Application of Three-Dimensional Laser Scanning and Surveying in Geological Investigation of High Rock Slope

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ABSTRACT: The appearance of 3D laser scanning technology is one of the most important technology revolutions in surveying and mapping field. It can be widely used in many interrelated fields, such as engineering constructions and 3D measurements, owing to its prominent characteristics of the high efficiency and high precision. At present its application is still in the initial state, and it is quite rarely used in China, especially in geotechnical engineering and geological engineering fields. Starting with a general introduction of 3D laser scanning technology, this article studies how to apply the technology to high rock slope investigations. By way of a case study, principles and methods of quick slope documentation and occurrence measurement of discontinuities are discussed and analyzed. Analysis results show that the application of 3D laser scanning technology to geotechnical and geological engineering has a great prospect and value.

KEY WORDS: 3D laser scanning system, point cloud, high steep slope, rock mass structure, quick documentation.

INTRODUCTION

With the implementation of Chinese western development policy and the demand of power transmission from west to east of China, a series of key projects of hydraulic engineering and water-power engineering are under construction or planning. These projects are getting larger and larger, and corresponding slopes excavated are also getting higher and higher. Slope stability problem as a rock mass mechanics problem is restricting engineering construction feasibility and is influencing construction safety. High slope stability evaluation is usually based on the investigations of geological structure conditions (Huang et al., 2007, 2004). Hydroelectric resource is commonly exploited in high mountain areas with very deep and steep valleys. Geological investigation is very difficult there because it is nearly impossible for researcher to achieve the target location. In addition, quick geological investigation is just required to suit quick slope excavation with modern machines during engineering construction. How to enhance the efficiency and precision of geological investigation has become a very important problem. In order to resolve it, a new geological investigation technology has to be adopted, which should be characterized by high efficiency, precision, and applicability.

In view of those difficult problems above, domestic and foreign researchers proposed some
technical methods, such as digital photographic survey (Li et al., 2004) and digital picture interpretation (Fan and Li, 2005), which had been used in many engineering construction areas. But all the technical methods need to reprocess pictures that have been taken from digital camera. The processing is complicated, furthermore the precision declines. In addition, they still demand a lot of field investigations (Chen et al., 2002). They have too many irreformable problems. Consequently, they cannot be further widely applied.

Three-dimensional laser scanning technology, however, is effective in solving these problems above. It is also called the real-life scenery duplication technique (Fan et al., 2004) because it can veridically rebuild the scanned object and swiftly give three-dimensional coordinate data of the object. The technology is mainly characterized by high precision, quick speed, and high fidelity. This equipment can pick up truthful three-dimensional data directly from the object and rebuild the object model. The whole process does not need any kind of surface treatment. And finally processing of point cloud data is reliable due to the truthful data achieved from object through laser scanning. So this method is widely applied to engineering constructions and three-dimensional measurements fields, such as civil engineering, conservation of historic buildings, protection of historical relics, factory remodeling, and urban planning (Cheng and Liang, 2004).

Three-dimensional laser scanning technology is of international focus in the area of surveying and mapping fields, and prompt application of this advanced technology to geological investigations of high slope will entail great practical significance to engineering constructions.

APPLICATION OF 3D LASER SCANNING TECHNOLOGY TO ENGINEERING

Just as the increasingly large scale of Chinese water conservation and hydroelectricity engineering construction, the project problems of high steep slope are also getting more and more recognition. The investigations of those slopes are difficult because of dangerous geological conditions. Some engineering slopes reach several hundreds of meters high, some are even almost one thousand meters high. Traditional methods of geological measurement and investigation are inefficient to those slopes and sometimes they are unsatisfactory due to low precision of measurement results. The appearance and development of three-dimensional laser scanning technology provided a new method for engineering slope investigations regardless of middle or long distance. It made more options of methods viable (Ma, 2005).

Orientation Application in Engineering

Three-dimensional laser scanning technology can obtain 3D data of target object, even under complex scene conditions. But the technology has faults in some aspects and needs to be improved constantly, such as the orientation problem of scanned scene. Up to now, the problem has been resolved through geodetic coordinate conversion. Different types of laser scanner have different methods of geodetic coordinate conversion, but all of them have the same principle, that is, first selecting three typical reference points in point cloud of scanned scene, and second confirming geodetic coordinates of those three points. Through this method, relative coordinates of all points can be obtained by scanning, and at last they can be converted into geodetic coordinates. This process needs several times of land surveying. Coordinate conversion precision is commonly affected by some operation conditions, such as occurrence measurement and survey of rock mass structure in vertical or horizontal direction. And it will have corresponding influence on measurement results.

Some types of laser scanners can adjust themselves to horizontal plane automatically, but they can not set orientation on their own. Based on experimentation, the authors found a simple orientation method: an auxiliary geological compass was added to ILRIS 3D laser scanner manufactured by Optech Company in Canada. And using this method, a good orientation result can be obtained even in a small space. This method can still quickly confirm scanning load and horizontal plane without geodetic coordinates. Rock mass structure parameters and vertical or horizontal distance can be measured in laser scanner system coordinates. The operating process is presented as follows. Lay aside geological compass on
the head of tripod after the tripod is set. By virtue of centering control blister, readjust three feet constantly until head of tripod keeps level; fix the scanner on the head of tripod but don’t fix it too tightly so as to freely rotate. Then, examine two level blisters on the scanner base. If they are not at center, readjust feet of tripod. Since the shape of ILRIS 3D three-dimensional laser scanner is approximately square, its scanning axis (Y axis) is parallel to the sidewall of scanner. By the same token, the X axis is vertical to sidewall and Z axis is vertical to bottom (Fig. 1). Angle $\alpha$ between scanning axis (Y axis) and north orientation has to be recorded because all scanning data are going to be rotated ($-\alpha$) degree around Z axis in order to accord with the object orientation. The scanning orientation precision of a compass is low because of many aspects, such as the precision of a compass itself and personal errors. Another main reason for the low precision is that the process of orientation is only accomplished in one situs, especially in a wide space. In general, both level error and orientation error are less than one degree. These errors lie in whether the tripod is at level or the angle (with north) is accurate. Some practices are shown in Table 1. This method is suitable for the condition that precise geodetic coordinate measurement is not available at some spot or the scene is required to be quickly measured without high precision.

**Measurement of Rock Mass Discontinuity Occurrence**

The occurrence of rock mass discontinuities is the most basic geological data in a survey, but it often variegates greatly, especially for long and big faults, and some important occurrences of rock mass discontinuities are very difficult to measure by hand because of special topography. All factors above result in the difficulties of obtaining precise occurrence of rock mass discontinuities. But the three-dimensional laser scanning technology can effectively resolve those problems. Although the software of three-dimensional laser scanning system (PolyWorks 8.0) doesn’t directly provide tools to measure occurrence of rock mass discontinuities, the occurrence can be measured with the “plane” tool in the software. This method can conquer the disadvantage of a compass because at this juncture occurrence measurement can be accomplished only at a single point site. And its result is perfect (the process is shown in Figs. 2–3). First, the point cloud of rock mass discontinuities is selected in processing software. Second, a plane is created by the point cloud, which can simulate the rock mass discontinuities by the “plane” tool in the software. Finally, these plane equation parameters are shown and the rock mass discontinuity occurrence can be calculated by the equation. The plane equation is shown as follows

$$Ax + By + Cz + D = 0$$

$A$, $B$, $C$, and $D$ are parameters. They constitute normal vector coordinates of plane: $n = \{A, B, C\}$. Y axis corresponds with north in the laser scanning system coordinates, the $X$ axis corresponds with east, and $Z$

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**Table 1** The orientation practices of laser scanning with compass

<table>
<thead>
<tr>
<th>Rock occurrence</th>
<th>Scanned orientation with compass</th>
<th>Scanning distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N18°W/SW ∠ 57°</td>
<td>N18°W/SW ∠ 57°</td>
<td>50</td>
</tr>
<tr>
<td>N18°W/SW ∠ 56°</td>
<td>N17°W/SW ∠ 57°</td>
<td>100</td>
</tr>
<tr>
<td>N18°W/SW ∠ 56°</td>
<td>N17°W/SW ∠ 57°</td>
<td>200</td>
</tr>
<tr>
<td>N14°W/SW ∠ 63°</td>
<td>N15°W/SW ∠ 64°</td>
<td>50</td>
</tr>
</tbody>
</table>

**Table 2** Calculation of discontinuity occurrences

<table>
<thead>
<tr>
<th>Parameter of the plane equation</th>
<th>Rock mass discontinuity occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$ 0.857 887</td>
<td>Strike N26°E</td>
</tr>
<tr>
<td>$B$ 0.409 343</td>
<td>Dip SE</td>
</tr>
<tr>
<td>$C$ 0.310 593</td>
<td>Dip angle 72°</td>
</tr>
<tr>
<td>$D$ 20 706.251 535</td>
<td>Occurrence N26°E/SE ∠ 72°</td>
</tr>
</tbody>
</table>

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Investigations of Surface Fissures and Geological Documentation of High Steep Slope

In general, some slopes in the southwest mountainous zone of China are too high and steep to obtain the data by hand for the stability evaluation. Under this condition, how to explore the rock mass discontinuities is an important problem, especially to make sure the right location of rock mass discontinuities. However, application of three-dimensional laser scanning technology provides an extremely effective solution of this problem.

The intake slope of a power station on Yalongjiang River (Fig. 4) is very steep, about 200 m high. The rock mass discontinuities survey of this slope is very difficult because the slope is nearly not climbable. Three-dimensional laser scanning system was used for geological survey of the slope. It took three hours to obtain the data of 7 173 125 points in the process of field scanning. After these data were processed, images of the long and big joints exposed on the steep slope surface were surveyed. Trajectories of rock mass discontinuities were copied by a “polyline” tool in IMInspect, which was a module of software PolyWorks, and then the occurrence of rock mass discontinuities was measured. These joints can be classed according to the scanning and survey data (Fig. 5), and they could also be exported to software AutoCAD (Fig. 6).

Besides geological investigations of high steep slope, there are many excavation practices about it. Because the scale of working surface is becoming increasingly large, and the excavation speed is also
being increased, the documentation is required to speed up to adapt to excavation speed. To meet the requirement above, three-dimensional laser scanning system was applied to this field. Proven in practices, it had greatly enhanced work efficiency and data precision. Altogether, the application of three-dimensional laser scanning technology in slope excavation mainly contributed to finding out regularities of distribution and geometry parameters of rock mass discontinuities.

Quickly Creating Topographic Map of High Steep Slope

Plotting topographic map is the premise and foundation of the engineering design and construction. Along with everyday change of science and technology, the measurement equipment and method had also changed tremendously. In addition, the efficiency and precision of topographic map survey had been unprecedentedly improved. But it is still very hard to get the efficiency and precision terrain survey of some special project spots, such as unclimbable escarpment. As a new method of terrain survey, three-dimensional laser scanning technology can enhance the efficiency and location adaptability, as the following example shows.

During the construction of a small hydropower station on Minjiang River the top of seepage tunnel near the outlet had collapsed partially, which led to the tunnel blockage by cracked rock and partial sinkage of the corresponding slope surface. The accident greatly affected the progress and safety of the construction. Therefore, the disposal of the accident was obligatory and urgent (Fig. 7a). There were commonly great differences between the initial terrain and the present conditions because of excavation and support. So it was necessary that the topographic map of the slope had been surveyed quickly. Traditional survey method needed much time and labor resource, but the construction time was so limited that there was no more time to wait. In view of this condition, the three-dimensional laser scanning technology was used, and then all the above problems were solved.

It took about two hours to scan the slope, and at last, data of 9 949 507 points were collected (Fig. 7b). After geodetic coordinate conversion of the scanned point cloud data, the scanned three-dimensional data created a topographic map in which the vertical distance between contours was one meter (shown in Fig. 8).

The topographic map created by laser scanning data can reflect the detail of terrain much better than traditional survey methods, especially, for the steep slope and rugged surface. In addition, the scanned data can create refined section outline of the slope quickly.

Other Applications

The three-dimensional laser scanning technology can still be used in monitoring slope deformation because it has high precision and can process a number of data quickly, but the premise is such that the slope deformation is much bigger than the instrument error of point position. Unstable slope will be scanned periodically so that the trend and magnitude of slope deformation can be displayed through the comparison among scanned images. Three-dimensional laser scanning technology enjoys high superiority to the traditional monitoring of slope deformation. First, it doesn’t need to bury the monitoring equipment in slope body in advance, which can save time and power; second, it is convenient and rapid because the measuring device doesn’t need to touch the object, which reduces danger level for investigators; third, it is not influenced by tremor of construction and exploding; and last, but not least, the monitoring results reflect the whole trend of slope deformation, which breaks through the limit of the traditional method that only does measurement in a single point.
Measurement of cubic meter of earth and stone is fussy but is a delicate job in construction period. Application of three-dimensional laser scanning technology to this measurement can enhance the precision and efficiency.

In short, the three-dimensional laser scanning technology can be applied in many aspects, especially those fields in which traditional survey method has poor contribution.

**DISCUSSION**

As the three-dimensional laser scanning system may realize long-distance range and noncontact survey, the system shows great superiority when dangerous or unclimbable sites are measured. In addition, this technology breaks through the limit of traditional survey way because it substitutes “surface” survey for “point” survey. Main characteristics of three-dimensional laser scanning system are quick survey and high precision. The latter processing software has such formidable functions that it can meet most requirement of survey work. Moreover, the system has secondary developing functions. The output of scanned data is convenient and the output-data can be used by other software.

However, at present, three-dimensional laser scanning technology is deficient in some ways: (1) the scanning distance and scope is limited because the safe laser power is low; (2) blind spots often appear in the scanning scope because some special materials are insufficiently sensitive to the laser photosource reflection, such as moist ground and green vegetation, which has tremendous influence on laser scanning; (3) errors often occur during the coordinate system conversion and it is difficult to avoid these errors because the adjusting method of coordinate system is immature (Zheng et al., 2005); (4) it is difficult to distinguish the peripheral details of the scanned object.
because laser facula becomes bigger with the scanning distance increasing.

Like other technologies, the three-dimensional laser scanning technology is experiencing a process of invention, development, and maturation. It has some deficiencies, but they will overcome along with the development of future technology.

CONCLUSIONS

Three-dimensional laser scanning technology is a new method in survey domain, which breaks through the limit of traditional “one point” survey method (Mao and Wang, 2005) and points out a new research direction for survey domain. The appearance and development of three-dimensional laser scanning technology is “an important technological revolution in survey domain after the application of global positioning system—GPS, which can bring the research contents and methods of survey to a new development stage”. Three-dimensional laser scanning technology is applicable to geotechnical engineering and geological engineering. The survey of rock mass discontinuities parameters and the quick documentation of excavation surface are better developed with laser scanning technology, and this research work can provide a new method to resolve project problems. At present, three-dimensional laser scanning technology is still at a developing stage. Although it has some deficiencies, it has a spacious application prospect for the future.

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