CHAPTER 2 - LiDAR HARDWARE

HOW 3D LASER SCANNERS WORK

3D laser scanners work by emitting light and detecting the reflection of the light in order to accurately determine the distance to the reflected object. Rather than making a single measurement as in a laser rangefinder, 3D laser scanners have rotating mirrors (or the entire unit rotates) that allow millions of measurements to be made over a scene in just a few seconds or minutes (depending on the type of scanner).

There are two primary types of 3D laser scanners: time-of-flight scanners and phase-shift scanners. Time-of-flight laser scanners emit a pulse of laser light that is reflected off the scanned object. A sensor measures the time of flight for the optical pulse to travel to and from the reflected surface. The distance the pulse traveled is then calculated using the following equation.

$$\textbf{Distance} = \textbf{(Speed of Light * Time of Flight)/2} \qquad \textbf{(1)}$$

Some time-of-flight scanners have the ability to measure several arrival times for an emitted pulse. In a scan of a slope with vegetation, for example, the “first arrival” would indicate the distance to the top of the vegetation, and the “last arrival” would indicate the distance to the ground surface.

In phase-shift scanners, a laser beam with sinusoidally modulated optical power is emitted and reflected off an object. The reflected light is then detected and compared with the emitted light to determine the phase shift. The time of flight can then be determined from the following equation:

$$\textbf{Time of Flight} = \textbf{Phase Shift} / (2\pi * \textbf{Modulation Frequency}) \qquad \textbf{(2)}$$

The values calculated by Equation 2 are then substituted into Equation 1 to find the distance. Multiple modulation frequencies are often used to increase the accuracy of the time-of-flight determination.

THE POINT CLOUD

Immediately after one pulse is received and measured, the scanner transmits another optical pulse slightly horizontal (or vertical – depending on the scanner) to the previous pulse using a rotating mirror. This process is repeated thousands of times per second, thus generating distance values for millions of points on a reflected surface. From the distance and the orientation of the laser pulse, the xyz coordinates associated with each reflected pulse can be determined. In addition, the intensity of the returned pulse is determined. In general, light colored objects and closer objects give a higher reflection compared with darker objects and objects farther away. Together, the xyz coordinates and associated intensity values for millions of data points outputted by the laser make up the "point cloud". An example of a point cloud of a rock face along the Mt. Lemmon Highway in southern Arizona is shown in Figure 1a. This point cloud has about one million points. Also, it has a photographic quality because of the intensity values, that is, light objects are brighter than darker objects. A color point cloud can also be produced by associating color information from a digital image with the location of each point. An example of a color point cloud is shown in Figure 1b.

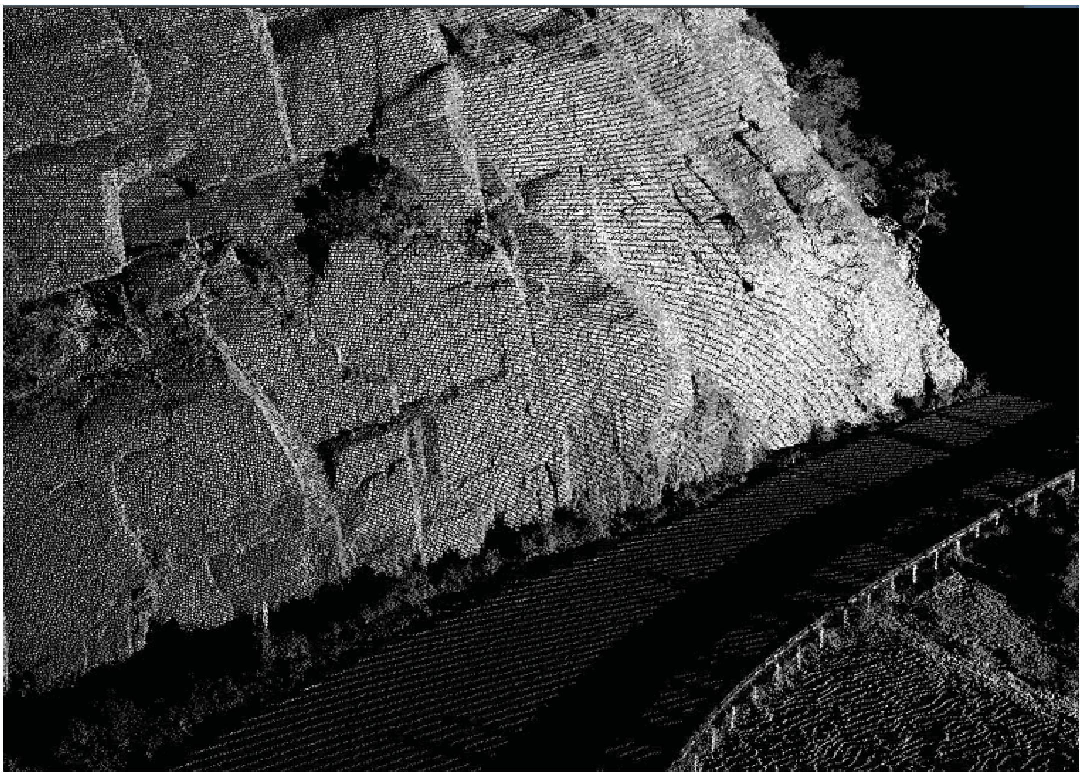

Figure 1a. Schematic. Point cloud of a rock face along Mt. Lemmon Highway, Arizona.

Figure 1b. Schematic. Color point cloud of a rock face near San Juan, Argentina.

MANUFACTURES AND PRODUCT SPECIFICATIONS

At the current time, there are a number of ground-based LiDAR manufacturers making scanners suitable for highway rock slope stability investigations. These included:

- Optech (www.optech.ca)
- Trimble (www.trimble.com)
- Leica Geosystems (www.leica-geosystems.com)
- Riegl (www.riegl.com)
- Faro (www.faro.com)
- Isite (www.isite3d.com)
- Zoller+Fröhlich (www.zofre.de)
- InteliSum (www.rappidmapper.net)

There are other scanners that are not listed because the range is not suitable for rock slope investigations (less than 10 meters). A complete list of terrestrial scanners is given in Appendix A. Several of these scanners are shown in Figure 2.

Figure 2. Photo. Examples of ground-based LiDAR scanners (time-of-flight unless noted otherwise, photos from 2006 models).

A complete list of specifications on currently available 3D laser scanners is given in Appendix A (from POB, 2008). Example specifications for the Optech ILRIS 3D time-of-flight scanner and the Leica HDS6000 phase-shift scanner are given in Table 1 below.

Table 1. Specifications for ILRIS-3D and HDS6000 scanners (from POB, 2008).

Parameter	**Optec ILRIS 3D** (time of flight)	**Leica HDS6000** (phase shift)
Wavelength	1550 nm	650, 690 nm
Minimum range	3 m	0.1 m
Maximum range	1500 m at 80% reflectivity	79 m at 90% reflectivity
Average data acquisition rate	2500 points per second	125,000 points per second
Beam diameter	29 mm @ 100 m	8 mm @ 25 m
Distance accuracy	7 mm @ 100 m	4 mm @ 25 m
Position accuracy	8 mm @ 100 m	6 mm @ 25 m
Angular accuracy	0.00115 degrees	0.0071 degrees
Scanner weight	13 kg not including batteries	14 kg including batteries
Distance and position accuracies are ± 1 sigma (68% confidence level)		

Table 1 points out some of the differences between time-of-flight and phase shift scanners. The time-of-flight scanners are capable of a much larger range compared with the phase shift scanners. Thus time-of-flight scanners would be preferred for large highway slopes and cliffs, while phase shift scanners would be preferred for small underground tunnels, for example. Also, the phase shift scanners have a much higher average data acquisition rate compared with the time-of-flight scanners. In terms of distance and position accuracies, the phase shift scanners have a slightly higher accuracy compared with the time-of-flight scanners. Both types of scanners are portable but, the phase shift scanners are lighter. When comparing weights note that the batteries are usually included in the phase-shift scanner unit, while the external batteries in the time-of-flight scanners can add at least 10 kg (22 lb) to the weight of the time of flight scanners.

PRICE

3D laser scanners range in price from $70,000 to over $150,000 (based on 2008 prices). Alternatives to purchasing a new scanner include buying a used scanner or renting a scanner on a daily or weekly basis. Distributors for the purchase of new scanners can be found on the LiDAR manufactures web sites. A good source for used scanners is the classified section of the Spar Point Research web site (http://sparllc.com/classifieds.php). Companies that rent scanners include surveying companies as well s the LiDAR manufacturers.

SCANNING PROCEDURES

A brief overview of the procedures for scanning a highway slope or natural rock outcrop is given below. Note that additional details on these steps are given in the “best practices” section of Chapter 5. Figure 3 illustrates some of the basic steps involved in field scanning.

1. The scanner is placed at the outcrop of interest, at a safe distance from moving cars and steep cliffs. The scanner does not need to be level; however, leveling the scanner simplifies the scanner registration process.

2. The manufacturer’s software is used to set the scanner field of view and the LiDAR point spacing, using either a laptop computer or a handheld device.

3. A method for survey control is established (scanner registration). Methods include placing surveyed targets in the scene as shown in Figure 3, establishing the location and orientation of the scanner, back sighting to known points, and other methods.

4. Scanning is conducted. With a time-of-flight scanner this generally requires 5-25 minutes per scan to produce a point cloud with one to three million points. A phase-shift scanner would require less than 30 seconds for a point cloud with one to three million points.

Figure 3. Photo. Scanning with the Leica ScanStation at Milepost 15 on Mt. Lemmon Highway. Point cloud shown in the lower right photo.

5. Digital images are taken. High-resolution digital images accompany each LiDAR scan. Most scanners automatically capture the images using a built in camera. Some cameras are mounted on the inside of the scanner, some are mounted on the outside. By knowing the position of the camera relative to the laser and the camera characteristics, a color point cloud can be produced, and also the digital images can be draped onto the point cloud using texture-mapping techniques.

6. Point clouds are produced, as illustrated in Figures 1 and 3. Details on the point cloud file and software used for further processing are described in Chapter 3.

7. In general, 5-10 scans can be conducted in a day, depending on terrain, scan area, and the travel time to each site. A typical scan is taken from 20 to 100 meters from the rock outcrop, and a typical scan area can vary from 15x15 m^2 to over 50x50 m^2. The smaller areas require less than 10 minutes to scan, while a 50x50 m^2 area takes about 45 minutes to scan with a time-of-flight scanner. More details are provided in Chapter 5.