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Applications of terrestrial laser scanning for tunnels: a review

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Abstract: In recent years, the use of terrestrial laser scanning (TLS) technique in engineering surveys is gaining an increasing interest due to the advantages of non-contact, rapidity, high accuracy, and large scale. Millions of accurate 3D points (mm level accuracy) can be delivered by this technique with a high point density in a short time (up to 1 million points per second), which makes it a potential technique for large scale applications in engineering environments such as tunnels, bridges, and heritage buildings. Tunnels, in particular those with long lengths, create great challenges for surveyors to obtain the satisfactory scanned data. This paper presents a short history of TLS techniques used for tunnels. A general overview of TLS techniques is given, followed by a review of several applications of TLS for tunnels. These applications are classified as: detecting geological features of drilling tunnels, monitoring the geometry of tunnels during excavation, making deformation measurements, and extracting features. The review emphasizes how TLS techniques can be used to measure various aspects of tunnels. It is clear that TLS techniques are not yet a common tool for tunnel investigations, but there is still a huge potential to excavate.

Key words: terrestrial laser scanning; tunnel; deformation measurement; cross-section extraction; measurement planning

1 Introduction

In recent years, the use of terrestrial laser scanning technique in engineering surveys is gaining an increasing interest due to the advantages of non-contact, rapidity, high accuracy and large scale. This technique delivers millions of accurate 3D points (mm level accuracy) with a very high point density in a short time (up to 1 million points per second), which makes it a valuable alternative or complementary technique for classical topographical measurements based on total station or digital photogrammetry. The terrestrial laser scanning can still deliver very accurate points even in the situations where other topographical techniques are

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difficult or impossible to use.

The digital photogrammetry is inapplicable under some extreme conditions, such as the drilling tunnels, but the laser scanning is applicable in these complex situations. The measurement with a total station is also an option, but the advantage of the laser scanning is obvious: instead of focusing on the rather limited number of specified points, the laser scanning delivers millions of 3D points in a complete monitored tunnel section.

Recently, the improvements of this technique regarding the speed, accuracy, software algorithms, and the fall in price have introduced a high potential of large scale applications in highly demanding engineering environments such as tunnels, bridges, and heritage buildings. Tunnels, in particular those with long lengths, create great challenges for surveyors due to difficulty to obtain the satisfactory geometry of the scanned data.

The high resolution point clouds provided by laser scanning techniques have several applications in construction of tunnels (Decker and Dove 2008; Fekete et al. 2010; Fekete and Diederichs 2013; Roca-Pardiñas et al. 2014), such as construction survey of tunnels (Kong and Ou 2013), extraction of cross-section (Han et al. 2013) or feature line (Yoon et al. 2009) of tunnels, and deformation measurement of tunnels (Gordon and Lichti 2007; Han et al. 2013b).

2 Terrestrial laser scanning

2.1 LiDAR techniques

The core technology of the terrestrial laser scanning is the LiDAR technique, which is used to obtain the distance of each object point from the lens. The acronym LiDAR stands for light detection and ranging. The laser system produces and emits a beam (or a pulse series) of highly collimated, directional, coherent, and in-phase electromagnetic radiation. When the light reflected by the surface of an object is received, the system can calculate the range by the flight time and acquire the reflectivity of the surface. Fig. 1 shows one example of the laser scanners, and Fig. 2 illustrates the principle of the laser scanning technique. There are two different methods of range determination: phase and pulse (Jaboyedoff et al. 2012). The former is more accurate in range but suffers from a limited range. Alternatively, the latter can measure in a greater range. Therefore, the latter is implemented in most TLS used for the measurement of civil construction.

Fig. 1 An example of laser scanner

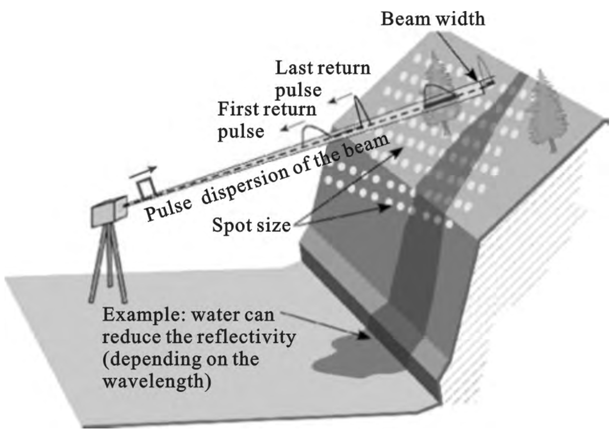

Fig. 2 Principles of laser scanner data acquisition

2.2 Measurement principle

A laser scanner consists of a transmitter/receiver of the laser beams, a scanning device and a timing device (Fig. 2). The scanner sends out laser pulses then receives and records the reflected signals. The timing device measures the time of flight (Δt), with which the scanner can compute the distance d

$$d = \frac{c\Delta t}{2} \quad (1)$$

where c stands for light speed.