University Of Technology
Building and Construction Eng. Dept.
Final Exam/ First Attempt –2014/2015

Subject :Laser Scanning Class: 3 rd Year
Division : Geomatics Time : 3.0 Hour
Examiner :Dr. Imzahim Abdulkareem Date: Monday 8/6/2015

Note: Answer All Questions

Q1) [20 marks] **(Answer Two items Only)**

A. A laser Scanning spaceborne operating at altitude 2500 m with speed 75 m/sec, the pulse duration of the scanning system is 10 ns and the peak power is 15 kW, which emits its pulses with a pulse repetition rate of 83 kHz, and the very high scan rate of 630 Hz at the wavelength (λ) of 1540 nm. If you know the scan angle is 30°, compute the following: 1) The minimum resolvable distance between targets 2) Maximum slant range. 3) Swath width. 4) Point spacing in both direction, if you know the scan rate up to 50,000 point/ line. 5) Point density. 6) Overlapping factor, if you the flight line separation is 400 m.

Solution:

$$\omega = 2.44 \times \frac{1540 \times 10^{-9}}{4.807 \times 10^{-4}} = 7.817\ mrad$$

$$\text{d (diameter of Footprint)} = R \times \omega$$

$$d = 2500\ m \times \left(\frac{7.817}{1000}\right) = 19.542\ meters$$

$$A = \pi d^2/4 = 300\ m^2$$

$$\Delta R_{\text{tar}} = \frac{c}{2} . T_p = \frac{3 \times 10^8}{2} .10 \times 10^{-9} = 1.5\ m$$

$$R_{max} = H/cos\left(\frac{\theta}{2}\right) = 2500\ m \times cos^{-1}\left(\frac{30^{\circ}}{2}\right) = 2588.190\ m$$

$$SW = 2 \times H \times \tan\left(\frac{\theta}{2}\right) = 2 \times 2500 \times \tan\left(\frac{30}{2}\right) = 1339.75\ m$$

$$\Delta x_{along} = \frac{v}{f_{sc}} = \frac{75\ m/sec}{630\ Hz} = 0.119m$$

$$\Delta x_{across} = \frac{\theta}{N} . \frac{H}{cos^2(\frac{\theta}{2})} = \frac{(30 \times \pi/_{180})}{50000} \times \frac{2500\ m}{\cos\left(\frac{30}{2}\right)^2} = 0.028\ m$$

$$d_{min} = \frac{1}{\Delta x_{along} . \Delta x_{across}} = \frac{1}{0.119 \times 0.028} = 300.12\ Points/m^2$$

$$\xi = 1 - \frac{e}{SW} = 1 - \frac{400\ m}{1339.75\ m} = 0.7014$$

B. LiDAR CW signals using a 1 GHz ranging signal, which corresponds to a wavelength λ of 30 cm, and assuming a phase resolution of 0.4°, calculate the range resolution? And the unambiguous range?

$$\Delta R = \frac{\lambda}{4\pi} . \Delta\emptyset = \frac{\left(30\ cm\ \times \frac{10mm}{cm}\right) \times (0.4^{\circ} \times \frac{\pi}{180})}{4\ \times \pi} = 0.166m\ \approx 0.2\ mm$$

$$R_{Unamb} = \frac{\lambda}{2} = \frac{300\ mm}{2} \approx 150\ mm$$

C. Summarize and sketch draw for Topographic LiDAR systems consist?

Solution:

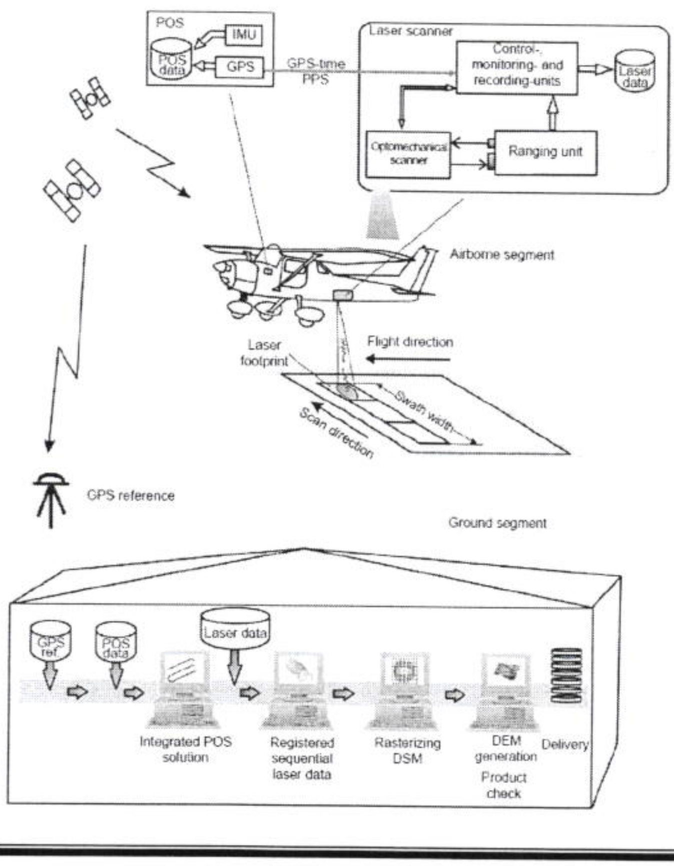
The Topographic LiDAR systems used to execute the survey activities, because a valid surveying result is impossible if a LiDAR is used as an isolated device. A surveying result means geocoded laser measurements. Figure 2.1 shows that LiDAR systems consist of an airborne and ground segment.

The airborne segment includes:

1) Airborne platform
2) LiDAR
3) Position and orientation system (POS)

The ground segment is comprised of

1) Global positioning system (GPS) reference stations
2) Processing hardware and software for synchronization and registration which is carried out off-line



Q2) [20 marks]

A Laser Scanning Airborne flying at altitude 2500 m ; if you know the XYZ geocentric coordinates for LiDAR data system through POS unit is X=820,600.00 m , Y=-5,800,750.656, Z=3,140,700.300 m . The Longitude of the local origin $\lambda_0 = 85^\circ 45' 0'' West$ and the Latitude of the local vertical origin $\phi_0 = 28^\circ 46' 10'' North$

Use ellipsoid parameter for GRS80 [a=6,378,137m, f=1/298.25722210088]

1. Convert LiDAR data geocentric coordinates to local vertical coordinates X_L, Y_L *and* Z_L ?
2. Convert back to the original geocentric coordinates?

Solution:

1.

$$e^2 = f\,(2-f) = \frac{a^2 - b^2}{a^2} = 0.006694380023$$

$$N = \frac{a}{\sqrt{1 - e^2 sin^2 \emptyset}} = 6383400.249\ m$$

$$x = (N+h)\cos\emptyset\cos\lambda = 811195.778\ m$$

$$y = (N+h)\cos\emptyset\sin\lambda = -5482371.413m$$

$$z = [N(1-e^2)+h]\sin\phi = 3146343.779\ m$$

$$\begin{bmatrix} x_l \\ y_l \\ z_l \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} x - x_0 \\ y - y_0 \\ z - z_0 \end{bmatrix}$$

$$M = \begin{bmatrix} 0.98922979728 & 0.14637079003 & 0 \\ -0.072631601671 & 0.49087215134 & 0.86819881449 \\ 0.12707894638 & -0.85884813725 & 0.49621650368 \end{bmatrix}$$

$$\begin{bmatrix} x - x_0 \\ y - y_0 \\ z - z_0 \end{bmatrix} = \begin{bmatrix} 815519.912 - 811195.778 \\ -5482723.662 - (-5482371.413) \\ 3144707.279 - 3146343.779 \end{bmatrix} = \begin{bmatrix} 4226.003 \\ -1907.785 \\ 39.976 \end{bmatrix}$$

3. Convert back to the original geocentric coordinates

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [M^T] \begin{bmatrix} x_l \\ y_l \\ z_l \end{bmatrix} + \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [M^T] \begin{bmatrix} 4226.003 \\ -1907.785 \\ 39.976 \end{bmatrix} + \begin{bmatrix} 811195.778 \\ -5482371.413 \\ 3146343.779 \end{bmatrix} = \begin{bmatrix} 815519.912 \\ -5482723.662 \\ 3144707.279 \end{bmatrix}$$

Q3) [30 marks] **(Answer Two items Only)**

A. Define the following terms: [15 marks]

Direct detection laser receivers, heterodyne receivers, Airborne Laser Profilers, Registration

Direct detection laser receivers: are convert the echo directly into a voltage or current using PIN (**Positive, Intrinsic, Negative**) or APD (**Avalanche photodiodes**).

Heterodyne receivers: down-convert the received signal to a lower frequency by mixing with the output of a stable local oscillator. The signal can then be amplified and filtered to enhance the detection process.

Airborne Laser Profilers: The first lasers had been constructed and demonstrated, they began to be used for rangefinding purposes.

This device could measure flying heights of 1000 ft. (300 m) above ground level (AGL) to an accuracy of 5 ft. (1.5 m). Shortly after that, the first airborne laser profiler was introduced for use in commercial topographic mapping operations.

The rangefinder part of the system was based on a helium-neon gas laser operating as a continuous wave (CW) device at the wavelength of 632.8 nm. The output signal was modulated using a KDP crystal that allowed the radiation to be emitted simultaneously at three different frequencies −1, 5, and 25 MHz

In each case, the return signals reflected from the ground were received and compared with the transmitted reference signal to determine the respective phase differences, so determining the actual range.

Registration: The registration process is best mathematically described by the simple vector approach already $\vec{G} = \vec{r_L} + \vec{s}$ $\vec{G}$ is the vector from the earth center to the ground point where: $\vec{r_L}$ vector from the earth center to the LiDAR's point of origin $\vec{s}$ slant ranging vector

B. Compute the terrestrial laser ranger, different in the height and resolution of a single measured range, if the measurement of the terrain profile is executed in a series of steps with the successive measured distances (slant ranges) and vertical angles equal $9^\circ 00' 00''$ while the value of the horizontal distance is 750 m; if you know the timing of the pulse is equal to 3 ps (picoseconds). [15 marks]

$D = R\cos V$

$$R = \frac{D}{\cos V} = \frac{750\ m}{\cos 9^\circ 00' 00''} = 759.3488\ \ m$$

$\Delta H = R\sin V$

$\Delta H = 759.3488\ \times \sin 9^\circ 00' 00'' = 118.788\ m$

f = PRF=1/t = $1/(3\times 10^{-12})$ sec.

C= 300,000,000 m/sec

C = λ* f⇒ Resolution of a single measured range **(λ)** =**300,000,000 m/sec×**1/ (3×10^{-12}) sec. = 0.001 m = 1.0 mm

C. If the length of a laser optical component in a typical ALS system was 632.8 nm and having an aperture of 10 cm. if you know the Energy (E) generated per pulse is 20 μ J; the pulse repetition rate (PRF) is 15 KHz, the pulse duration of the system is 10 ns.

1. ALS height [5 marks]
2. What is the average power output? [5 marks]
3. Compute the area covered by the diverging beam when it reaches the target in a scan mission of 3.0 mrad beam divergence. [5 marks]

Solution:

PRF= 15 kHz = 15,000 Hz
Elapsed time = 1/PRF = 1/15,000 = 0.00006667 sec = 66.67 μsec
ALS height (Travel & Back) = 300,000,000 m/sec. ×0.00006667 sec.=20,000 m
∴ ALS height = 20,000 / 2 = 10,000 m

$E= P_{peak} \cdot t_p$;
P_{peak} (Peak Power) = E (Energy per pulse) /t_p (Pulse duration) = 20 μ J/ 10 ns =0.000020 J /0.00000001 sec=2000 watt. =2 Kw.
$P_{average}$ =E F = E(Energy per pulse) × F (Pulse Repetition Rate [PRF])
= 0.000020 J× 15,000 Hz =0.3 W

$$A = \frac{\pi\,(\theta/2R + d)}{2}$$

$$A = \frac{\pi\,(3.0\text{mrad}\,/20{,}000{,}000\text{mm} + 100\text{mm})}{2} = 0.02357\ m^2$$

<u>Q4)</u> [30 marks] **(Answer <u>Two items</u> Only)**

A. Explain and Compare between: [15 marks]

1. Timed Pulse Method and Phase Comparison Method

In airborne laser scanning, radar measurement principles are applied, because high range dynamics have to be covered. The most direct ranging measurement is determining the time-of-flight of a light pulse, i.e., by measuring the traveling time between the emitted and received pulse (see Figure 2.4).

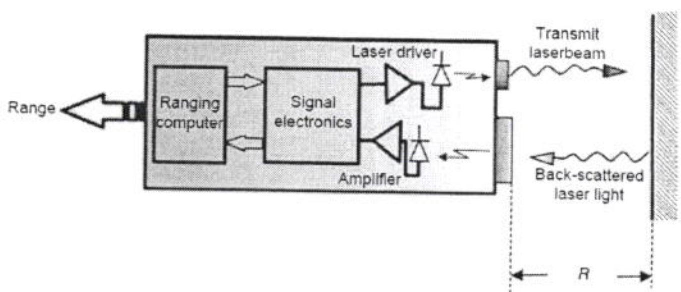


FIGURE 2.3: Two-way ranging setup.

According to Figure 2.4 the traveling time t_L of a light pulse is

$$t_L = 2\,\frac{R}{C} \quad ...(2.1)$$

Where

R is the distance between the ranging unit and the object surface

C. is the speed of light

As the signal travels the distance two times (see Figures 2.3 and 2.4), one talks of two-way ranging. If the traveling time t_L is measured, the range can be directly computed by

$$R = \frac{C}{2}\,.\,t_L \quad ...(2.2)$$

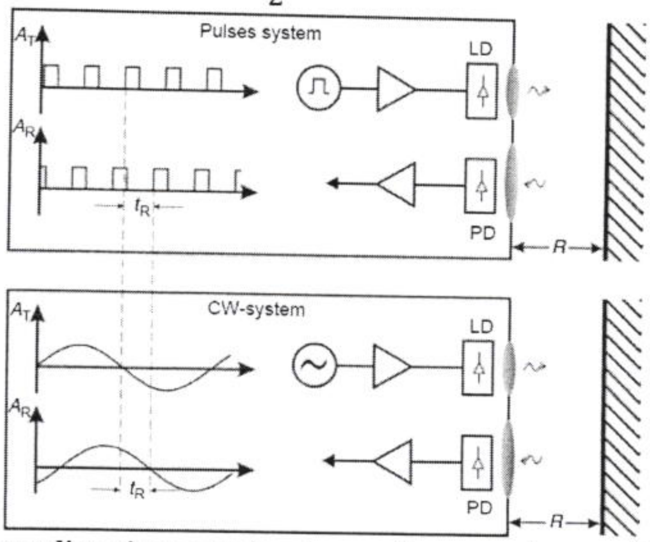


FIGURE 2.4: Traveling time ranging (upper image pulse ranging, lower image phase difference ranging).

The range resolution **Δ***R* is determined by the obtainable time resolution Δt_L of the traveling time measuring instrument and is given by

$$\Delta R = \frac{C}{2}\,.\,\Delta t_L \quad ...(2.3)$$

It is also possible to determine the range, if the laser emits light continuously. Such a signal is called continuous wave (CW) signal. However, ranging can only be carried out, if the light has a deterministic intensity structure. This means that the intensity of laser light is modulated. Assuming the laser light is intensity modulated with a sinusoidal signal (Figure 2.4) which has the period *T*, the ratio traveling time t_L to period *T* equals the ratio phase difference between transmitted and received signal to 2π:

$$\frac{t_L}{T} = \frac{\emptyset}{2\pi} \quad ...(2.4)$$

Putting Equation 2.4 into Equation 2.2 the range for two-way ranging is given by

$$R = \frac{C}{2}\cdot\frac{T}{2\pi}.\emptyset \quad ...(2.5)$$

As the period is the reciprocal of the intensity modulation frequency f, R can be calculated by

$$R = \frac{1}{4\pi}\cdot\frac{C}{f}.\emptyset \quad ...(2.6)$$

The ratio c/f is equivalent to the wavelength λ of the ranging signal, so that

$$R = \frac{\lambda}{4\pi} . \emptyset \quad ... (2.7)$$

Measuring the range by the phase difference the achievable range resolution ΔR is not only dependent on the maximum phase resolution f but also on wavelength l:

$$\Delta R = \frac{\lambda}{4\pi} . \Delta\emptyset \quad ... (2.8)$$

In comparison to pulsed systems (Equation 2.3), Equation 2.8 makes clear that by using CW signals one has an additional physical parameter that can be used to design a system with a desired resolution. This means, even if the phase resolution is kept constant, the range resolution can be improved by applying ranging signals with shorter wavelength.

This is not possible with pulsed systems, because in Equation 2.3 the constant of proportionality is the speed of light which cannot be varied. Therefore CW signals are applied if very high range resolutions are required.

2. Coherent and Incoherent light.

The emitted light is said to be INCOHERENT in time and space if

a. The light is composed of many different wavelengths.
b. The light is emitted in random directions.
c. The light is emitted with different amplitudes.
d. There is no phase correspondence between any of the emitted photons

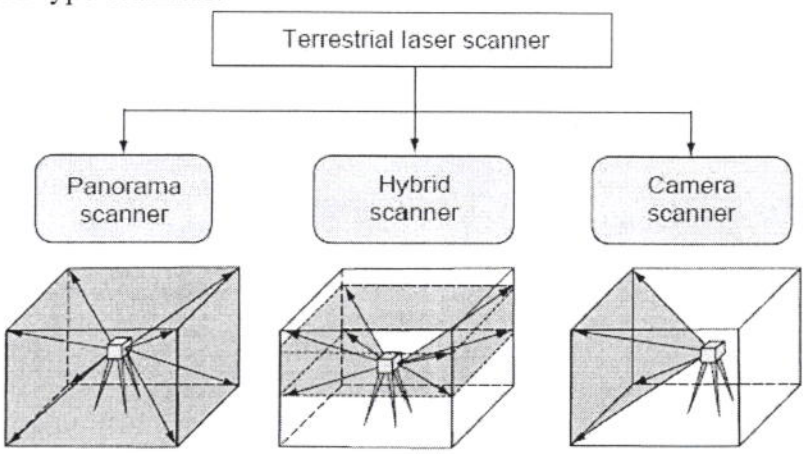
Properties of laser light:

a. Mono-chromaticity.
b. Coherence.
c. Beam divergence: All photons travel in the same direction; the light is contained in a very narrow pencil (almost COLLIMATED), laser light is low in divergence (usually).
d. High irradiance.

3. Differentiates between three types of static terrestrial laser-scanners (Panoramic type scanners; Hybrid scanners; and Camera-type scanners).

The classification that has been adopted here is that which differentiates between three types of static terrestrial or ground-based laser-scanners.

(i) panoramic-type scanners;
(ii) Hybrid scanners; and
(iii) Camera-type scanners.



The classification of terrestrial laser scanners based on their respective scanning mechanisms and coverage.

A. The panoramic-type scanners carry out distance and angular measurements in a systematic pattern that gives a full 360°angular coverage within the horizontal plane passing through the instrument's center and typically a minimum 180° coverage in the vertical plane lying at right angles to the horizontal plane thus giving hemispheric coverage. However a still greater vertical field-of-view (FOV) of 270° or more is not uncommon which means that a substantial coverage of the ground lying below the instrument's horizontal plane can be achieved.
Indeed, the only gap or void in the coverage of a full sphere on a number of instruments is that produced by the base of the scanner instrument and its supporting tripod. While this panoramic scanning pattern is very useful in the context of topographic mapping, it is even more desirable, indeed often obligatory, in the measurement of complex industrial facilities, large quarries and opencast mines and the facades of buildings within urban are as oreven indoors in large halls, churches, rooms, etc.
B. The instruments falling within the second category of hybrid scanners are those where the scanning action is unrestricted around one rotation axis usually the horizontal scanning movement in the azimuth direction produced by a rotation of the instrument around its vertical axis. However, the vertical angular scan movement in elevation around the horizontal axis of the instrument is restricted or limited typically to 50°-60°. This reflects the situation that is commonly encountered in medium and long-range laser scanning carried out for topographic mapping purposes where there is no requirement to measure objects overhead or at steep angles, as will be needed within buildings.
C. The camera-type scanners that make up the third category carry out their distance and angular measurements over a much more limited angular range and within a quite specific FOV. Typical might be the systematic scanning of the surrounding area over an angular field of 40°×40° in much the same manner as a photogrammetric camera at least in terms of its angular coverage, though obviously not in terms of the actual measurements that are being made and recorded.

B. Compute the area of footprint for Aerial laser scanning system flying altitude about 700 meters operating at a Green wavelength 532 nm, if you know the diameter of the lens is 5.0×10^{-4} m. [15 marks]

Solution:

$$\omega = 2.44 \cdot \frac{\lambda}{D} \qquad \text{Typical laser beam divergences } 0.3 \le \omega \le 2.7\, mrad$$

$$\omega = 2.44 \times \frac{532 \times 10^{-9}}{5.0 \times 10^{-4}} = 2.59\, mrad$$

$$\text{d (diameter of Footprint)} = \text{R} \times \omega$$

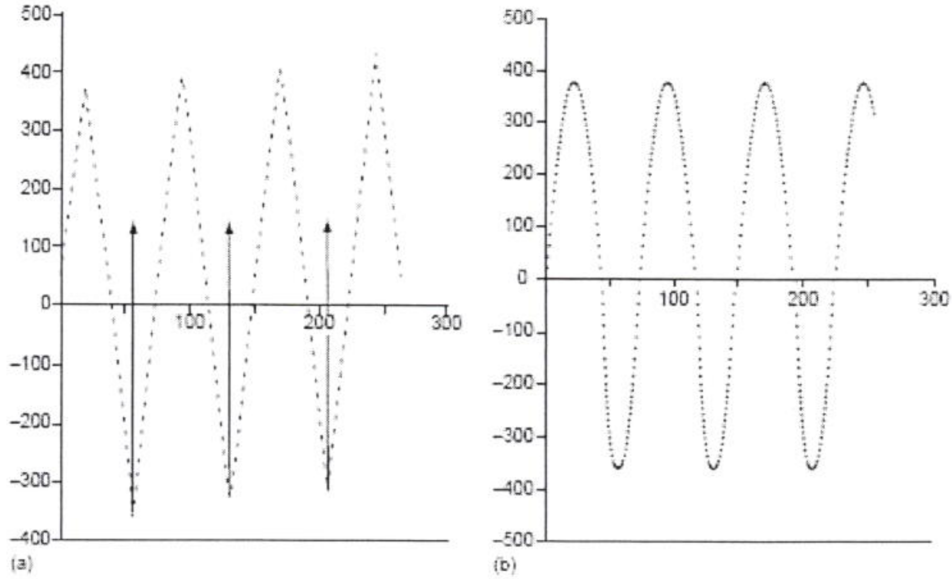
$$\text{d (diameter of Footprint)} = 700 \text{ m} \times \left(\frac{2.59}{1000}\right) \text{ rad} = 1.813 \text{ m}$$

$$A = \pi d^2/4 = \frac{3.14 \times (1.813)^2}{4} = 2.583 m^2$$

C. There are four main scanning mechanisms for Airborne Topographic laser scanners, each with its own distinctive ground measuring pattern can be distinguished; Explain and drawings these mechanisms? [15 marks]

There are four main scanning mechanisms for Airborne Topographic laser scanners, each with its own distinctive ground measuring pattern can be distinguished, as follows:

1. Either a single mirror or a pair of oscillating plane mirrors is used in the systems that have been constructed by the two largest commercial suppliers of airborne laser scanning systems Optech with its ALTM series and Leica Geosystems with its Aeroscan and ALS scanners. The precise angle that the mirror makes with the direction of the vertical is measured continuously using an angular encoder. The use of this type of bidirectional scanning mechanism results either in a Z-shaped (saw-toothed) pattern or in a very similar sinusoidal pattern of points being measured on the ground



(a) Saw-toothed pattern over the ground that is produced by the Optech ALTM series of laser scanners; and
(b) Sinusoidal pattern produced by the Leica ALS laser scanners—in both cases, using oscillating mirrors as the scanning mechanisms

2. An optical polygon that is continuously spinning in one direction providing a unidirectional scanning motion is used in the various systems such as the IGILiteMapper, TopoSys Harrier, iMAR… etc. that utilize the Riegl laser ranging and scanning engine, besides the complete airborne laser scanning systems that are supplied by the Riegl company . Similarly, the Terrapoint Company uses multi-faceted polygons in the several ALTMS systems that it has constructed in-house to form the basis of its early airborne laser scanning services. The use of this type of scanning device results in a series of parallel lines of measured points being generated over the ground. The constant rotational velocity of the optical polygon means that there is no repetitive acceleration or deceleration of the mirror. This provides for high frequencies such as the 160 Hz reached by the Riegl LMS-Q560 laser scanner. In turn, this offers better control over the spacing of the LiDAR points. The RASCAL airborne laser scanner constructed and operated by NASA

also uses a polygon mirror. However this does not spin continuously in one direction. Instead it oscillates in a unidirectional mode over a range of $\mp 16^{\circ}$ from the nadir. Thus it falls into the previous category.

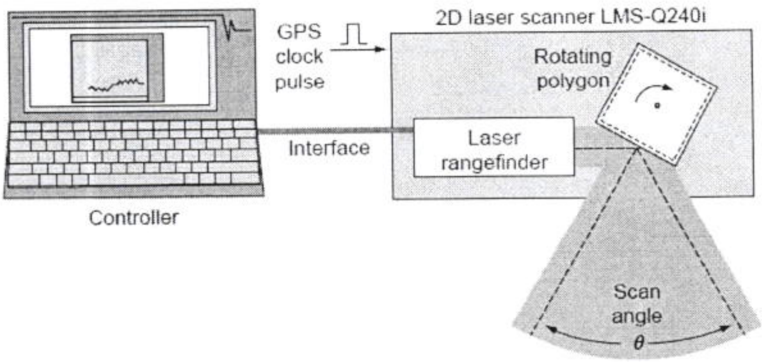


Figure: Diagram showing the unidirectional rotating optical polygon that forms the scanning mechanism that is used in Riegl laser scanning engines.

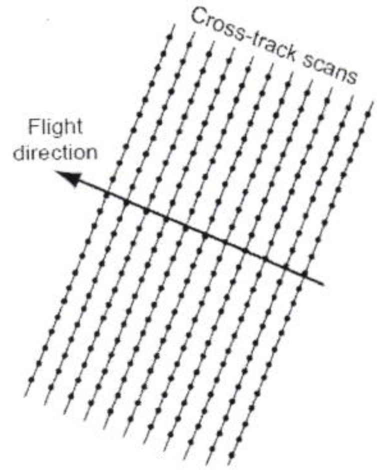


Figure: The resulting raster scanning pattern that covers the ground.

3. A nutating mirror producing an elliptical scan pattern the so-called Palmer scan over the ground is used in NASA's ATM and Airborne Oceanographic Lidar (AOL) series of scanners; in the ScaLARS system of the University of Stuttgart; in the GeographiaSurvair systems; and in the later models in the TopEye series of airborne laser scanners. This produces a series of overlapping elliptical scans over the ground.

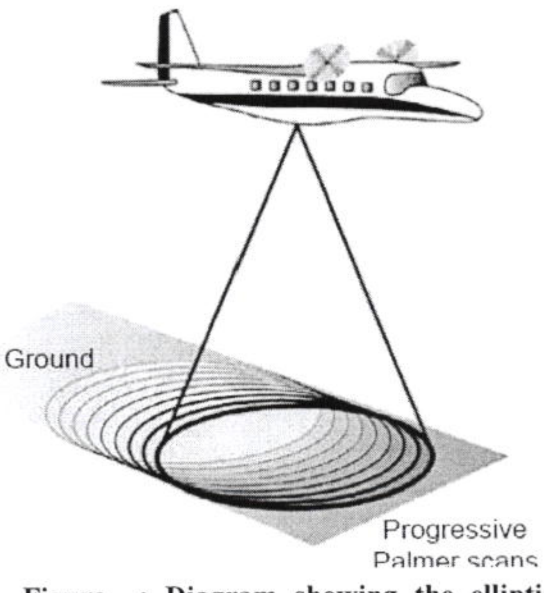


Figure : Diagram showing the elliptical ground scanning pattern and coverage of an airborne laser scanning system that is utilizing progressive Palmer scans.

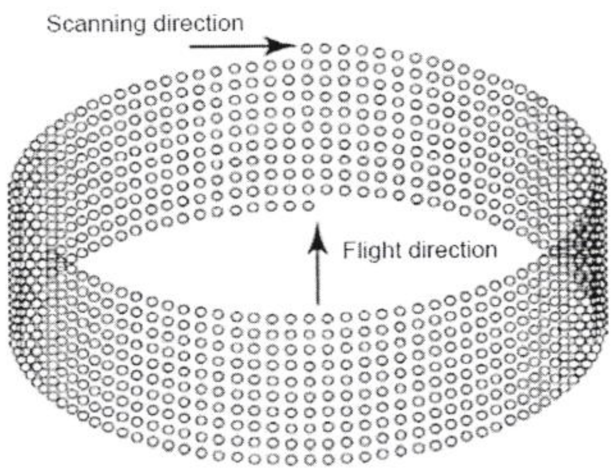


Figure : LiDAR point distribution on the ground of an airborne laser scanner using progressive Palmer scans.

4. A pair of linear fiber-optic arrays is employed in the Falcon systems that have been built and operated in-house by the TopoSys Company. A pair of tilted mirrors driven by a motor distributes and collects the pulses being sent to and from the arrays. The smaller size of the mirror allows a higher scan rate to be implemented. This arrangement results in a series of scan lines that run parallel to the flight line as the measuring pattern . However, as will be seen later, this basic pattern has been modified somewhat in the later models in the series through the use of an additional swing mirror.

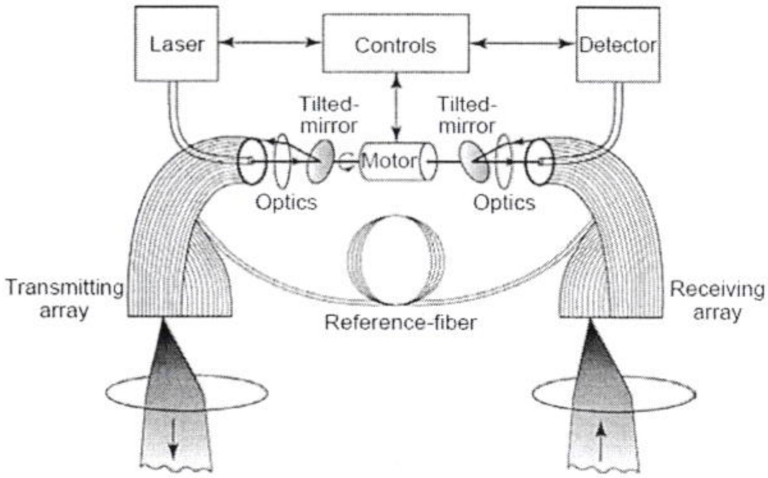


Figure: The optical and mechanical elements of the TopoSys Falcon series of airborne laser scanners are based on the use of linear fiber-optic arrays.

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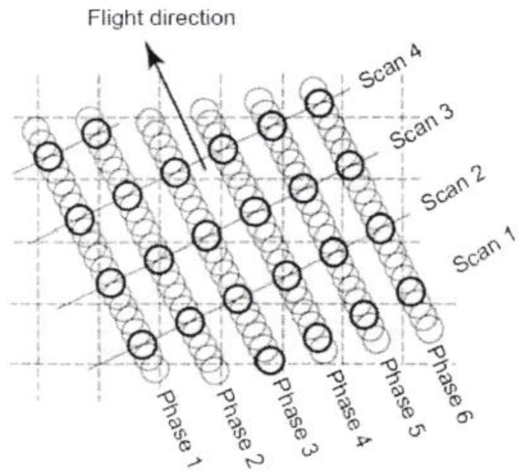

Figure: The resulting pattern of points measured over the ground by the Falcon system is a series of lines parallel to the fight