

MODULE 1.

INTRODUCTION

Learning Outcomes:

This module gives students an overview of electronic distance measurement (EDM) and the role of 3D laser scanning in land surveying as the latest EDM technology. Student should be able to :

- Explain the evolution of EDM in land surveying;
- Differentiate 3D laser scanning from other types of EDM instruments;
- Distinguish the two types of 3D laser scanning; and
- Explain the role and the current status of 3D laser scanning in land surveying.

Lecture Contents:

1.1 *History of Electronic Distance Measurement*

3D laser scanning is an advanced technology that uses latest laser distance measurement technique to obtain measurements at thousands of points per second. While the use of laser technology to measure distance has been around for many years, the time-of-flight (TOF) laser scanning became available only in the last few years. To understand how 3D laser scanning revolutionizes land surveying, a brief discussion on the history of Electronic Distance Measurement (EDM) is in order.

1.1.1 *The Early EDM*

Electronic Distance Measurement has been used in land surveying for over 50 years . The early EDM instruments employed either a modulated light beam or modulated microwaves for distance measurements. The former was called a *Geodimeter* and the latter *Tellurometer*. These instruments became standard for measuring over long distances in the early period of EDM. The origin of the EDM with light beam can be traced back to 1938 when Swedish physicist Erik Bergstrand started to explore the possibility of measuring the speed of light with an optical shutter. The instrument that he used utilized pulses of light at a frequency controlled by a crystal oscillator. It took him nine years to achieve a measurement of $299,793.1 \pm 0.2$ km per second. He started with a known distance and compared the phase difference between the outgoing light and that reflected from a mirror to determine the velocity of light. He then suggested in 1948 that one could use the reverse process to measure distance and asked a Swedish company (AGA) to produce a commercial product, the Geodimeter. That started the electronic distance measurement age. The first geodimeter weighed more than 200 lbs with range of 30 to 35 km. Tests conducted at the time showed its accuracy is comparable with the best invar tapes. The Geodimeter was used in the United States for the first time in 1953. The Model 2 Geodimeter was introduced in 1955 and the range was increased to 50 km. Figure 1.1 shows a circa 1959 AGA Geodimeter 2A.



Figure 1.1 A circa 1959 AGA Geodimeter 2A showing the front control panel. (From NOAA 200 Years Celebration Website, Photos courtesy of the University of New South Wales School of Surveying and Spatial Information Systems Virtual Surveying Instrument Collection)

The first Tellurometer was developed around 1957 in South Africa. Unlike the Geodimeter which used light waves, the Tellurometer used microwave. The range of this instrument was 30 to 50 km. Because microwave signals are more affected by many environmental factors such as humidity, powerline, geomagnetic storm, etc., the instruments using microwaves were not as accurate as those using light waves. Figure 1.2 shows a Tellurometer.



Figure 1.2 A Tellurometer (From NOAA 200 Years Celebration Website, Photos courtesy of the Alberta Land Surveyor's Association Surveying Instrument Collection)

1.1.2 The Second Generation EDM

Geodimeter evolved quickly through the 1960s. The weight was reduced from 200 lb to 20 lb and the measurement time from 45 minutes to 10. The tungsten light bulb was replaced with a high-pressure mercury vapor lamp in Geodimeter 4D where D stood for day-light in 1963 and the first EDM instrument with a laser light source was created when George Lesley of the Coast and Geodetic Survey (C&GS) replaced the mercury vapor lamp in Geodimeter 4D with a three-milliwatt helium-neon gas laser in 1966, opening the age of EDM with laser. Figure 1.3 shows a modified Geodimeter with laser as a light source.

With the introduction of semiconductors into electrical circuitry, the design of EDM instruments was revolutionized. First, the vacuum tubes were replaced with transistors and then, light-emitting photo-diode was invented which significantly reduced the size of the light source. In Geodimeter Model 6 introduced in 1964, vacuum tubes were replaced with transistors, significantly reducing measurement time since the warm-up time for the vacuum tubes was eliminated. Wild DI 10 Distomat was one of the first EDM instruments to use a semiconductor



Figure 1.3 The "Big Red", a modified Geodimeter with Laser. Clockwise from top left: Control panel; optics; set up showing separate power packs for Geodimeter and laser; and a side view of the instrument. (From NOAA 200 Years Celebration Website, Photos courtesy of Charlie Glover)

photo-diode as a light source. It used a gallium-arsenide light-emitting diode and the electromagnetic wave length was in the infrared range. Wild started to experiment with gallium-arsenide diodes as early as 1963. Power consumption of these diodes was very low and their electromagnetic waves can be directly modulated in intensity. By the end of 1966, Wild, in collaboration with another organization (SERCEL), had produced a prototype that could measure

912 meters in misty weather. The commercial product arrived in the United States in October 1969, about the same time when HP introduced their EDM instrument, HP Model 3800B distance meter (Figure 1.4). The HP instrument also used a gallium-arsenide light-emitting diode, emitting infrared radiation of 910 nm, with a range of two miles. Both the Wild and HP instruments were part of the second generation EDM which was much lighter, consumed less power and was much easier to operate and read. Many of the instruments were designed for plane surveying and therefore, they had a shorter range.



Figure 1.4 A HP Model 3800B Distance Meter. The cover shown on the bottom right is a calibration cap designed and built by the Instrument and Methodologies Branch of the National Geodetic Survey. (From NOAA 200 Years Celebration Website, Photos courtesy of Charlie Glover)

1.1.3 Total Stations

A Total Station (TS) is a combination of theodolite and EDM. Prior to the introduction of TS, angular and distance measurements were obtained separately with theodolite measuring angles and EDM distance. Zeiss began to combine the two into one instrument in 1968. They gave their new instrument the name Elta, meaning "electronic tachometer." Figure 1.5 shows a Zeiss Elta 46 manufactured in 1983. The instrument had an angular accuracy of ± 3 seconds, an infra-red light source, and a range of 1.2 miles. TS instruments are still in use today although with much improved technologies. They generally have an EDM unit with infrared or laser light

as a carrier signal, a digital theodolite, a microprocessor and a data collector. These instruments can automatically observe both angle and distance, calculate the coordinates and store data. Most of the EDM systems used in these TS instruments are based on the *phase-shift* distance determination principle. In this method, a light beam emitted by a diode is split into an external beam which bounces back from the target (prism) to be measured and an internal reference beam and, the phase difference between the two is determined. In addition to the phase difference, the number of full cycles that a light wave has undergone must also be known before the full distance can be calculated. The determination of the number of full cycles is referred to as resolving the cycle ambiguity. Most of these instruments require the use of a reflector (prism). EDM reflectors also went through a lot changes over the years. The first reflector used for the Geodimeter was a flat mirror, then a spherical mirror was used and eventually prisms are adopted. Most reflectors in use today are retro-reflector made of cube corner prism which is formed by cutting the corners off a glass cube. Figure 1.6 shows a modern prism reflector.



Figure 1.5 A Zeiss Elta 46 Total Station. (Photo Courtesy of National Museum of American History)



Figure 1.6 Modern Prism Reflectors. (a). SECO 360° Robotic Prism Assembly; (b). SECO Tilting Triple Prism Assembly. (Courtesy of California Surveying/Drafting Supply)

In recent years, with the improvement of signal processing technology and precision, the *Time-of-Flight (TOF)* TS instruments also began to appear. In these instruments, the EDM system generates many short infrared or laser light pulses, which are transmitted through the telescope to a target. These pulses bounce back from the target and return to the instrument, where the time for the round-trip is determined directly by the system for each light pulse. With the velocity of the light through a medium known, the distance between the instrument and target can be easily determined. The pulses generated by the TOF instruments can be many times more powerful than the energy used for a phase-shift instrument, and hence the TOF method can achieve a much longer distance measurement. Taking the Trimble TS as an example, the Trimble DR 300+ with the TOF technology can measure up to 400 meters, reflecting off a concrete surface while the Trimble DR Standard employing the phase-shift method can only measure up to 100 meters off the same surface. When a reflector (prism) is used, however, the ranges for the two instruments are comparable, 5500 m for the DR 300+ and 5000 m for the DR Standard. Because of its long range, the TOF method is preferred over phase-shift for reflectorless measurement. The phase-shift technology did have one advantage over TOF: it can achieve better accuracy. However, with the improvement of signal processing technology in TOF method, the accuracy discrepancy between the two is becoming insignificant in many applications. Figure 1.7 shows a Trimble S6 DR Total Station.



Figure 1.7 Trimble S6 DR Total Station. (Courtesy of Trimble Navigation Limited)

1.1.4 GPS (Global Positioning System)

GPS measurements are also electronic distance measurement although one usually does not use the term EDM to describe them. In GPS, the distances between satellites in space and the ground receivers are determined using electromagnetic waves in the microwave radio frequency range. The GPS satellites emit electronic signals with two carrier frequencies: L1, 1575.42 MHz and L2, 1227.60 MHz. The carriers are modulated into two codes: P code, with 10.23 MHz frequency and C/A code with 1.023 MHz frequency. The distances are determined with either the phase-shift method similar to that in EDM or code-ranging method analogous to TOF.

The global position system can be divided into three segments based on segment functions: space segment, control segment and user segment. The space segment consists of a constellation of 24 satellites placed in six orbital planes at 60 degrees apart around the equator and the planes have an inclination angle of 55 degrees with the equator. This orbital design provides enough coverage so that a sufficient number of satellites can be tracked at any location on earth at any time to determine the position of that location. The satellites travel in near-circular orbit with mean altitude of 10900 nautical miles (20200 km) in a period of 11 hours, 58 minutes. They are usually identified by their PRN (Pseudo Random Noise) number or space vehicle number (SVN).

The control segment is composed of five monitoring stations around the globe. They are located at Colorado Springs, the Islands of Hawaii, Ascension, Diego Garcia, and Kwajalein. The stations monitor the signals of the satellites, track their orbits and send tracking information to the main control station in the Consolidated Space Operations Center located at Shriever Air Force base in Colorado Springs. The main station uses the tracking information to calculate the precise near-future orbits of the satellites and clock correction coefficients, and transmit these data back to the satellites via upload stations. The satellites, in turn, broadcast the information as part of their transmission for use by receivers on the ground to determine positions.

The user segment consists of GPS receivers and user community. The receivers receive the signals from the satellites, determine the distances and convert the distances to positions. A minimum of four satellites are required to compute the X, Y, and Z coordinates with reasonable accuracy. Receivers range in capability from high-end survey level receiver with mm accuracy to mapping and GIS types of receiver with submeter accuracy, to marine navigation receiver and to vehicle tracking system (<10 m). The main differences among receivers are the number of channels (number of satellites that can be tracked simultaneously) available and whether they are single (L1) or dual-frequency (L1 and L2) receivers. The high-end survey level receivers are capable of tracking many satellites simultaneously and can receive information using both L1 and L2 frequencies. Figure 1.8 shows a Trimble 5800 receiver and the antenna for a Trimble 5700 receiver.



(a)



(b)

Figure 1.8 GPS user segment equipments. (a) Trimble 5800 receiver; (b) the antenna for a Trimble 5700 receiver.

1.1.5 Terrestrial 3D Laser Scanners

To date, all the Total Station instruments are designed to measure one point at a time. The user would aim the telescope at the prism and push a button to measure the distance. It takes time to setup, aim and shoot. Even the latest robotic TS with automatic tracking takes 1 to 5 seconds to measure a distance. GPS measurements were also conducted at one position at a time. In contrast, the 3D laser scanner can measure 5000 distances per second, thousands of times more efficient than a TS. The improvement in productivity and the benefits to the surveying industry are very obvious.

Currently, most 3D laser scanners employ the TOF method. Unlike in a TOF Total Station where the laser pulses are aimed at one point and the resulting distances averaged, the laser pulses in a 3D laser scanner are deflected to different targets by rotating or oscillating mirrors inside the instrument or by rotating the instrument itself. Some instruments deploy two deflection mirrors, one for the vertical view field and the other for the horizontal view field. Others use one deflector for the vertical view field and the horizontal view field is accessed by rotating the instrument horizontally. These systems can acquire a few thousand points per second with a range of a 200 to 300 m and an accuracy of a few mm for a distance of 100 m. The horizontal view field for most scanners is 360° and the vertical view field ranges from 60° to 320° . Sophisticated field software are used to setup the system, gather data (called "point clouds") and transfer data between field devices and office computer. In addition, post-processing is a major part of the 3D laser scanning technology. Post-processing software allows multiple point-cloud registration; data filtering and checking; 3D modeling; digital image calibration; multi-ortho projection; contour, cross-section and profile generation; volume and surface calculations; feature code management; and other functions.



Figure 1.10 3D laser scanners. (a) Trimble GX 3D scanner; (b) Leica ScanStation. (Courtesy of Trimble Navigation Limited and Leica Geosystem.)

1.1.6 Airborne Laser Scanning System (Lidar)

The airborne laser scanning system, alternatively referred as Lidar (Light Detecting and Ranging), uses the same principles as 3D laser scanners. The system usually is mounted on an airplane or helicopter. The scanned distances are relative to the position of the airplane. To obtain the absolute position of a point on the ground, a system that tracks the position of the airplane itself must be installed on the airplane. This system usual is a GPS unit in combination of an INS (Inertia Navigation System). Airborne laser scanning system has a longer history than the terrestrial 3D laser scanning system. NASA started to experiment with Lidar in the 1970's, but it was not until the 1990's when the first commercial unit became available. Figure 1.11 shows NASA's Harlie airborne lidar system.



Figure 1.11 NASA's Harlie Holographic Airborne Rotating Lidar . Left: transceiver (scanning system) and Right: electronics rack. (Courtesy of NASA)

1.2 3D Laser Scanning Applications in Land Surveying

As mentioned earlier, 3D laser scanners can be thousands of times more efficient than traditional TS instruments and GPS in acquiring positional data. Because of this, the surveying industry is quickly adopting this technology. Currently the terrestrial 3D laser scanner market is growing at a rate of 35-40% annually.

In general, the application of 3D laser scanning is most beneficial in two situations: a) the points to be surveyed are dense, and b) the area to be surveyed is not accessible. Here are some specific applications:

- Topographical surveying or mapping surveying. The results from this type of surveying are used to create contour maps for engineering design or other purposes. It generally requires a lot of points to be surveyed, especially for large scale maps such as those used in land development. Using conventional methods or GPS, each point must be surveyed individually and the process is very time-consuming. With 3D laser scanning, the surveying time can be reduced dramatically.
- As-built surveying. Surveys are conducted periodically in large construction project to check progress for payments to contractors and for compliance with design plans and to document the project when it is complete. This type of surveying requires a lot of details and may interrupt normal construction activities and endanger the instrument operator if conventional surveying methods are used. In some case, the targets may not be accessible, a bridge pier in a deep river, for example.
- Facility improvement. Whether one tries to add an annex to an existing building or re-route the pipelines in a chemical plant, the engineers must obtain the existing details before they can start the new design. Capturing all the details would be a time-consuming process with conventional surveying method. 3D laser scanning can shorten the working schedule considerably.
- 3D imaging. The point clouds captured by a 3D scanner can be used to construct 3D vector images which can be readily incorporated into a CAD model created by the engineers for engineering design and modeling. In contrast, the images created by a digital camera are two-dimensional and in raster format which cannot be easily incorporated into CAD models. The applications of 3D laser scanner in 3D imaging are not limited to land surveying, and known applications include forensic investigations, environmental protection and restoration, historical preservations, architectural design and reverse engineering.

1.3 Economic Impacts of 3D Laser Scanning Applications in Land Surveying

Terrestrial 3D laser scanning for land surveying is still at its early stage and has the potential of reducing surveying cost significantly. Tom Greaves of Sparc Point Research, LLC, an organization specializing in research on 3D laser scanning applications, discussed the economic benefits of using 3D laser scanning from four different areas:

1. Direct cost savings in comparison with conventional survey methods. Base on anecdotal evidences, he estimated that direct cost savings from using 3D laser scanning are on the

order of 10 to 20%. In cases where access is difficult, the savings can be much higher. He stated that the time taken to collect data can be reduced from weeks to days by using 3D laser scanning.

2. Construction savings. Greaves used documented and validated examples to show that by using laser scanning, a construction project can save 5 to 10% of the total cost. The savings mainly come from construction schedule reductions, reduced errors and rework. He estimated that there is a \$2.2 billion potential savings in U. S. non-residential construction sector by adoption of 3D laser scanning.
3. Asset operation and maintenance benefit. Here again, 3D laser scanning reduce maintenance and repair costs through capturing the existing condition and providing 3D data for retro-fitting and repair design.
4. Safety dividend. In economic analysis, it is hard to put a dollar figure on the value of improved safety. However, it is one of the forces driving the adoption of laser scanning technology. Using 3D scanning means that surveyors do not have to go to dangerous locations such as a fast-moving traffic lanes, a cliff or under a construction crane.

Questions

1. What is the difference between a *Geodimeter* and *Tellurometer*?
2. What kind of distance measurement principles are most total stations based on?
3. What kind of the distance measurement principle is 3D laser scanning based on?
4. What are the two types of 3D laser scanning in land surveying?
5. List three applications in which using 3D laser scanning is advantageous.
6. Conduct an internet search and write a report on the history of electronic distance measurement.
7. Conduct an Internet search and write a summary on the current status of 3D laser scanning applications in surveying industry.