"TECHNOLOGY IN NATURAL DISASTER PREVENTION AND RISK REDUCTION"

HANOI UNIVERSITY OF NATURAL RESOURCES AND ENVIRONMENT

41A Phu Dien road, Phu Dien ward, North Tu Liem, Hanoi

dhtnmt@hunre.edu.vn

(84-24) 37645798

hunre.edu.vn

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WORKING PRINCIPLE AND ERROR SOURCES EFFECTING THE RESULTS OF THE 3D TERRESTRIAL LASER SCANNING TECHNOLOGY IN NATURAL DISASTER RESEARCH

Hanh Tran

University of Mining and Geology, Vietnam

Corresponding author. Email: hanhtranvub@gmail.com

Abstract

The 3D Terrestrial Laser Scanning (TLS) is a modern technology. It is widely applied in many fields today, including natural disaster research. The aims of the paper are to study the working principle and to analyze the error sources affecting the results of the TLS. There are two main groups of TLS errors including instrumentation errors caused by the quality of fabrication, assembly and correction of optical, mechanical, and electronic parts of the scanning device; and methodological errors that the measurands themselves are determined by 3D TLS equipment. This study will help the technicians and researchers in resolving the quality of the collected data, as well as in choosing reasonable equipment when performing different work purposes.

Keywords: Working principle; Error sources; 3D Terrestrial Laser Scanning; Natural disaster.

1. Introduction

1.1. 3D Terrestrial Laser Scanning technology

Nowadays, the power development of information technology on the basis of the microprocessor and digital technologies is increasingly moving towards the trend of automation in all areas of production activities in order to minimize the impact of humans on the products. The 3D TLS is a revolution in ground data collection for 3D applications [1].

In terms of the 3D TLS operating principle, it is similar to the working mechanism of new generation electronic total station instruments, which is to use the light speed with the time that the signal from the source to the objects and return to the source in order to calculate the distances [1]. The fundamental differences are in the laser wavelength, the numbers and speed of data acquisition of points (point clouds), field-work operations, and measurement data processing.

Soohee Han presented an automated and efficient method for extracting tunnel segments using the TLS data in 2013 [2]. The proposed method has proven to offer advantages, including detailed description and improved efficiency of survey and data processing. Chen et al., studied using point cloud data and images obtained from the TLS to automatically restore and regenerate industrial facilities in 2013 [3]. Object and equipment details in the factory were automatically scanned and recognized through cylindrical modeling algorithms. Hanh Hong Tran et al. compared the similarities and differences between the use of 3D terrestrial laser scanning technology in terrain applications and cultural heritage conservation in the case study of Bac Ninh province [4].

Regarding the studies of natural disasters using this technology, there are some typical ones. In 2011, Peter Schürch published a study on complex topographical surface changes using the TLS. It was about the broken rock flows in the Illgraben channel. The author used many scanning periods, at different times, compared the terrain surface through the DTM and calculated the volume of landslides [5].

The 3D TLS is very useful for natural hazards and risk assessment where the morphological investigation is a starting point to evaluate stability properties, to acquire and monitor emergency situations

[6]. A coal mine map with high accuracy using the TLS technology in adverse conditions was studied in 2020 in Vietnam [7]. Open pit and underground mine maps are usually established by conventional surveys such as total stations. However, a low point density often results in low accuracy maps.

1.2. 3D TLS devices

There are several famous TLS which are used popularly today.

The Leica ScanStation P50 scanners of the Leica Geosystems use ‘waveform processing’ which is the most advanced technology with the fastest signal transmission and reception (up to millions of points per second). In addition to using ‘time - of - flight’ technology for distancing calculation, it also allows real-time waveform processing to determine multiple reflections of the same emitted pulse. It allows identifying intermediate objects on the moving path before touching the ground surface, with a measuring distance of 1000 m [8].

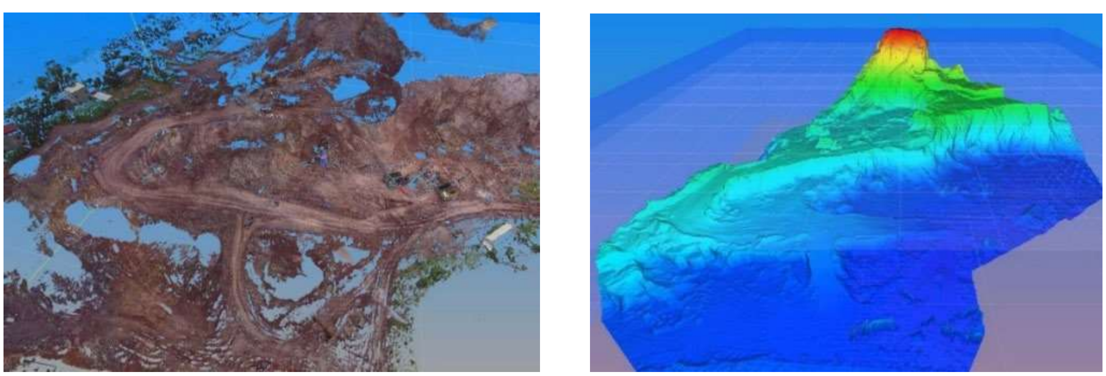
The Trimble SX10 scanners use ‘time - of - flight’ technology to determine the distances, with a measuring distance of 700 m, a speed of 260 thousand points/second and an accuracy of ±2.5 mm [9].

The FARO Focus3D S350 scanners are devices that use ‘phase shift’ technology to determine the distances, with a measuring range of 350 m, a speed of up to 976,000 points/second, and an accuracy of ±3.5 mm. In addition, this is a product that integrates a camera with a resolution of up to 70 megapixels, an HD photography mode and the most compact size (size 240 × 200 × 100 mm, weight 5.2 kg) [10].

GEOMAX’s SPS Zoom 300 scanners use the ‘time - of - flight’ technology to determine the distances. The scanning distance is from 2.5 - 300 m, the accuracy is ±10 mm at 100 m distance. It is composed with 2 digital cameras and 5 megapixels resolution [11].

1.3. Main applications of 3D TLS

There are many applications of the 3D TLS technology in terrain and non - terrain fields [12] (Figure 1, Figure 2). In terms of the terrain field, for example, establishing the topographic maps; building the DTM; measuring and determining the cross sections and volumes; monitoring and assessing terrain changes, etc. The 3D TLS is applied for mapping purposes not only to sparse feature areas but also to high - density areas. The main strength of the method is to transfer the workload of creating large - scale topographic maps into the office - work. Thus, the amount of fieldwork will be reduced many times.



(a) ***(b)***

Figure 1: Topographic survey of land mines in the Bac Giang province
((a) Point cloud model; (b) DTM model)

There are also many applications of the 3D TLS technology in the non - terrain field including the application in architecture, construction and construction design; application in archeology; applications in the oil and gas sector; applications in medicine.

This technology is applied in forecasting dangerous disasters such as the application of detailed 3D modeling by the 3D TLS with a monitoring system in the online mode to assess the details of the disaster recovery process, the problem occurs especially for meaningful constructions. In addition, it also improves the flexibility and efficiency of decision management in the field when a disaster occurs.

(a) ***(b)***

Figure 2: 3D model in the design and construction of civil works [70]
((a) Point cloud model; (b) Photo taken from a digital camera)

2. Working principle of 3D TLS

The essence of the TLS is to measure the distance with high accuracy from the scanning station to the feature points, record the corresponding scanning directions (according to the vertical and horizontal scanning angles), the same measurement ones as the total stations. However, the TLS system produces a very large number of coordinates of scanned points with the 3D scanned images [13].

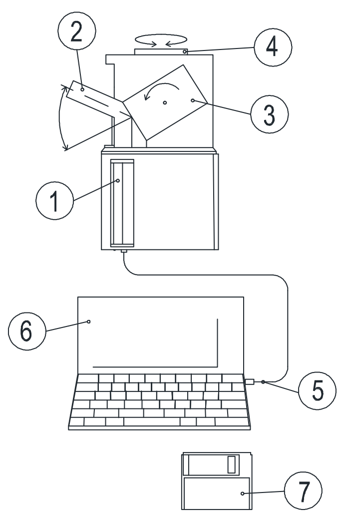


Figure 3: Components and principle diagram of the 3D TLS [62]

1 - Laser length measurement; 2 - Long transmission and reception routes; 3 - Scanning mirror (prism); 4 - Scanner head; 5 - Laser scanner wire to computer; 6 - Laptop with specialized software; 7 - Data saver

The 3D TLS system consists of scanning equipment and specialized high-speed processing computer equipment installed with specialized software [14]. The laser scanning equipment system is composed of a block of adaptive laser measuring devices with high frequencies and a rotating block of TLS equipment (Figure 3).

The operating principle of the 3D TLS device is to automatically obtain coordinates on the basis of measuring distances and angles from the scanning stations to the objects. The main differences with aviation laser scanning are the structure of the scanners and the TLS device in a static state during the operation.

The 3D TLS results can be also saved in another form by the density of the laser reflected point cloud of the features with five characteristics including three spatial coordinates (X, Y, Z), signal intensity and true color (Figure 4).

(a) *(b)* *(c)*

Figure 4: 3D TLS results ((a) Intensity photo; (b) Real color photo; (c) Point cloud)

3. Error sources affecting 3D TLS's results

All errors of measurands when using the TLS can be divided into two groups including instrumentation errors are caused by the quality of manufacturing, assembly and correction of optical, mechanical, and electronic components of the scanning device; method errors that the measurands themselves are determined by the 3D TLS device.

3.1. Instrumentation errors

These errors are shown in the profile of the scanning device during the manufacturing and assembly process and are periodically checked. The accuracy survey results include conclusions about the accuracy of each component block by technical characteristics. Eliminating equipment errors in principle is only by replacing parts or by manufacturing technology.

3.1.1. Working stability of TLS equipment

Using a laser radiation source in the scanning station is either continuous or pulsed with high frequency, which can easily lead to burning of the laser source itself and the internal space of the scanner. Therefore, in the equipment system, a cooling unit is often assembled.

If the equipment is not cooled, the following damage will result including the hot laser source will lead to deformation of the rotating and measuring parts of the TLS station; and jamming of the rotating part of the scanner resulting in broken equipment [15]. In the TLS equipment, the cooling step is done in two ways including exchanging cool air from outside by fan system; and expelling hot air from the device by using a nitrogen vacuum pump.

3.1.2. Accuracy of distancing length measurement block of TLS

The error of measuring distance by phase measurement method with different ways is determined by the formula (1) [16]:

$$M_R = \sqrt{m^2{}_c + \left(\frac{v}{4\pi f}\right)^2 m^2{}_\alpha + R^2 \left[\left(\frac{m_f}{f}\right)^2 + \left(\frac{m_v}{v}\right)^2\right]} \quad (1)$$

Where, m_c - The error that determines the stability correction of the device;

$m\alpha$ - Error determining the phase difference between the origin and the measuring point signal;

m_f - Error due to difference in frequency of measurement with its reference value;

m_v - Error that determines the speed of electromagnetic waves in the atmosphere.

Among the error components, the error of determining the phase difference leads to the largest total error of measuring the distance of the TLS station. The error m_f is due to frequency instability and reference phase has the same property. Given the soft frequency variation of the laser scanners, the m_f error will mainly depend on the phase measurement method. The phase measurement error includes both random and systematic errors due to frequency setting to the standard and due to frequency drift delay of the frequency generator.

3.1.3. Errors of angle measurement blocks of TLS station

We see randomly generated errors of the TLS equipment angle blocks, resulting in code bars, code discs with number plate overlays, pulse disks, combination tables. On that basis, the error of angular measurement blocks of the 3D TLS station is divided into the following groups [16]:

- Device eccentricity;
- Graduation table errors;
- Horizontal tilt of a prism or mirror;
- Tilt of the vertical axis of the device;
- Inclination errors of the readout plane relative to its axis of rotation.

In addition, there is an additional error due to tilting the vertical axis of the device into the vertical position (there is an error when assembling the micro-adjustment of the tilt angle) when using the laser scanner tilt angle micro-adjuster. Besides, there is the measuring angle error by laser scanning due to the structure of the long-period and short-period digital readout.

3.2. Methodological errors

Methodological errors are usually eliminated during the processing of scan results. They can be mentioned as follows [17]:

- Methodological errors are caused by the surrounding environment (atmosphere, refraction, attenuated electromagnetic waves, device vibration, etc.);
- Methodological errors are caused by the characteristics of the scanned objects (size, scanning directions, structure, color, etc.).

To eliminate methodological errors caused by TLS, there are two basic solutions can be applied. The first one is to evaluate separately the effects of the causative components to eliminate errors. The second one is using statistics synchronously to deal with the influence of factors causing measurands like the elimination of systematic errors into pixel coordinates in the photogrammetry method.

3.2.1. Environment effects

There are the influences of factors such as atmosphere, refraction, attenuating electromagnetic waves, vibration of equipment, etc. The measurands from the TLS station (distance, vertical angle, horizontal angle, point intensity, actual color of feature surface, signal reflected from them) show the influence of the atmosphere, especially the layer near the earth's surface.

The significant changes in air density, air mass movement and oscillations lead to a decrease in the speed of light transmission and a change in the direction of radiation (refraction) as well as a decrease in the density of the reflected signal, and chromatic aberration is often called the blur effect [16]. Almost all of the above-mentioned factors affecting the actual scanning accuracy are not eliminated. This leads to a decrease in the measuring characteristics of the scanner.

3.2.2. Errors caused by characteristics of scanned objects

The characteristics of the scanned object that affect the 3D TLS results can be mentioned as size, scanning direction, structure, color, etc. Affecting the 3D TLS results shows the basic nature of the scanned object are shape and reflectivity, which are determined by material composition and color. The influence of the measuring objects on the accuracy of spatial information, which mainly appears about the error of the measuring distances.

3.2.3. Effects of scanning parameters and scanner characteristics on the accuracy of measurement results

When using the 3D TLS, it is necessary to select equipment, technical parameters and technological processes to build the DTM ad DSM according to the accuracy requirements and the detailed level.

Determination of TLS station characteristics includes as follows:

- Maximum vertical and horizontal scanning resolution;
- Wavelength of laser radiation;
- Edge, vertical and horizontal angle measurement accuracy;
- Dispersion of the laser beam.

3.2.4. Errors during data reference transformation

When conducting the fieldwork, the scanner stations need to fix in order to minimize the machine's vibration during the scanning process. The errors are related to the acquisition and response of data of the scan rays from objects in the form of a point cloud to refer to a geodetic reference system. These influencing factors will be described in details on data quality [18] including as follows:

- Accuracy of determining the coordinates of the scan point and the response signal of the scan ray.
- Accuracy of the measuring azimuth (K) from the scanning stations to the echo targets.
- Scanning device setting errors: scanner balance, scanner optical centering accuracy and scanning target accuracy, response scanning target accuracy (with the optical zoom lens).

3.2.5. Errors in data format conversion

Similarly with other graphic data processes, converting (exporting or importing) the 3D laser scan data from different software has the potential to cause errors or alter data quality because each application software has different methods, formats and operating mechanisms [16].

4. Conclusions

The 3D TLS technology operates on the foundation of science, technology and information technology development. It affirms its superiority compared to other traditional technologies and contributes to strengthening and modernizing the survey, mapping and geographic information. The article was studied about the working principles of the 3D TLS and the error sources (instrumentation and methodological errors) affecting the results of 3D TLS. It is found that the errors in the data parameter conversion process have a large and systematic influence on the accuracy of the point cloud.

The research will contribute to supplementing and perfecting the theoretical basis of the working principle as well as the error sources of the 3D TLS for scientific research in many fields, including natural disaster research. This research will help the technicians and researchers improve the quality of the collected data, as well as in choosing reasonable equipment when conducting different work purposes.

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