of the Landslide Monitoring by Using Terrestrial Laser Scanning

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Abstract: The landslide has been on the rise and has a wide-ranging impact, such as lives lost, structure destruction, road damage, and natural resource depletion. This study aims to determine the advantages, limitations, and applicability of Terrestrial Laser Scanning (TLS) for monitoring various landslide movements and identify the maximum measuring range of scanner in TLS. This study will provide a description for future researchers on the outcome of monitoring landslides using TLS method. The previous research papers are obtained based on the PRISMA guideline and search string. The review found that researchers most use Reigl model scanners due to their high scanning range, and TLS can be used to monitor rockfall, earth slides, earth flow, rockslide, complex, debris flow, and rock topples. However, TLS has difficulties filtering vegetations, scanning the topography of seabed and detecting millimetre scale deformations. Hence, recommendations are proposed to overcome the limitations of TLS.

Keywords: Landslide, TLS

1. Introduction

Landslides are significantly associated with the slope's steepness, moisture content of the subsoil, climatic conditions that raise the soil's water content and other anthropogenic variables, earthquakes, volcanoes, and floods can drive them. It is critical to determine the location and extent of prospective slope collapses to comprehend and control future landslides properly. Unfortunately, determining the accurate size and location of potential landslides is complicated [1]. Landslide investigation such as mapping, detecting, monitoring, analysing, and predicting landslides needs high-resolution spatial information on topsoil, topography, hydrologic conditions, and geotechnical properties. However, considering slope failure occurs frequently in mountainous regions, particularly in steep terrain, obtaining high-resolution data for landslide research is challenging. In the past decades, the advancement in computing abilities consequently enhances the development of technologies to be implemented for monitoring and prevent landslide occurrence. The researcher verifies landslide processes by analysing their geographical distribution, constructing algorithms and codes, and creating

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susceptibility maps and models. One of the technologies developed and implemented in landslide monitoring is terrestrial laser scanning (TLS).

The aim of this research is to determine the advantages, limitations, and applicability of TLS for monitoring various landslide movements and identify the maximum measuring range of scanner in TLS. This study will provide a description for future researchers on the outcome of monitoring landslides using TLS method. TLS technique used to monitor landslides can observe the movement of slope and predict landslide occurrence. Hence, safety precautions such as evacuation or slope stabilization can prevent life loss and structure damage.

2. Materials and Methods

In this chapter, the steps to acquire research paper using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline and search string to search for technical review in is determined. The procedure is divided into three distinct stages: The first step is the identification of target publications using specific keyword in the Scopus, Google Scholar and Dimensions database. The second stage involved screening the selected papers based on their titles, abstract and keywords. The third stage narrowed the search to the selected publications based on the study's eligibility. As a result, 18 papers referenced from the initial review were used within the restriction methods, and 4 paper were used outside the limitation. The total number of reviewed papers incorporated in this review article is 22, down from the initial 387 evaluated publications. Finally, the method and previous research of monitoring different slope using TLS is discussed. Then, the method and previous research of monitoring various slope using TLS is discussed. The research will determine the advantages, limitations, and applicability of TLS to monitor various landslide movements. Finally, the research will identify the maximum measuring range of scanners in TLS.

2.1 Location for setting TLS stations

When surveying a landslide region, selecting a location for the TLS is both challenging and critical. Due to terrain topography, vision between the device and the area to be investigated is often restricted. In addition, the laser beam is typically angled in proportion to the surface of the ground, obstructing the view of the landslide. Furthermore, the land is frequently shrouded with vegetations and can block the ground to varying degrees depending on the beam's angle with respect to the landslide surface, making accurate reconstruction of the terrain surface challenging. This problem can impact the survey's reliability and precision, particularly in the case of ground deformation monitoring, which is done through the comparison of multiple surveys performed at periodic intervals. Estimating the shape change of a landslide, as well as determining which areas of it have remained stable after a specific period, and estimating the volume of material that has shifted or been eliminated, are thus difficult problems to handle [2].

2.2 Near reference frame

It is critical to determine a set of stable points across time when monitoring ground deformations using TLS. The points must be around the fixed reference system, which repeated series of measurements taken at various times can be framed. This approach can produce significantly more reliable data if the stable areas are at the cloud's border. Such fixed points must be positioned outside the monitoring region, near enough to make the connection between them and the landslide points straightforward and precise. There is no requirement for visibility from the GPS receivers to the landslide area if GPS is used to connect the survey area to the near reference frame [2].

2.3 Data processing

Typically, every TLS model employs a unique software package capable of accurately processing data from the instrument. For example, Leica Cyclone software is used to process data from the Leica Scanstation C10, while Riegl Riscan Pro is used to process data from the Riegl VZ400. In any case, exporting the data in text format is a common practice so that user is able to use other software packages with capabilities specialized for a specific processing stage. The data processing stages are the same for all types of software [2].

2.4 Registration of point cloud data

Due to the restricted range of TLS, several stations must be set up to acquire a 3D point cloud based on the reference frame of each station in order to collect whole landslide slope data. Point cloud registration aims to align and unify the point cloud data acquired by each station into the same reference coordinate system to obtain complete point cloud data. In general, point cloud registration consists of two steps: coarse registration and fine registration [3]. There are three primary algorithms for fine point cloud registration: feature point matching, iterative closest points (ICP), and robust global registration 4PCS [4].

2.5 Filtering of point cloud data

To correctly monitor landslides, non-slope points such as vegetation and infrastructure must be removed prior to post-point cloud processing. The filtering algorithm is primarily concerned with the geometric aspects of the topography and the density of the point cloud. The most common morphological methods are the iterative least squares interpolation, irregular triangulation, mathematical morphology and elevation and slope-based raster filtering methods. However, there is no general vegetation filtering algorithm due to the diverse geometric patterns of the slopes [4].

2.6 Global georeferencing

Point clouds can be georeferenced using any software package. The technique involves allocating a set of 3D coordinates to the centre of several visible targets in the point cloud. Since they have been measured on the ground, their position in relation to a specific reference system is identified. The software tool generally enables the automated recognition of the target shape in spherical, cylindrical, or flat forms. Bordering the portion of points on the target may be required to be employed for the fitting calculus to estimate the centre's position precisely. Correct georeferencing in a stable reference system over time enables accurate comparison of scans in an absolute system for ground monitoring [2].

2.7 Digital Elevation Model (DEM)

All point clouds may be compared across time once they've been framed in a common reference system. A DEM that replicates the earth's surface is required to make the comparison. DEMs can be grid based or triangulated irregular network (TIN). The precision of a DEM and its capability to accurately replicate the surface is determined by terrain structure, interpolation algorithm and sample density [5].

3. Results and Discussion

In this chapter, the outcome of previous research related to advantages and limitations of TLS will be discussed. Then, the applicability of TLS to monitor different type of landslide movement and material is identified. Finally, the comparison for the TLS models and measuring range will be analysed.

3.1 Results

i. Advantages and limitations of TLS

The advantages of TLS from previous research are provide a detailed 3D model of the landslide surface as they have a high acquisition rate and high-resolution point clouds [2]. Besides that, TLS is easy to transport and can be set up quickly [6]. In addition, TLS can detect centimetre scale displacement and is suitable for long-term landslide monitoring [7]. Moreover, TLS is a suitable alternative to GB-InSAR deformation monitoring for early warning monitoring of landslides [8]. Next, TLS has better spatial resolution and accuracy than aerial photogrammetry and ALS [9]. Lastly, the orientation of the landslide may be estimated using data gathered from the scanner using the three-point problem technique [10].

The limitations of TLS are the filtering process of point cloud data in high vegetation areas is challenging [11]. On top of that, TLS is unable to scan the topography of the seabed [9]. Lastly, TLS data accuracy was insufficient to investigate densely vegetated areas in terms of landcover and process rate [12].

ii. Applicability to monitor different type of movement and material

Based on the review of 22 previous research, three of the research did not specify the type of landslide movement. Six research implement TLS to monitor rockfall, followed by four research for earth slides. There are three research studies related to earth flow type of movement, while the rockslide and complex movement have two previous research studies. Lastly, there is only one previous research related to debris flow and rock topples type of movement. It can be concluded that the research of spread type of movement using TLS is still not sufficient. However, all types of material in landslide movement can be detected by using TLS.

Table 1: Number of research papers for different type of movements and materials.

Type of movements and materials	Number of research papers
Rock falls	6
Rock topples	1
Earth slide	4
Rockslide	2
Earth flow	3
Complex	2

iii. Measuring range of TLS

Based on the review, the Reigl scanner has the highest measuring range of 6000 m and is most frequently used by researchers to monitor different landslide occurrences. It may be the most frequently used TLS scanner due to its higher measuring range capability than other models. The scanner model with the second highest frequency is Leica with the maximum measuring range of 2000 m. Optech and Trimble scanners have the same frequency used in the previous study with a maximum measuring range of 1500 m and 1300 m. Lastly, Topcon and MAPTEK scanners have the same frequency used by researchers in previous studies and maximum measuring range.

Table 2: Frequency and maximum measuring range of TLS in previous research.

TLS model		Frequency used in previous studies	Total	Maximum measuring range (m)
Reigl	VZ-400	3	11	6000
	LMS-Z240i	2		
	VZ-2000	2		
	VZ-2000i	1		
	VZ-1000	1		
	6000	1		
	LPM-2k	1		
Leica	Scan Station C10	1	6	2000
	Scan Station II	3		
	Scan Station C5	1		
	HDS-8800	1		
Trimble	GX	1	4	1300
	VX	1		
	TX8	1		
	TX5	1		
Optech	Ilris 3D	4	4	1500
MAPTEK	I-site 8200	1	1	500
Topcon	GLS-1500	1	1	500

3.2 Discussions

Based on the review of previous research, it is found that the main advantage of TLS is providing a detailed 3D model of the landslide surface as they have a high acquisition rate and high-resolution point clouds. Besides that, TLS is easy to transport and can be set up quickly. In addition, TLS can detect centimetre scale displacement and is suitable for long-term landslide monitoring. It is also found that TLS is a suitable alternative to GB-InSAR deformation monitoring for early warning monitoring of landslides. Furthermore, TLS has better spatial resolution and accuracy than aerial photogrammetry and ALS. In addition, the orientation of the landslide may be estimated using data gathered from the scanner using the three-point problem technique. Lastly, a comparison of DEMs from different epochs generated from TLS point clouds can detect the direction of landslide displacements, obtain geological features such as ridge and valley feature points, quantify erosion and deposits volumes and categorise rockfalls. The common limitation of TLS is the complicated and time-consuming vegetation editing process, inability to scan topography of seabed and impotence of millimetre scale deformation accuracy.

The lack of research on spread type movement could be caused by most researchers focusing on locations of steep slopes, while spread type movement commonly occurs on mild slopes or flat surfaces. The spread failure is due to liquefaction and often happens in cohesive material that sits on top of liquefiable material. However, the study area must also be suitable for TLS to monitor the landslide as TLS has difficulties acquiring data in high vegetation and shadow areas. It is recommended that other landslide monitoring techniques such as Interferometric Synthetic Aperture Radar (InSAR), photogrammetric, Global Positioning System (GPS) and geotechnical sensors be implemented with TLS to cover the limitations of TLS.

From the analysis of the maximum range of scanners, the frequency of the scanner model used by researchers in the previous study correlates with the maximum measuring range of scanners. It can be concluded that researchers prefer to use the scanner with a higher measuring range.

4. Conclusion

This paper has review previous research to identify the applicability of TLS to monitor different landslide occurrences and determine the advantages and limitations of TLS to monitor different landslides. It is found that TLS can be used to monitor rockfall, earth slides, earth flow, rockslide, complex, debris flow and rock topples.

Aside from that, TLS is lightweight and easy to set up. TLS can also detect centimetre-scale displacement and is suitable for long-term landslide monitoring. TLS is also proven to be a feasible alternative to GB-InSAR deformation monitoring for landslide early warning monitoring. Furthermore, TLS provides higher spatial resolution and accuracy than aerial photogrammetry and ALS. Furthermore, using the three-point problem technique, the orientation of the landslide may be calculated using data from the scanner. Ultimately, comparing DEMs derived from TLS point clouds from multiple epochs can determine the direction of landslide displacements, acquire geological characteristics such as ridge and valley feature points, quantify erosion and deposit volumes, and categorise rockfalls. The complex and time-consuming vegetation editing procedure, inability to scan seafloor topography, and impotence of millimetre scale deformation accuracy are typical limitations of TLS.

The scarcity of studies on spread type movement may be due to most researchers focusing on regions with steep slopes, whereas spread type movement is more prevalent on mild slopes or flat surfaces. From the analysis of the maximum range of scanners, the frequency of the scanner model used by researchers in the previous study correlates with the maximum measuring range of scanners. It is evident that researchers opt to use scanners with a greater measurement range.

The vegetation editing process can be eased by using a full-waveform instrument. The manual filtering method takes a long time and does not always result in complete success. The use of a full-waveform instrument and software tool that can take advantage of this feature allows for a quick and efficient initial separation between the vegetation and the ground; however, the separation results must be carefully checked to ensure that they are reliable. The data must be edited to eliminate noise;

nevertheless, without this, the data cannot be used for an accurate quantitative study of the displacement. In order to solve the limitation of TLS to scan the topography of the seabed, a new algorithm based on the classic flow-oriented coordinates transformation is developed to create riverbed topography from measured cross-sections. The algorithm incorporates the dimensionless channel width (DCW) processing method to improve prediction accuracy vastly. The produced riverbed topography can be combined with the floodplain DEM to form an integrated DEM for 2D and 3D hydrodynamic simulation models. Additional registration algorithms, including fixed targets and stable points, can be tested in the future to increase the monitoring precision of this system to sub-centimetre or even millimetre levels. An improved station arrangement or Airborne Laser Scanning (ALS) can be implemented to eliminate the DTM spacing inaccuracy due to incomplete scanning of the slope.

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