Chapter 2

Principles of LiDAR Remote Sensing

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2.1 INTRODUCTION

- The following topics will be introduced: (1) basic components of LiDAR, (2) physical principles of LiDAR, (3) LiDAR accuracy, (4) LiDAR data formats, (5) LiDAR systems, and (6) LiDAR resources.
- At the end of the chapter, three projects are available for a review of zonal statistics in ArcGIS, creating a LASer (LAS) dataset and working with LiDAR data using the LAS Dataset Toolbar in ArcGIS, and visualization of LiDAR data using QT Reader (Applied Imagery) and Fugroviewer (Fugro).

2.2 BASIC COMPONENTS OF LiDAR

- Lasers with a wavelength of 500–600 nm are normally used in ground-based LiDAR systems, whereas lasers with a wavelength of 1000–1600 nm are used in airborne LiDAR systems.

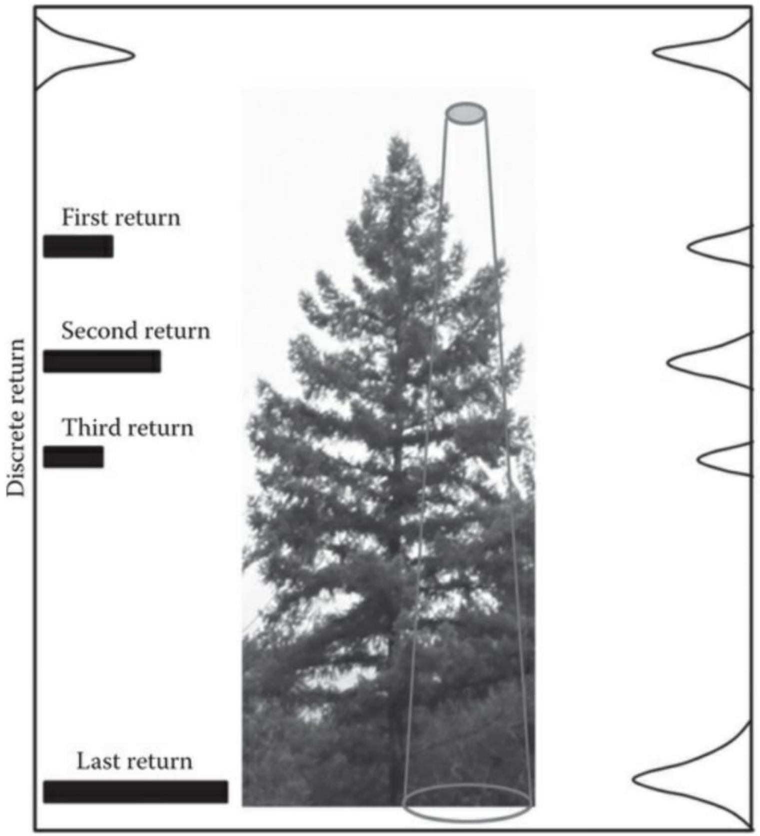

FIGURE 2.1 Discrete return and full-waveform measurement using airborne LiDAR.

2.2 BASIC COMPONENTS OF LiDAR

- A typical airborne LiDAR system is composed of a laser scanner; a ranging unit; control, monitoring, and recording units; differential global positioning system* (DGPS); and an inertial measurement unit (IMU)

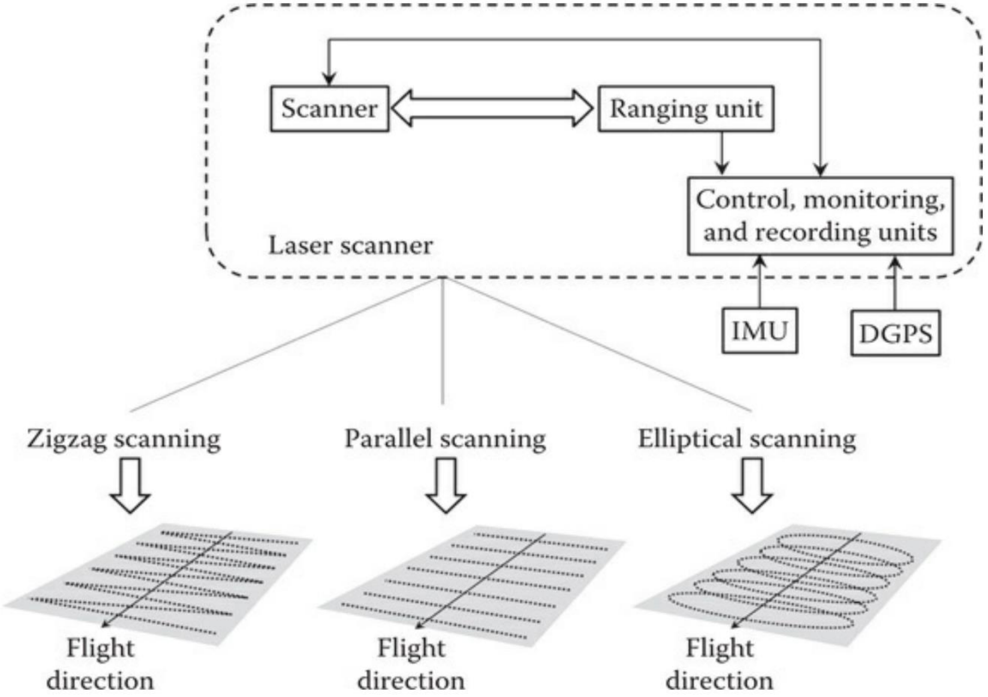

FIGURE 2.2 A typical airborne LiDAR system.

- An integrated DGPS/IMU system is also called a position and orientation system that generates accurate position (longitude, latitude, and altitude) and orientation (roll, pitch, and heading= yaw) information.

***A Differential Global Positioning System** (DGPS) is an enhancement to the Global Positioning System (GPS) which provides improved location accuracy

2.3 PHYSICAL PRINCIPLES OF LiDAR

- Pulsed LiDAR systems measure the round-trip time of a short light pulse from the laser to the target and back to the receiver.

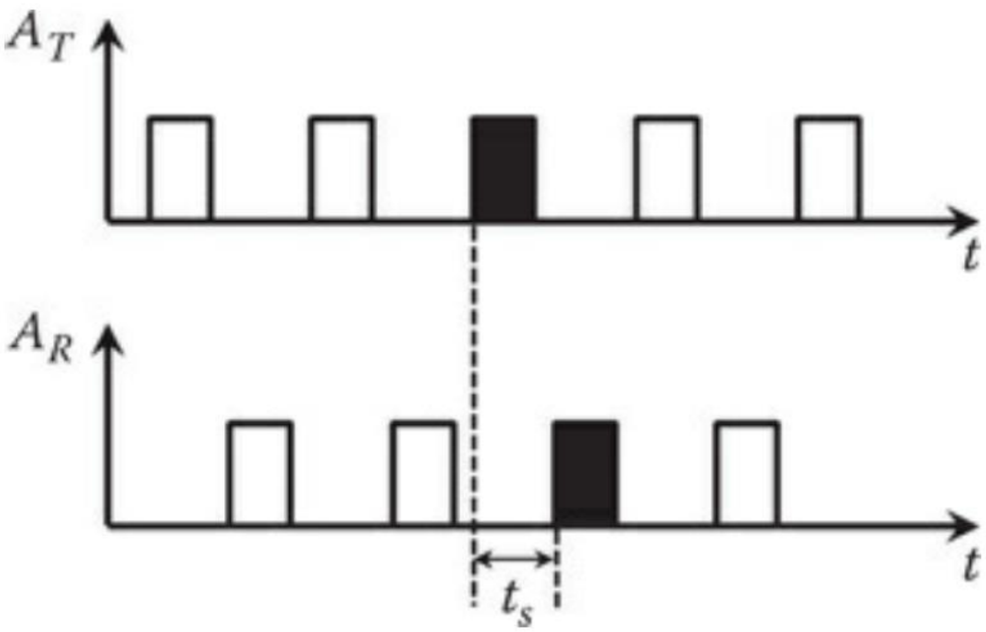

FIGURE 2.3 Amplitudes of transmitted (A_T) and received (A_R) light signals. t_s is the traveling time of a laser pulse.

Range: $R = \frac{1}{2} c \cdot t_s$

Range resolution: $\Delta R = \frac{1}{2} c \cdot \Delta t_s$

Maximum range: $R_{max} = \frac{1}{2} c \cdot t_{s_{max}}$

where C is the speed of light
R is the distance between the ranging unit and the object

2.3 PHYSICAL PRINCIPLES OF LiDAR

$$P_r(t) = \frac{D^2}{4\pi\lambda^2} \int_0^H \frac{\eta_{sys}\eta_{atm}}{R^4} P_t\left(t - \frac{2R}{\upsilon_g}\right)\sigma(R)\, dR$$

where P_r and P_t are the power of received and transmitted signals; t is the time; D is the aperture diameter; λ is the wavelength; H is the flying height; η_{sys} and η_{atm} are the system and atmospheric transmission factors; v_g is the group velocity of the laser pulse; $\sigma(R)dR$ is the apparent effective differential cross section.

2.4 LiDAR ACCURACY

- LiDAR accuracy is usually determined by statistical comparison between known (surveyed) points and measured laser points, and is typically measured as the standard deviation and root mean square error (RMSE).

- Sources of LiDAR measurement error: laser, the inertial navigation unit (INU), IMU, filtering, etc.

- Laser induced errors are normally caused by grain noise and changes in height for the points on the terrain surface at a narrow angle (ridges and ditches)

- GPS/INU/IMU errors can be caused by initiation errors and variances in measuremets.

- Filtering errors are related to incomplete or excessive removal of laser points.

- Vertical accuracies of better than 15 cm can be obtained at 1,200 m of altitude.

2.5 LiDAR DATA FORMATS

- Major problems of ASCII interchange file adopted in the early days of LiDAR: (1) reading and interpreting ASCII files can be very slow, even for small amounts of LiDAR data, (2) much of the useful information is lost, and (3) the format is not standard.

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99 358289.210 5973161.180 959.530 24
99 358290.870 5973162.460 959.290 36
5 358288.690 5973160.120 978.120 9
99 358292.470 5973163.670 959.390 19
5 358290.730 5973161.750 975.930 8
5 358291.210 5973162.200 973.580 7
5 358292.310 5973162.940 976.090 9
5 358293.780 5973162.420 973.610 11
5 358292.130 5973161.150 973.850 1
5 358293.180 5973162.130 968.680 9
5 358291.310 5973160.660 969.960 6
10 358293.510 5973162.720 959.090 46
10 358291.870 5973161.450 959.230 37
5 358289.800 5973159.790 961.540 17
10 358290.250 5973160.210 959.270 28
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597546.5670 1770.970 -2482.530 182.670 188.0
597546.5670 1772.030 -2482.500 182.660 173.0
597546.5670 1773.080 -2482.490 182.610 188.0
597546.5870 1774.240 -2483.750 182.560 182.0
597546.5870 1773.100 -2483.770 182.710 150.0
597546.5870 1771.930 -2483.810 182.630 176.0
597546.5870 1770.870 -2483.830 182.630 176.0
597546.5870 1769.720 -2483.860 182.680 183.0
597546.5870 1768.560 -2483.880 182.720 172.0
597546.5870 1767.410 -2483.910 182.810 171.0
597546.5870 1766.350 -2483.930 182.820 176.0
597546.5870 1765.200 -2483.960 182.860 195.0
597546.5870 1763.950 -2483.990 182.930 182.0
597546.5870 1762.890 -2484.010 182.990 158.0
597546.5870 1761.740 -2484.040 183.090 166.0
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FIGURE 2.4 Examples of LiDAR data in ASCII files. The numbers in each row are: (Left) classification code, x, y, z, and intensity; (Right) GPS time, x, y, z, and intensity.

2.5 LiDAR DATA FORMATS

- For better exchange of LiDAR point cloud data, the American Society for Photogrammetry and Remote Sensing (ASPRS) introduced a sequential binary LASer (LAS) file format to contain LiDAR or other point cloud data records in 2003 (Ver.1.0). Please refer to ASPRS website for specifications of all LAS versions.

- Each LAS file could consist of a public header block, any number of Variable Length Records (VLRs), point data records, and any number of Extended Variable Length Records (EVLRs).

LAS File Section	Note
Public header block	Required
Variable length records (VLRs)	Optional
Point data records	Required
Extended variable length records (EVLRs)	Optional

Public header block → Basic summary information such as no. & boundary of points

Variable length records (VLRs) → Map projection & metadata

Extended variable length records (EVLRs) → Waveform data (LAS 1.3 or 1.4 only)

TABLE 2.1 The Basic Structure of an LAS File

2.5 LiDAR DATA FORMATS

- Each record for point data stores information such as the point's x, y, z, intensity, return number, number of returns (of a given pulse), scan direction, classification, GPS time, point source, etc.

- A value of 4 for the number of returns and a value of 2 for the return number means that the point is the second return of a pulse that generated four returns.

TABLE 2.2 An Example Format for LiDAR Point Data

x	
y	
z	Red
Intensity	Green
Return Number	Blue
Number of returns	Wave packet descriptor index
Scan direction flag	Byte offset to waveform data
Edge of flight line	Waveform packet size in bytes
Classification	Return point waveform location
Scan angle rank	*x*(*t*)
User data	*y*(*t*)
Point source ID	*z*(*t*)
GPS time	

2.5 LiDAR DATA FORMATS

- If a digital camera is integrated with a LiDAR system, each laser point can be linked with an image pixel based on photogrammetric techniques. In such a case, a point data record could also store the spectral (e.g., blue, green, red, and near-infrared) values of the associated pixel. Such spectral information is very useful for realistically visualizing the scanned landscapes in three-dimensions (3D)

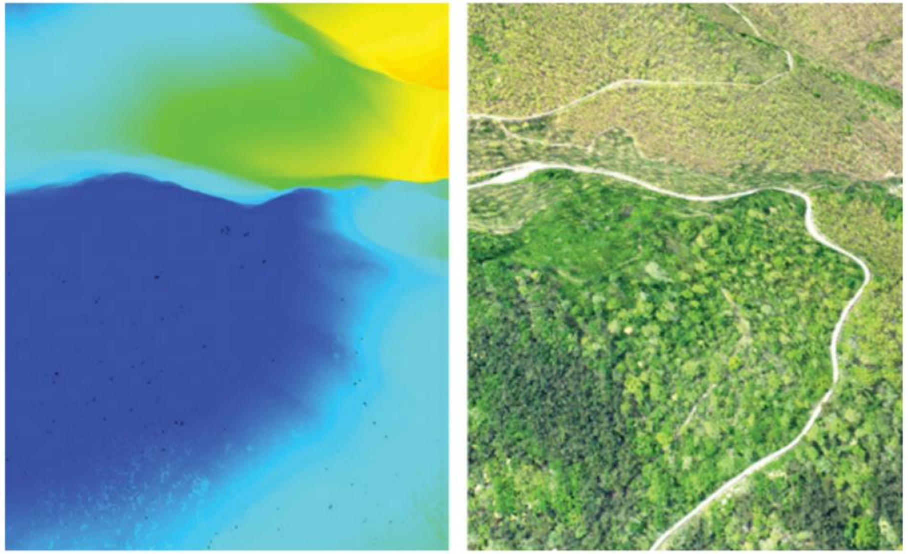

FIGURE 2.5 Laser points rendered based on their Z elevation (left) and camera pixels' RGB spectral values (right).

2.5 LiDAR DATA FORMATS

- With the large variety of LiDAR systems many kinds of point data record formats have been defined (ex. LAS 1.0 specifies two kinds of record formats whereas LAS 1.4 does 10 different formats).

- Among point data X, Y, Z coordinates are most important and 'class' is the second most important information: without the class information, a LiDAR dataset is limited to 3D visualization of the point clouds.

TABLE 2.3 ASPRS Standard Classes for Point Data Record Formats 6~10 in LAS1.4

Classification Value	Meaning	Classification Value	Meaning
0	Created, never classified	10	Rail
1	Unclassified	11	Road surface
2	Ground	12	Reserved
3	Low vegetation	13	Wire—guard (Shield)
4	Medium vegetation	14	Wire—conductor (Phase)
5	High vegetation	15	Transmission tower
6	Building	16	Wire—structure connector (e.g., Insulator)
7	Low point (noise)	17	Bridge deck
8	Reserved	18	Nigh noise
9	Water	19–63	Reserved
		64–255	User definable

2.5 LiDAR DATA FORMATS

- Compressed LiDAR binary formats have been proposed by individual developers (e.g., the .laz format) or companies (e.g., the ESRI's.zlas format). These formats can reduce the file size to ~10%–20% of the corresponding LAS files. However, they have not been endorsed by professional societies such as ASPRS.

2.6 LiDAR SYSTEMS

- The National Aeronautics and Space Administration (NASA) had several experimental laser mapping systems including the Scanning Lidar Imager of Canopies by Echo Recovery

- In 2013, NASA developed the Goddard’s LiDAR, Hyperspectral and Thermal airborne imager (G-LiHT) for simultaneous measurements of vegetation structure, foliar spectra, and surface temperatures at very high spatial resolution (~1 m).

- Manufactures of commercial LiDAR systems include Riegl (Austria), Toposys (Germany), TopEye/Blom (Sweden), and Optech (Canada), among others.

2.7 LiDAR RESOURCES

- A list of some LiDAR data sources:

1. Open Topography http://www.opentopography.org
2. USGS Earth Explorer http://earthexplorer.usgs.gov
3. United States Interagency Elevation Inventory https://coast.noaa.gov/inventory/
4. National Oceanic and Atmospheric Administration (NOAA) Digital Coast https://www.coast.noaa.gov/dataviewer/#
5. Wikipedia LiDAR https://en.wikipedia.org/wiki/National_Lidar_Dataset_(United_States)
6. National Ecological Observatory Network—NEON http://www.neonscience.org/data-resources/get-data/airborne-data
7. LiDAR Data for the United Kingdom http://catalogue.ceda.ac.uk/list/?return_obj=ob&id=8049, 8042, 8051, 8053

2.7 LiDAR RESOURCES

- A list of some free LiDAR software:

1. FugroViewer (for LiDAR and other raster/vector data) http://www.fugroviewer.com/
2. FUSION/LDV (LiDAR data visualization, conversion, and analysis) http://forsys.cfr.washington.edu/fusion/fusionlatest.html
3. LAS Tools (Code and software for reading and writing LAS files) http://www.cs.unc.edu/~isenburg/lastools/
4. LASUtility (A set of GUI utilities for visualization and conversion of LAS files) http://home.iitk.ac.in/~blohani/LASUtility/LASUtility.html
5. MCC-LiDAR (Multi-scale curvature classification for LiDAR) http://sourceforge.net/projects/mcclidar/

PROJECTS

- PROJECT 2.1: REVIEW OF ZONAL STATISTICS FOR RASTER DATA IN ARCGIS
- PROJECT 2.2: CREATING AN LAS DATASET USING LIDAR POINT CLOUDS FROM FREMONT, CA, USA
- PROJECT 2.3: EXPLORING AIRBORNE LiDAR DATA