Engineering Survey Applications of Terrestrial Laser Scanner in Highways Department of the Government of Hong Kong Special Administration Region (HKSAR)

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Key words: Terrestrial Laser Scanner

SUMMARY

This paper describes about the development on the engineering survey applications by making use of the "contact-free" laser scanning technology in Highways Department of the Government of HKSAR. In early 2006, the department purchased one set of terrestrial laser scanner. Since then, it has been used for the capture of survey data in different highway working environments. Discussion is around the experience gained in the surveying of ground profile of high-speed roads where traditional survey is greatly difficult to be done without road closure, the steep roadside slope and the headroom clearance of high-voltage overhanging cables across the expressway. The strengths, limitations, and other possible applications of using the terrestrial laser scanner in highway engineering surveys are also addressed.

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1. INTRODUCTION

1.1 Surveying Principles

Terrestrial laser scanner is making use of the high definition laser scanning technology for measurement of surface profile of objects. Measurement is either by time-of-flight or phase-resolving principle [6]. In view of the advantages such as suitability for long range measurments, higher spatial resolution, no requirement for post-processing to provide extensive noise filtering [3], the time-of-flight systems have been widely developed in the terrestrial larser scanner industry. When taking measurement, the scanner transmits laser pulse to the surface of the object which reflects the laser signal back to the instrument. The distance between the scanner and the object is determined by multiplying the light velocity with half the time-of-flight between the signal transmission and reception. Combining the distance with the measured horizontal and vertical angles and having them georeferenced with the known survey control points, the three dimensional coordinates of each single point on the surface of object can be worked out. Unlike the traditional total station of only making a few measurements in a minute, the terrestrial laser scanner captures thousands of surface points (i.e. point cloud) instead. After making a series of distance measurement in uniform angular increments in both horizontal and vertical planes, the terrestrial laser scanner can provide a detailed portrait of the surface of the object.

1.2 Highway Working Environment

The Highways Department of the Government of the HKSAR is responsible to develop and upkeep the road network as well as to plan and implement railway development to world class standards. To achieve these departmental goals and objectives, the surveying staff have to provide high quality surveying supports for the planning, design, construction and maintenance of the road network, and the implementation and updating of the railway development strategy. In this connection, the survey of existing ground profiles is of particular importance for the design, construction and ongoing maintenance of the road and railway network. In Hong Kong, the traffic is extremely busy. Road closure for surveying ground profiles, in particular for the high speed roads, is costly, easy to attract public discontent and not easy to be approved by the Police and Transport Department. To overcome the difficulties and for safety sake, the terrestrial laser scanner that employing the "contact-free" laser scanning technology is considered as a useful supplementary surveying tool for getting the road profiles without the need of road closure. In early 2006, the department purchased one set of Leica HDS3000 terrestrial laser scanner. Since then, it has been used for the capture of survey data in different highway working sites including the tasks highlighted in the forthcoming paragraphs.

2. THE TERRESTRIAL LASER SCANNER

The Leica HDS3000 terrestrial laser scanner consists of the hardware and software components as shown in Figure 1. The hardware includes the main scanner unit, a notebook computer to drive the scanner unit and to store the scanned data temporarily at field, the special proprietory targets and a desktop PC in office for processing the scanned data. The software includes the Cyclone, Microstation with COE (Cyclone Object Exchange) and the Cloudworx for Microstation. Cyclone is used to drive the scanning unit at field with the notebook and process the scanned data with the desktop PC in the office. The Microstation with COE is a plug-in application for exchange data between Cyclone and Microstation. Whereas, the Cloudworx for Microstation is another plug-in application module to enable the viewing of point clouds under Microstation environment.

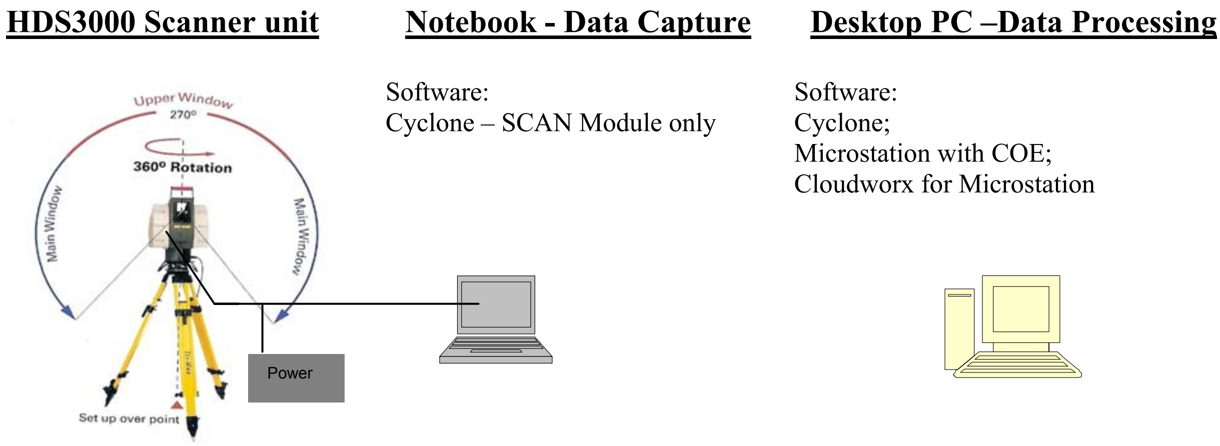


Figure 1 – Setup of Terrestrial Laser Scanning System

3. WORKFLOW OF SCANNING SURVEY

The workflow of employing the terrestrial laser scanner for survey is broadly divided into 2 parts, i.e. field operation and office compilation.

In the field, the scanner controlled by a notebook has to be set up at a location with good view to the site area to be surveyed and safely out of traffic. The scope of scan should be defined and done with an appropriate density that meeting the accuracy requirements of the deliverables. Scan may be required to take place in more than one set-up station if the area to be surveyed is large or due to other site constraints. Depending on the survey requirement, the station where the scanner is set up may be required to link up with the target stations which have been or to be surveyed by traditional ground survey methods in terms of the local coordinates system (i.e. Hong Kong 1980 Grid System) and the local level datum (i.e. Principle Datum of Hong Kong).

When returning to office, the scanned data is compiled by going through the steps of registration, geo-referencing, data clean-up, point selection and model/2D drawing creation [5]. Registration is the process for merging various point clouds from individual scans together in a correct and 3D geometry with a single coordinate system. Geo-referencing is for tying the point clouds to the Hong Kong 1980 Grid System (HKGS). For doing so, coordinates of the targets in HKGS have to be provided. Data clean-up includes removing noise and differentiating features from the point cloud. The noise is produced during the scanning when undesired features were surveyed. e.g. the passing vehicles and pedestrian. Point selection is the process to pick up useful points from point clouds and then assign suitable feature codes with the aid of a function of the Cyclone, i.e. Virtual Surveyor. Model or 2D drawing creation is to create the surface model of the selected points with the MXRoad software or output a two dimensional drawing with the Microstation.

4. INSTRUMENT TEST AND TRIAL SURVEYS

Instead of conducting a rigorous investigation on the accuracy of the Leica HDS3000 under a controlled environment in laboratory [1] & [7], a test of the instrument on its distance measurement accuracy was done in paragraph 4.1. In addition, the instrument was used in two trial surveys in paragraphs 4.2 and 4.3 for testing its effectiveness in the typical highway working environment.

4.1 Distance Test

This test is to compare the distances measured from the scanner to the standard target plate mounted with a white paper against the known distances ranging from 10m to 100m [4]. The results in Table 1 reveal that the scanner is able to achieve its claimed accuracy (+/- 4mm @ 1-50m; 1 sigma, σ) within its effective range at 95% confidence level.

Interval (m)	Known Distance Ro (m)	Measured Distance Rm (m)	Difference Ro – Rm (mm)	Interval (m)	Known Distance Ro (m)	Measured Distance Rm (m)	Difference Ro – Rm (mm)
0 – 10	10.000	9.998	+2	0 – 60	59.997	59.993	+4
0 – 20	20.000	19.995	+5	0 – 70	70.000	69.997	+3
0 – 30	30.000	29.996	+4	0 – 80	79.998	79.997	+1
0 – 40	39.998	39.992	+6	0 – 90	89.990	89.991	-1
0 – 50	50.002	49.998	+4	0 – 100	99.985	99.990	-5

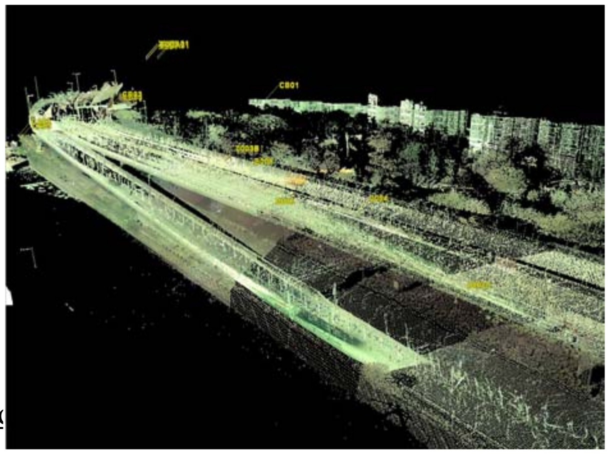
Table 1 – Test on Distance Measurement of Leica HDS3000

4.2 Trial Survey for High-speed Road

This is a test survey in addition to the instrument test in paragraph 4.1. The road features along a portion of high-speed road, Kwun Tong Bypass near Laguna Park, in Figure 2 are scanned at a known station with a good view of the site. Like the conventional topographical surveys, the scanned data is geo-referenced to the Hong Kong 1980 Grid System, then processed in MXRoad and output to the Microstation environment for production of a topographical survey plan of scale 1:500. The final plan of this survey is then compared with the topographical survey plan of same scale done by a reflectorless total station previously for the design of retrofitting of noise barrier along the carriageway.

Photo

Scanned Point Clouds



In both surveys, the site is surveyed without road closure. However, the field operation by using refectorless total station has been found slow and tedious. Field time is drained to recognize distant ground features and to wait for the reflected signals which are often interrupted by the busy traffic. For the scanning survey, thousands of points are captured at a suitable density in a few hours. Due to the site constraints, some of the scanned feature points are captured at a distance outside the recommended effective range of the instrument and with flat angle of incidence. Despite of these, the ground model is formed. After filtering away the unwanted points such as the false measurements due to the passing vehicles, the point clouds are geo-referenced and processed to produce a 1:500 topographical survey plan. By comparing the processed data and the topographical plans of the two surveys, the results illustrate that the field measurements of the scanner can achieve centimeter level accuracy which is acceptable for general engineering purposes. The scanner is found effective for surveying of high-speed road ground profile without road closure.

4.3 Trial Survey for Roadside Slope

This is another test survey in addition to the one in paragraph 4.2. Previously, a topographical survey for a roadside slope next to Lin Tak Road of Lam Tin (Figure 3) was conducted by traditional ground survey method using the total station and prism reflectors. The surveyed data is for the design of slope stability measures associated with the widening of the road. The slope is about 100m x 80m in area. It is steep and difficult to access. Some portions of the slope are covered with vegetation. At that time, scaffoldings had been erected and safety harnesses were used to facilitate the surveying staff to access the dangerous locations of the steep slope in order to complete the survey and produce a 1: 500 topographical survey plan.

Photo

Scanned Point Clouds

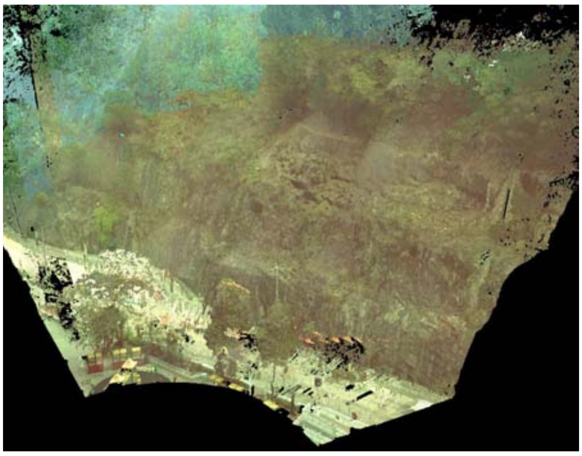


Figure 3 – Photo and Scanned Point Clouds of Roadside Slope at Lin Tak Road

In this test survey, the same slope is surveyed using the terrestrial laser scanner without the aid of the scaffoldings and safety harnesses. The scanner is set up at a staircase opposite to the slope. It is high enough and has a good view to scan the slope surface and features where some of them are dangerous for having direct access. Like the other test survey, the scanned data is subsequently geo-referenced and processed to produce a 1:500 topographical survey plan with contours of 1m intervals. By comparing the two contour plans, the positions and levels of the surveyed points are consistent with each other. In addition, the scanner is found effective for surveying inaccessible slopes with no vegetation cover because field time and cost for erecting the scaffoldings are saved. More importantly, the risk to staff arising from gaining direct access to the steep and dangerous locations can be minimized. However, the scanning survey of roadside slope is not without limitations. The laser beam requires a clear line-of-sight between the scanner and the measured object features. This has debarred the survey of invert levels of the channels on the slope. Besides, the laser beam is unable to penetrate vegetation that making the vegetation areas blank. To fill up the blank areas or collect the invert level of surface drains, supplementary ground survey by traditional methods is still required.

5. SCANNING TASKS

The terrestrial laser scanner has been deployed for surveying the ground profiles of high-speed roads, roadside slopes, and the headroom clearance of high voltage cables, etc. Among the completed surveyed tasks, the following two cases are highlighted.

5.1 Uneven Road Surface Survey

This is a ground profile survey for a portion of the high-speed road, Yuen Long Highway (Tuen Mun Bound) near Shap Pat Heung Interchange (Figure 4). Upon receiving the report from drivers about the bumping caused by the uneven road surface in the concerned area, a detailed ground survey is requested to find out the area-in-question and the magnitude of unevenness. From the preliminary investigation at site, the change of road levels in the concerned area is too small and difficult to be detected with naked eyes. If conventional survey method is used in collecting the level data of the carriageway, it would be necessary to carry out a ground profile survey at 20cm grid intervals at the concerned portion. This is time consuming and difficult for doing so on high-speed road that requiring special logistics and road closure arrangement and usually takes time to get the approval from the relevant authority.

Photo　　　　　　　　　　Point Clouds

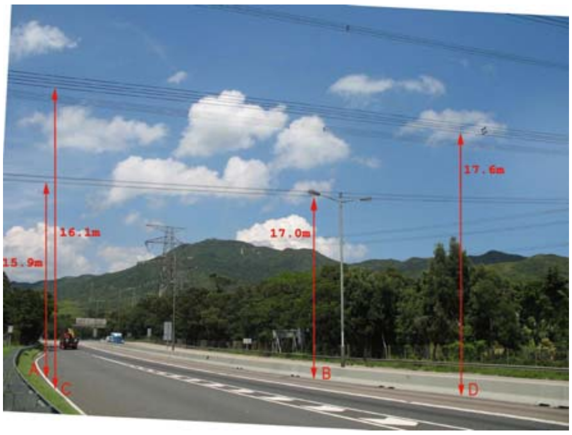
Figure 4 – Photo and Scanned Point Clouds of Yuen Long Highway

The suspected portion of carriageway is subsequently surveyed by the terrestrial laser scanner from two stations next to the high-speed road which are safely out of traffic and of good view to the carriageway. The maximum scanned distances are about 60m and its scan coverage is about 120m x 15m. The scanner has captured about 1 million of points and provided a representation of the ground profile in a few hours at field. Among the measured points, unwanted points such as the false measurements due to the passing vehicles are filtered out in the office. The useful points are then geo-referenced and modeled for the production of a 1cm interval contour plan. From the contours pattern, the uneven area is easily identified for remedial works.

5.2 Headroom Clearance of High-tension Power Cables over High-speed Road

This is a survey for the headroom of the overhanging high-tension power cables over a high-speed road, i.e. the Fanling Highway, near Hong Lok Yuen. The site is shown in Figure 5 where some high-tension power cables run across the road. The vertical clearance information is requested for the proposed road widening design. Conventional survey method using total station and prism target is not feasible due to the great potential danger of the high-tensioned cables and inaccessibility. The use of reflectorless total station has once been considered. However, it is difficult and time-consuming to survey the points on the cables and their corresponding points on the carriageway surface in order to determine the vertical clearance above the ground.

Photo



Point Clouds

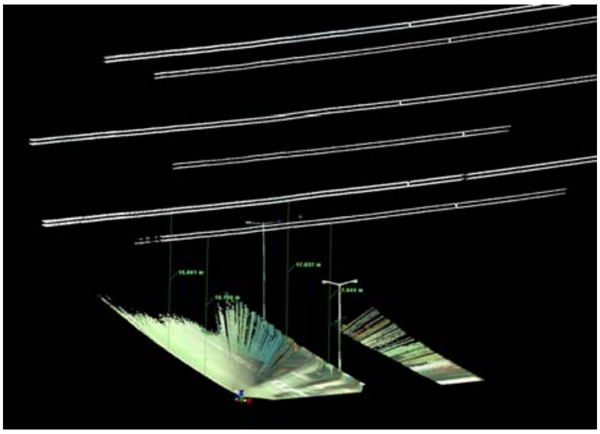


Figure 5 – Photo and Scanned Point Clouds of Overhanging Cables across Fanling Highway

To overcome the site constraint and difficulties encountered by the traditional survey method, the headroom is eventually surveyed by the terrestrial laser scanner. Similarly, the scanner is set up at the side of the high-speed road with a good view to the power cables and road surface. The distances of scan are within 50m. It takes about one hour to capture thousands of points of the cables and the road surface with centimeter accuracy. Since the relative height difference is able to meet the work requirement, there is no need for geo-referencing the scanned data, hence to link the set-up station of the scanner with the local coordinates system and level datum. This in turn saves a lot of time in both field survey and data processing in the office. Direct measurements of the headroom of cables are made by measuring the corresponding pairs of points of power cable and road surface from the captured point cloud in Figure 5. As illustrated, the terrestrial laser scanner has been proved a very effective tool for surveying the headroom of overhead cables where direct access is difficult or inaccessible.

6. EXPERIENCE GAINED

In the instrument test and the two trial surveys as mentioned in the foregoing paragraphs, the terrestrial laser scanner is able to meet the general engineering requirements in capturing survey data for the preparation of topographical plan of scale 1:500 and measurement of headroom clearance of overhead power cables or highway structures. The accuracy of the measured points is dependent on the incident angle between the laser beam and the object's surface. In general, shorter range and sharp angle of incidence will yield accurate points. A flat incident angle of less than 5 degrees of the laser beam on the object's surface of longer range will affect the precision of the measured points.

The scanner is able to measure a large number of points on an object's surface in a short time. However, the object features such as building corners or edges falling between two successive angular increments of the laser beam in either horizontal or vertical planes may not be completely measured by the laser beam due to its spot size. When the laser beam spot hits the object edge, only part of it will be reflected there. The rest may be reflected from other objects behind. The object edge may therefore be missed from the data set. This edging effect can be minimized technically by adjusting the resolution of the scanner to the smallest possible increment of the angle between two successive laser spots on the object's surface at field [1]. Or else, the building or feature edge can be modeled in office by intersecting the two adjacent plane surfaces of the same building in the captured point cloud with the proprietary software of the scanning system during the data processing stage. Besides, experience tells that the scanner works well for both dry and wet surface. However, special care should be taken when comes across the existence of a shallow layer of water on the road surface or the object surface is of high degree of reflectivity such as glasses, since the scanner is unable to measure or may give unreliable measurements for these surfaces. It also works independent of lighting conditions and performs well both indoor and outdoor under dim light conditions.

As illustrated, the scanner demonstrates its advantages over the conventional survey methods in the ground profile survey for high-speed roads without road closure and topographical survey for inaccessible slopes. Field working time is relatively short in collecting data as compared with the conventional survey methods. However, supplementary survey by traditional methods for those areas blocked by line of sight or vegetation is still required. In addition, considerable time is required to process the huge volume of data in the office, from registration to geo-referencing, noise removal to the differentiation of features from the scanned data, selection of points/lines for the export of data to MX and Microstaion for computation and preparation of survey plan. Experience shows that the ratio of field to office working time of a scanning survey is about 1:5. The office time can be reduced with the accumulation of the experience of staff.

7. CONCLUDING REMARKS

The terrestrial laser scanner is an effective tool for conducting engineering surveys. It is complement to but not substitute for the conventional surveying tools. Unlike the traditional Electronic Distance Measurement (EDM) equipment that the number of times for a measurement is usually repeated and averaged, the terrestrial laser scanner has much faster data acquisition rate since the number of laser shots may be as few as one. Because of this special characteristic, the scanner has enabled the survey of ground profile of high-speed roads even the traffic flow is high and shortens the field time significantly.

With the built-in camera device, the scanning environment can be recorded in addition to the captured point clouds. The photos plus the dense, accurate and comprehensive point clouds of the whole surveyed area can provide more complete and accurate survey data, and hence minimize the needs of returning to the site for further clarification. The 3D models of ground profile can also be further manipulated and visualized for subsequent detail design and analysis. Besides, the capabilities of working under the dim light working environment and allowing real time 3D visualization of the site while scanning have certainly added values for the scanner to be used for the engineering surveys in less favourable working conditions.

From the experience of the scanning surveys, the terrestrial laser scanner is found effective and accurate enough for the ground profile or as-built survey of high-speed roads without the need of road closure for general engineering purposes. Apart from the key safety benefit, it helps avoid the high cost/time implications and the easy attraction of public discontent arising from the road closure. The scanner is useful for surveying features of inaccessible and steep slopes without dense vegetation where erection of scaffoldings is usually unavoidable for sake of safety when the conventional surveying methods are employed. In the case of measuring the headroom of overhead power cables over the high-speed road, the laser scanning survey method has been proved of extremely high value in measuring the relative height difference directly from the captured point cloud without the need of paying extra field and office efforts to have the scanned points geo-referenced to the local grid system and level datum.

The terrestrial laser scanner on the other hand is not without limitations. It is not advisable for use in adverse weather conditions, such as under foggy, misty and rainy weather, because the water drops in air may cause noise or false signals for the measurements. Like the conventional EDM equipment, a clear line-of-sight from the scanner to the ground features is required. The scanner is thus unable to survey the ground profile of slope covered with vegetation and the invert levels of channels on slope. To have a full picture of the ground profile, clearance of vegetation prior to scanning or supplementary survey by conventional survey is required. It is also unable to scan the road surface with a shallow layer of water due to its high reflective nature. In addition, its effective working range is shorter than that of the EDM's. More office time is required for the post data processing in filtering the noise signals and differentiating ground features from the measured points in office despite that the field time for scanning is shortened in comparison with the conventional survey methods.

8. THE WAY FORWARD

The terrestrial laser scanner will be used more widely for the highway engineering survey applications in the department. At present, some scanning test surveys are being conducted in parallel with the traditional survey methods for the monitoring of roadside slopes/retaining walls which are difficult for having direct access. Unlike the conventional monitoring survey methods which only give the surveyed positions and levels of the monitoring marks installed at selected locations, the scanner can depict the trend of movement/settlement of the whole structure by comparing the scanned 3D models captured at different time epochs. Although the precision of the scanner has restricted the monitoring accuracy at centimeter level for the time being, the scanning method is a useful means to record surface model data for the analysis of deflection of the structures. There are many other applications relevant to the functions of the department to be explored, such as the heritage survey to archive historical buildings and structures that affecting the highway projects, modeling of bridges and viaducts, scanning of tunnel profile geometry, asset management, etc. With the advance of technology and the accumulation of experience, it is anticipated that the terrestrial laser scanner can contribute further in enhancing the efficiency and effectiveness of the engineering survey operations.

BIOGRAPHICAL NOTES

The author has been working in the land and engineering survey discipline since 1978. He is a Member of the Hong Kong Institute of Surveyors (MHKIS) and the Royal Institute of Chartered Surveyor (MRICS). He was awarded with the MSc in Information System in 1997 and is now working as the Senior Land Surveyor in the Highways Department of the Government of the HKSAR.

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