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Slope excavation quality assessment and excavated volume calculation in hydraulic projects based on laser scanning technology

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Abstract

Slope excavation is one of the most crucial steps in the construction of a hydraulic project. Excavation project quality assessment and excavated volume calculation are critical in construction management. The positioning of excavation projects using traditional instruments is inefficient and may cause error. To improve the efficiency and precision of calculation and assessment, three-dimensional laser scanning technology was used for slope excavation quality assessment. An efficient data acquisition, processing, and management workflow was presented in this study. Based on the quality control indices, including the average gradient, slope toe elevation, and overbreak and underbreak, cross-sectional quality assessment and holistic quality assessment methods were proposed to assess the slope excavation quality with laser-scanned data. An algorithm was also presented to calculate the excavated volume with laser-scanned data. A field application and a laboratory experiment were carried out to verify the feasibility of these methods for excavation quality assessment and excavated volume calculation. The results show that the quality assessment indices can be obtained rapidly and accurately with design parameters and scanned data, and the results of holistic quality assessment are consistent with those of cross-sectional quality assessment. In addition, the time consumption in excavation quality assessment with the laser scanning technology can be reduced by 70%−90%, as compared with the traditional method. The excavated volume calculated with the scanned data only slightly differs from measured data, demonstrating the applicability of the excavated volume calculation method presented in this study.

Keywords: Slope excavation; Quality assessment; Volume calculation; Three-dimensional laser scanning technology

1. Introduction

In hydraulic engineering, slope excavation needs to be conducted before the pouring of concrete for dam foundations, dam abutments, water inlets, and so on. The quality of excavation projects directly affects the stability and safety of main structures. Highly efficient and precise control of excavation projects can not only reduce the workload and cost and shorten the time duration, but also diminish the disagreements between owners, contractors, and supervisors.

In the excavation process, the average gradient, overbreak and underbreak, and half cast factor (HCF) of each excavated surface should be inspected (Zhu and Sun, 2010). Quality assessment and testing methods are mainly based on profile analysis through assessment of characteristic point coordinates selected from excavated surfaces using the total station, theodolite, or other instruments (Li and Chen, 2004; Zheng et al., 2012; Fu, 2012). However, these instruments have some limitations: first, all these surveying methods are single-point surveying methods, the amount of data acquired is limited, and data processing is time-consuming and inefficient; second,

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hydraulic engineering project sites are generally located on complex terrain, and complete data sets are difficult to obtain, especially on steep terrain and inaccessible locations; third, data accuracy depends greatly on external environmental factors. Therefore, a new approach for excavation quality assessment should be developed to meet the construction requirements.

The three-dimensional (3D) laser scanning technology can capture integrated, comprehensive, consecutive, and associated panoramic coordinate data with high precision and resolution at an extremely high speed. This method has been widely applied in Ordnance Survey and earthwork engineering, including surveying of landslide deformation (Strouth et al., 2006; Xu et al., 2010), building structures (Olsen et al., 2010), rock deformation (Kim, 2002), and shoreline evolution (Olsen et al., 2009). A landslide volume was precisely evaluated by Du and Teng (2007) using a 3D laser scanner and GPS in Taiwan. Dong (2007) developed a highly precise digital terrain model (DTM) for an engineering project based on 3D laser-scanned data. Zhang and Arditi (2013) proposed an automated progress control method using the scanning technology. However, literature and methods related to the application of the 3D laser scanning technology in hydraulic engineering are rare because of the limitations: first, there are no official standards or instructions regarding the application of this technology in hydraulic engineering; second, the data quantity acquired by the laser scanner is much higher than that acquired by other instruments, and it is difficult to process such massive data sets automatically; third, research needs to be conducted on quality assessment indices and calculation of the excavated volume with scanned data at a high efficiency.

This study aimed to demonstrate that the 3D laser scanning technology is capable of slope excavation quality assessment. Two different types of scanners were used in this study. A workflow of slope excavation data acquisition was developed, which is quite different from that of traditional methods, such as those involving the total station, GPS, or real time kinematic (RTK) technology. A ray casting algorithm was used for scanned data de-noising, a least-distance algorithm was used for data compression, and an effective scanned data management method using the SQL server was introduced. According to the *Inspection and Assessment Standard for Separated Item Project Construction Quality of Water Conservancy and Hydroelectric Engineering-Earth-Rock Works* (SL 631−2012), methods for slope excavation quality assessment using the average gradient, slope toe elevation, and overbreak and underbreak were established. An excavated volume calculation method was also presented in this study. To verify these methods, a field application and a laboratory experiment were carried out.

2. Methodology

2.1. Data acquisition and management

2.1.1. Data acquisition by 3D laser scanner

Two types of laser scanners were used in this study: the Leica ScanStation C10 and Leica HDS8800. Table 1 compares the main parameters of the two scanners.

In practice, these two scanners can handle different situations. The HDS8800 can scan a large area with a high-resolution camera of 70 million pixels, and capture a clear picture of the target from a far distance at a high speed, whereas the ScanStation C10 can scan a small area at a low speed from a short distance, but with a high precision. In this study, the HDS8800 was used to collect data at a hydropower construction site in southwestern China to verify the method of slope excavation quality assessment. To verify the excavated volume calculation, The ScanStation C10 was used in a laboratory experiment carried out at China Three Gorges University.

2.1.2. Data de-noising

The outline of each excavated surface can be considered a polygon, and the polygon vertexes refer to the control points of the excavated surface. The scanned area must cover the entire surface to ensure data integrity. During the scanning process, some noise points, meaning useless points, may be generated. These noise points can be divided into two categories: peripheral points and isolated points. Peripheral points are points outside the surface area, whereas isolated points are points that have an abnormal distance from the scanned surface. Isolated points are often caused by dust and ground vibration during the scanning process. To delete peripheral points, a ray casting algorithm was used in this study. The algorithm is appropriate for both convex and concave polygons. The workflow for the ray casting algorithm is shown in Fig. 1. The isolated points were removed in the data compression process.

2.1.3. Data compression

The scanned data contain millions of points. Thus, processing those data with high precision requires large amounts of computer memory. The computational efficiency will decrease, and some errors may be generated. According to the *Code for Water Resources and Hydropower Engineering Surveying* (SL 197−2013), the average point number in a specified area should be 8−15 per 100 cm^2, which means that the maximum distance between two points should be 0.035 m. However, the point density acquired by a highly accurate scanner is much higher than the standard. Therefore, a data

Table 1
Comparison of parameters of two scanners.

Scanner	Scan distance (m)	Reflectivity (%)	Scan angle (°)		Speed (points/s)	Accuracy (mm)
			Vertical	Horizontal		
HDS8800	1 400	80	80	360	8 800	10−200 000
	500	10				50−2 000 000
ScanStation C10	300	90	270	360	50 000	4−50 000
	134	18				