Paper ID: 278

Assessing the Accuracy of Terrestrial Laser Scanner Against the Total Station for Surveying Applications in Sri Lanka.

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Abstract: 3D laser scanning or terrestrial lidar instruments have been in used in surveying task since the 1990's but it is very new technology for the Sri Lankan surveying field. Terrestrial laser scanners have been proven to be a very versatile surveying instrument with applications in many sectors of use like, Detail topographic survey, Road & Railway survey, Construction Site, Volumetric Survey/ Mining Survey, Monitoring Survey, Critical location survey, Crime Scene, Accidents, Tunnel Survey, BIM – Building Information Modelling & EMP – Electrical Mechanical Plumbing and Archaeological site survey.

The results of any surveying task must meet specific conditions to provide the required accuracy. Therefore, any surveying work includes not only the relative positions of points and objects but also an accuracy of the results. It is imperative that a new technology like terrestrial laser scanning instrument before been use in the actual field data collection to go under accuracy analysis for Sri Lankan field conditions.

One of the fundamental theories is "Practical is up on proven principal" in accordance with this theory the accuracy of the terrestrial laser scanner is going to be analysed against the most commonly used surveying instrument in the field the Total station. The comparison will be done in normal Sri Lankan field condition with weather, heat, and pressure to get much better accuracy comparison.

The experiments are designed in the following way, two traverses from both the Total Station and the Terrestrial Laser Scanner are going to be run on the same set of ground points then 3D error of each measurement is going to analyse using adjustment theory. The calculation will be done using and computer algorithm.

Key words: 3D laser scanning, 3D

Introduction

Surveying is the technique, profession, art and science of determining positions of features of the ground and the distances and angles between them and as to construct a map, plan, or numerical output of it. But the traditional technical definition of surveying can be expressed as follows,

"Surveying has been traditionally defined as the science and art of determining the relative positions of points above, on, or beneath the surface of the earth, or establishing such points."

Surveying is the second oldest professions in the world today. The history of surveying starts in the 1400 B.C. Egypt where Egyptians first used it to accurately divide land into plots for the purpose of taxation. From that surveying has developed along with the time and surveying field has sub divided into many division like Engineering, Cadastral, Hydrography, Remote sensing, geographic information system etcetera. With the development of the technology, the surveying instruments have also developed along with the time and method used for the survey.

In 120 B.C Greeks developed the first piece of surveying equipment (Diopter). Then the chain was developed in 1800 A.D. with the Beginning of the industrial revolution. At that time people thought that the chain is the most accurate instrument but later with the industrial revolution a lot of technologies for the surveying field were developed like the theodolite. With the introduction of the theodolite to the world and to the surveyors. The theodolite became the most popular angle measuring instrument among the land surveyors for last two centuries. It is a descendent of rudimentary angle measuring equipment such as optical square, sextant and astrolabe used to obtain vertical or horizontal angle measurements using graduated circle. Gradually the concept of the theodolite was developed which could measure horizontal and vertical angles simultaneously. The idea was appeared in the appendix of Magarita Philosophica by Gregorios Reisch published in Starasborg in 1512. Martin Waldseemuller, a germen topographer, and a cartographer made the device in 1512 and called the instrument as "polimetrum". The first occurrence of the word "Theodolite" was found in the surveying textbook "A Geometric Practice" by Leonerd Gigges. Later many technical developments made the theodolite precise easy to use vertical and horizontal angle measuring equipment to be a surveyor's choice in the field of land surveying.

Then Erik Bergstrand, the inventor of the Geodimeter, was made a radio receiver in the early days of broadcasting. In 1939 he got a position as geodesist at the Geographical Survey Office in Stockholm and invented a new type of instrument to measure distances by using the light signals, knowing the speed of light. Bergstrand however chose the Kerr cell method used by e.g. Karolus in Germany and Anderson, United State of America. Bergstrand had chance to join the new Nobel Institute of Physics and then he built an experimental model to measure the distance between two stations by using both light and radio signals. That was the introduction of the EDM to the world.

In 1960's with the digital revolution another technological breakthrough happened that was the introduction of the total station. Total stations are equipped with internal electromagnetic distance meter fixed aligned with the line of sight of the digital theodolite. It also equipped with a microprocessor to compute coordinates and other surveying related functions, internal memory to store data digitally, and alpha numeric keypad and a display unit as input and output devices.

In 1960's the Light Detection And Ranging (LiDAR) technology has been introduced and used for air borne surveys and the LiDAR instrument was mounted on air plane for air borne survey activities.

When presenting the first Total Station in 1968, nobody could foresee the profound effect this instrument would have on measurement and data-collection techniques. This instrument was the ZEISS RegELTA 14. With the new generation of equipment, the ELTA 2 and ELTA 4, it becomes obvious that the concept of that first instrument - namely combination of an electronic theodolite and optical rangefinder, automatic recording of the data and connection to the computer - is still fully valid today.

Then in 1980's United State Department of Defense introduced the satellite-based positioning system called GPS. The Global Positioning System (GPS) is consists of 24 satellites placed into orbit by the U.S. Department of Defense. This technique was originally used for military applications. In late 1980's, the government made the system available for civilian use. In early 1990's land surveyors start using the GPS system for land surveying and it was significant improvement for some field surveying tasks like horizontal control setting.

In late 1980's with the introduction of commercially viable GPS for the surveying works it was combined with the LiDAR instruments and then the LiDAR data became a useful tool for providing accurate geospatial data for the survey activities.

Then moving on to today, one of the most modern terrestrial surveying instruments is the Terrestrial Laser Scanner. A primary aspect of this study is to find the accuracy of the ground-based Light Detection and Ranging (LiDAR) systems, known as "Terrestrial Laser Scanning (TLS)". TLS instruments emit a pulsed laser signal and then it made to be detected its return signal by the instrument. Time travel of the light beam calculate the distance between the instrument and the reflected object surface, and the pulsed signal is rapid enough that thousands of points can be recorded in seconds. Each point is recorded as three-dimensionally, with an attribute relating to intensity of the returning signal. These observed points are known as a "Point Cloud". These point clouds having tens of thousands of points in a one scan station that are having rich detail of the scene as viewed from the instrument. These scans contain all manmade and natural features that can be "seen" from the instrument's viewing angle.

If think about the data collection modes of the TLS some instrument provides interactive data collection, and others operate in a point-and-shoot mode. Operator identification of targets and detail scanning of specific regions are examples of possible operator intervention during the scanning collection. Different types of TLS provide different range or distance the and the horizontal and vertical viewing angle within an individual scene. Newest versions of laser scanners collect a digital image of the scene in addition to the point clouds.

The results of any surveying task must meet specific conditions to provide the required accuracy. Therefore, any surveying work includes not only the relative positions of points and objects but also an accuracy of the results. In traditional surveying and photogrammetry where defined targets are observed, least squares adjustment based on overdetermination usually yields reliable information concerning the accuracy of the results as well as the accuracy of the observations. If the number of observations is not sufficient for an adjustment, one may estimate the accuracy of the results by propagating the errors of the observation instruments to the results. In this case, the accuracy of the measurement device must be known.

In the case of TLS, tens of thousands points with three dimensional coordinates on a surface of the object is measured in a very short time. Relevant object features, such as corner points or edges, are not directly recorded; instead, they must be modelled from the point clouds in a separate process. So, the problem is that all the existing surveying instruments have many different levels of accuracy depending up on a wide range of factors ranging from instrument type to atmospheric conditions. Before a survey instrument can be used in a survey, surveyor need to have good idea about the accuracy of the instrument. Laser scanner in new instrument to Sri Lanka according to the information there is only one instrument in whole of Sri Lanka. Before it can be used for surveying in Sri Lanka it is important that we identify the capabilities and the accuracy of the laser scanner compare to its rival instrument in the actual field that is been used to surveying work.

3D scanning instrument is a new technology to Sri Lanka, most of the Sri Lankan surveyors do not know about the applications of this Terrestrial Laser Scanner and as well as the accuracy of the instrument.

Terrestrial Laser Scanner

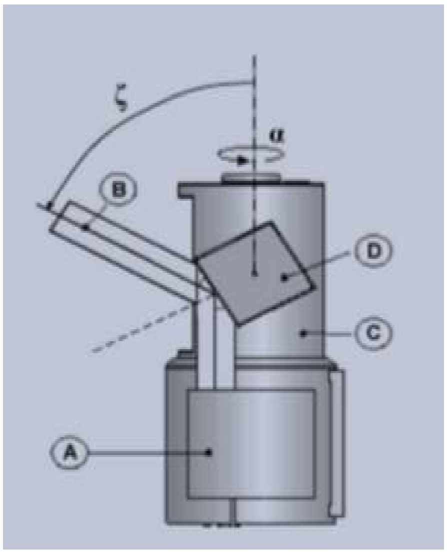
These TLS are primarily based on the "time-of-flight" principle of lidar. That is, a precise electronic time interval meter (TIM) marks the on the time a laser pulse exits the lidar sensor's transmitter, then calculate the duration (commonly in milliseconds) that passes because the laser pulse travels from the transmitter, to the target, and returns as a reflection detected by means of the sensor's receiver. The distance to the target d, is computed by using the equation (Conforti, 2017)

$$d=c.t/2$$

t - Flight time

c – The velocity of light

TLS being a lidar based instrument. It works on the main principle of lidar. Principal of lidar is that we know the speed of the light through the atmosphere and if we are able to calculate the time which it takes a light beam to travel some distances we can easily calculate those distances. This principle is used in most of the Remote Sensing instruments and some early EDM devices. Conforti describes the same principle in the sense of TLS measurements very clearly.



A TLS needs a two axis that are capable of freely rotating in two different planes like modern TS for surveying a different part of the target in different planes. These two-rotation axis directions can be simply explained as the vertical and horizontal.

Figure 3 Principle of TLS (Fangi et al, 2001; Pinarci, 2007)

The modulated laser light plus travels from the electronic unit (Figure 1, A) and hits the optical prism (Figure 1, D) which is rotating at high angular velocity. The surface of this optical unit (which act like a mirror) the plus is reflected and exits the TLS at a specific angle ζ (Figure 1, B). After the scanner has completed acquiring this ζ-profile, the upper part of the Terrestrial Laser Scanner (Figure 1, C) rotates at a very small angle (Δα) around the vertical axis in order to start capturing the next, adjacent ζ-profile. For each view profile, a huge point clouds are obtained, each and every point is defined through polar coordinates α, ζ and d (measured distance to the spot of the reflected beam on the object) (Vozikis et al, 2004). The microprocessor inside the TLS calculates Cartesian coordinates (X, Y, Z) of the points scanned by polar coordinates. The other data that is recorded is the intensity of the reflected laser pulse. (Fangi et al, 2001; Pinarci, 2007).

The working principle is not enough when we are considering the surveying principal of TLS Technology. To get a 3D coordinate of a position it is not enough to have and distance measuring instrument. As the author explains to 3D coordinate of a target the instrument needs the vector from the instrument station to the target. Vector simply means the bearing and the distance. Distance measured using the lidar principal and the bearings are measured using two angle measurement units fixed on to the TLS. They are the horizontal and the vertical angle measurement units as same as a modern TS. But there is a main difference between the two instruments according to the author that is in the modern TS EDM is rotating in the bouth directions but in this case of Terrestrial Laser Scanner EDM stationery because it would be impossible to move the EDM speeds which it requires to collect dense datasets in little time. For that in TLS they use a fixed EDM and a rotating optical element which is basically a mirror that is rotating at very high velocities. The modulated light beam that emits from the EDM (Electronic Unit) hits the rotating optical element and is reflected by it at a specific angle in one vertical circle. After the instrument is done scanning the vertical circle the upper part of the scanner rotates a very small amount to scan the next vertical circle. Using this method TLS can scan a pre-set area around it and collect very dense 3D point dataset. Each and every point obtained is uniquely described by 3D polar coordinates. The internal microprocessors convert values from the polar coordinates to the cartesian coordinates. A special note is that with every measurement light intensity data is recorded of the returning laser pulse. It can be used to calculate the physical properties of the target from using this data. In the same way as the aerial lidar instruments do.

Experimental Design

The best method of analysing the accuracy of TLS is to complete a practical surveying task and find out the accuracy of the resultant data set. Because if we test the accuracy of the Terrestrial Laser Scanner inside a laboratory under controlled conditions we cannot anticipate the effect of the natural factors that common to most of the surveys conducted in the field like temperature, humidity, light condition, weather etc. So, the research method was designed to do in the field by using regular traverse survey method. with the exception of conducting a verification survey in order to verify the data set that have been collected from the TLS. As the verification survey method, the Total Station (TS) survey method (EDM traversing method) have been chosen because it is a proven Terrestrial serving method use by many surveyors around the world.

Methodology

The methodology of this research can be divided in to two main parts they are

i. Field work

ii. Office work

Filed Work

As the first step of the field procedure reconnaissance survey have been done and a prospection diagram was drown indicating all the traverse points. Then the locations for the ten instrument stations were identified on the prospection diagram were marked on the real ground by wooden pegs that were driven into the ground. To mark the instrument stations that are located on cement floor or in tile floor a permanent marker was used. All the instrument stations were set up in a way that they have a clear line of sight.

Table 1: Instruments Used

No	Hardware/ Software	Amount	Type
1	Terrestrial Laser Scanner	1	GLS-1000
2	Total Station with accessories	1	Sokkia CX-101
3	Prism Targets	3	Sokkia
4	Prism Poles with prism	2	~
5	Sheet targets	As needed	~
6	Tri Pod (Wooden)	3	~
7	50M Steel Tapes	1	~
8	Gig Umbrella	1	~
9	Hammer	1	~
10	Topcon Scan-master or Collage-Software	1	Topcon
11	Sokkia Link Software	1	Sokkia

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Even the instrument stations inside the building were set up according to the above mention principle. Then as the first task the TS traverse using the arbitrary coordinate system was ran covering all the instrument stations. Then again TLS was used to traverse using the same coordinate system. From that coordinates of all the instrument station were collected from both methods. For both traverses a three tripod with two prism system was used.

Office Work

When considering the office work there were two main parts

Data processing

Data visualization

Data processing

The data collected by the TLS downloaded as a point cloud to the processing workstation computer with scan-master software that is capable of processing 3D point clouds that are collected from Topcon laser scanners. The coordinates of the traverse points were extracted from the travers data.

The data collected from the TS was download on to the processing workstation computer using a pen drive. Then the coordinates of the instrument station were processed using the Sokkia link software.

Data visualization

From this part visualization of the data collected from the TLS is done. And the points were exported as CAD drawing files by the scan master software and those exported files were open on the CAD.

Analysis

As described in the methodology and the research design, traverse by TLS which verified by the TS were used for checking the accuracy. For the error analysis and to have a result coordinates obtained from the TS are considered corrected values and values that are obtained from the Terrestrial Laser Scanner are considered as the measured values.

Error = Measured Value – True Value

Starting points for both instruments used the same coordinates therefore error that station becomes 0.0000m.

Traverse point and the error on each traverse point are given on the below table.

Table 2: Error comparison for both TLS and TS

Station Number	Error (m)
Stn 2	0.0004
Stn 3	0.0003
Stn 4	0.0007
Stn 5	0.0005
Stn 6	0.0004
Stn 7	0.0007
Stn 8	0.0004
Stn 9	0.0006
Stn 10	0.0004
Stn 11	0.0004

Discussion

The modern TS and the TLS both use the nearly the same working principal so both instruments have the nearly the same amount of accuracy. But with the new software and better hardware TLS allows the user to apply the basic surveying methods in many applications. Some of them have been not possible before the introduction of the TLS. As example to survey small cracks in concrete and other structures in order measure the deformations.

While analysing the above table, station 4, 7, and 9 shows higher errors. When selecting the target stations through the TLS monitor this can be happen. Because Topcon TLS has measured only 2mm points on the targeted object. Therefore, while selecting the target it is better to zoom the target very clearly trough the TLS monitor. All other stations are having small amount of error, that means TLS can be used for surveying works and can be obtained higher accuracy.

Conclusion

As conclusion it is possible to say that Terrestrial laser Scanner can be used in Sri Lankan Surveying industry with high accuracy. The digital data collection from the Terrestrial Laser Scanner is much efficient than the existing terrestrial surveying methods.

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Author Biography

I would like to do my further studies in geodesy, GNNS and LIDAR. My research interests are all related to surveying and earth sciences and I like to find out solutions for the problems in those fields.