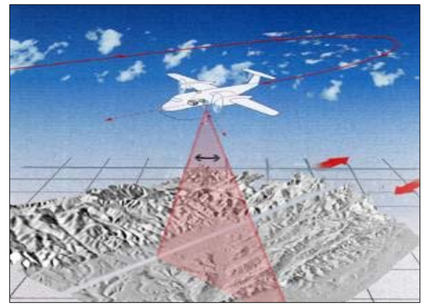
LIDAR MAPPING FACT SHEET

1. LIDAR THEORY



Lidar systems collect height and elevation data using light from the near-infrared wavelength.

What is lidar? Lidar is an acronym for "light detection and ranging." In the mapping industry, this term is used to describe an airborne laser profiling system that produces location and elevation data to define the surface of the earth and the heights of above-ground features. Mounted on either a helicopter or a fixed-wing aircraft, lidar systems use the near-infrared portion of the electro-magnetic light spectrum (1064 nm) to collect data night or day, in shadow, and beneath clouds. Using semi-automated techniques the "raw" lidar data is processed to generate a number of useful end products, including an accurate "bare-earth" terrain model in which trees, vegetation, and manmade structures have been edited out.

How does it work? Lidar systems vary by manufacturer, but all use the following instrumentation: a laser source and detector; a scanning mechanism and controller; airborne GPS and IMU equipment; a high-accuracy, high-resolution clock for timing laser emissions, reflections, GPS/IMU, and scan-angle measurements; high performance computers; and high capacity data recorders. With these components, lidar data collection is possible:

- A pulse of laser light is emitted and the precise time is recorded
- The reflection of that pulse from the surface is detected and the precise time is recorded
- Using the constant speed of light, the time difference between the emission and the reflection can be converted into a slant range distance (line-of-sight distance)
- With the very accurate position and orientation of the sensor provided by the airborne GPS and inertial measurement unit (IMU) data, the XYZ coordinate of the reflective surface can be calculated

What are the benefits of lidar? Lidar offers many advantages over traditional photogrammetric methods for collecting elevation data. These include high vertical accuracy, fast data collection and processing, robust data sets with many possible products, and the ability to collect data in a wide range of conditions.

2. TECHNICAL OVERVIEW

System calibration. System calibration must occur for each mission. This involves flying a specific pattern of flight lines to highlight systematic offsets to which adjustments are applied during the processing. Ground control also is used to determine any vertical bias that may occur from flight to flight.

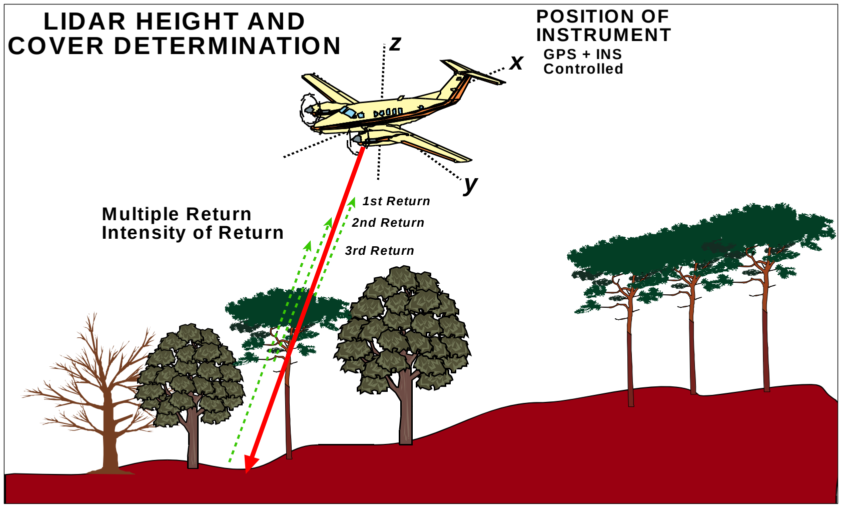
Collection Parameters. Lidar missions are tailored to meet individual project specifications, based on intended data use. Important collection parameters include:

- Point spacing and point density. Also referred to as "average" or "nominal" post spacing, point spacing is a one-dimensional measurement of points along a line. Point density refers to the number of points in a given area. The greater the number of points, the denser the dataset.
- Pulse rate. The pulse rate is the speed by which the lidar sensor emits laser pulses. Lidar systems can have fixed or variable pulse rates. Higher pulse rates are associated with denser data sets. The chosen pulse rate for a specific mission will impact the maximum operational altitude (higher pulse rates require lower altitudes).
- Field of view. The field of view (FOV) refers to a sensor's scan angle. The FOV can be fixed or variable and impacts the flying altitude and pulse rate (wider scan angles require higher altitudes and lower pulse rates). For areas containing intense shadows (mountainous regions, for instance) a narrow FOV is preferable to keep the beam nearly perpendicular to the earth's surface.
- Aircraft altitude. The altitude (and speed) of the aircraft during lidar missions depends on the desired point spacing/point density, pulse rate, and field of view. Typically, missions flown at high altitudes and fast speeds produce less dense datasets. Terrain features, aircraft safety, and air traffic control regulations must also be considered when choosing an altitude for a project.

Multiple Return Lidar. Multiple return lidar yields both range and intensity data from a single pass:

- Range data measures the distance from the sensor to the object struck.
- Intensity data measures the return signal strength, based on the way the object struck reflects the lidar energy. Intensity data is consistent among similar objects, making it possible to map the information in the form of a matrix, giving the appearance of a gray-scale image.

In multiple return lidar systems, the first pulse measures the range to the first object encountered. The last pulse measures the range to the last object. By acquiring first- and last-pulse data simultaneously, it is possible to measure both tree heights and the topography of the ground.

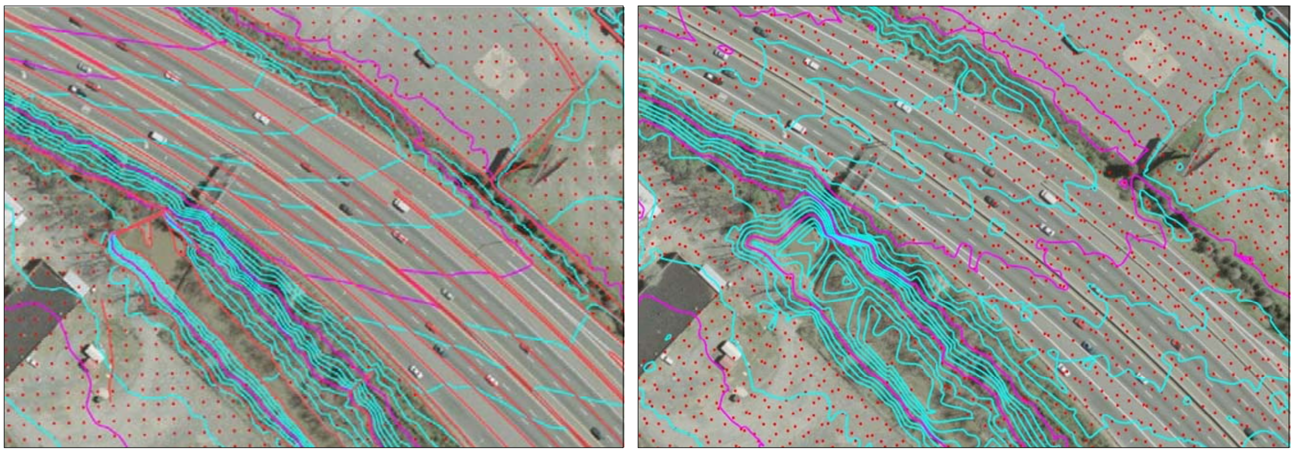


In this example, the first return measurement is a range value of the tree top; the last return is the ground. Lidar systems can return up to four range values and three intensity values for ground and above-ground elevation data from a single flight.

Multiple return lidar enables dense datasets even in treed areas. Note how ground points from first return lidar (left) are limited to the roadway, parking lot, and intermittent areas between trees. The number of ground points in the treed areas increases greatly when first and last returns are combined (right).

Lidar Processing for DEM production. Automated and manual procedures are used to process lidar data and associated GPS/IMU data to generate a digital elevation model (DEM). While auto-filtering removes a majority of data artifacts, manual editing is required to achieve an accurate bare-earth surface model, where vegetation, structures, and other above-ground features have been removed. Quality control of the lidar data processing often involves a peer review before final data acceptance.

Contours and Lidargrammetry. Topographic contours are extracted automatically from the bare-earth DEM then manually edited to correct any errors. For this process, the use of breaklines——lines that define breaks in the topography, such as cliffs, ditches, and rivers—is highly recommended as it provides a more realistic representation of the terrain. Breaklines can be extracted by stereo compilation of aerial photography, but since this mandates a separate mission for imagery acquisition, the method can be cost prohibitive unless the imagery is required for other purposes. To eliminate the need for imagery acquisition, a method known as "lidargrammetry" may be employed. Lidargrammetry enables breaklines to be extracted from stereoscopic pairs of lidar intensity imagery. The intensity data from the lidar collect is projected onto the lidar-derived DEM from two different viewing angles to artificially create two separate images that form a stereo pair.



Contours extracted without breaklines may be statistically accurate and meet most nationally recognized standards, but they appear messy and are difficult to interpret (right). With added breaklines, the contours "follow" the terrain more realistically (left); as a result, interpreting the contours is much more intuitive as terrain features (rivers, roads, etc.) become instantly recognizable.

3. LIDAR MYTHS

Though airborne lidar mapping has been mainstream for nearly a decade, many myths persist:

- **Myth 1: More points are always better.** Point spacing (the distance between points) and point density (the coverage of points within a given area) are critical considerations for any lidar mapping project. Factors that determine optimum point spacing include desired vertical accuracy, terrain, land cover, and the ultimate data application. For many applications, a lower point density is sufficient and can save time and costs by reducing acquisition time and data processing as well as potential data storage and handling difficulties.
- **Myth 2: Lidar can see through foliage.** Lidar does not "see through foliage." However, some lidar points do reach the ground through openings in the tree canopy. As the lidar point density increases, so does the probability of obtaining returns from the ground. In fact, lidar systems generate a significantly greater number of ground elevation points in vegetated areas, compared to what typically is achieved through photogrammetric compilation methods at comparable mapping scales. Among other problems, stereo compilation technicians are forced to contend with shadows and radial distortions (e.g. leaning buildings) which can obscure the technician's view of the ground when using traditional aerial photography.
- **Myth 3: Lidar replaces traditional mapping techniques.** Lidar is a complement to, not a replacement for, traditional aerial mapping methodologies. For most uses, lidar intensity imagery is not a viable replacement for aerial photography, nor does lidar data provide an option for planimetric mapping.
- **Myth 4: Lidar is an all-weather system.** The target must reflect the near infrared portion of the electro-magnetic light spectrum for lidar to work. Data collection can occur beneath the clouds and in some haze, but because water absorbs most near infrared light, it will not operate correctly during fog, rain, or snow.

4. LIDAR PRODUCTS

Many data products are possible from a single lidar mission:

- **Digital surface models.** Lidar provides a fast and cost-effective method for producing digital elevation models (DEMs) accurate for use in orthophoto rectification. Two types are available: reflective-surface DEMs from first returns for elevation of above ground features and bare-earth DEMs from all range and intensity values for accurate measurement of the earth's surface.
- **Contours.** Supplemented with breaklines, lidar-derived contours can be generated at 1' to 5' intervals, meeting National Map Accuracy Standards in accordance with FEMA lidar mapping specifications.
- **Land-use/land-cover.** Lidar data may be used to generate preliminary land-cover classification depicting open, scrub/shrub, urban, and forested classifications, useful for hydrologic and hydraulic modeling in support of floodplain mapping.
- **Intensity images.** Similar in appearance to low-resolution photographs, georeferenced lidar intensity images can be used to extract planimetric features and serve as ancillary input for lidar data processing. Intensity images also are used to check the horizontal accuracy of the lidar data and other criteria.
- **Point cloud.** Once all the elevation points are computed from each of the individual returns, the resulting dataset consists of a "cloud" of points that represent elevations of both ground and above-ground features.

5. LIDAR APPLICATIONS

Lidar data serves a wide range of applications:

- **Base mapping.** Lidar DEMs are accurate for orthorectification as well as for contour generation with supplemented 3D breaklines.
- **Floodplain mapping.** Lidar data supports flood hazard analyses and hydrologic and hydraulic modeling.
- **Natural resources management.** Lidar data is used to calculate tree-stand heights, biomass, and timber volumes and is useful in establishing volume calculations for mineral extraction.
- **Transportation and utility corridor mapping.** Lidar data can supplement traditional ground and aerial surveys in the planning and design of new transportation and utility corridors.
- **Urban modeling.** 3D models from bare-earth and reflective-surface lidar data can be used in analysis and visualization of urban planning, line-of-sight studies, and viewshed analysis, etc.

POINT SPACING	VERTICAL ACCURACY (RMSE)	CONTOUR INTERVAL	APPLICATION SUPPORTED				
			Base Mapping	Floodplain Mapping	Natural Resources	Transportation / Utility	Urban Modeling
1 m	0.09 m	1'	✓	✓	✓	✓	✓
2 m	0.20 m	2'	✓	✓	✓	✓	
3 m	0.30 m	3'	✓	✓	✓		
4 m	0.40 m	4'	✓				
5 m	0.51 m	5'	✓				

Note: this table is for example only. Other scenarios are possible and would be defined on a case-by-case basis depending on specific project requirements.

6. LIDAR PROCUREMENT

Industry Standards. Most local and state governments use lidar specifications developed by the Federal Emergency Management Agency (FEMA). See http://www.fema.gov/plan/prevent/fhm/lidar_4b.shtm. Published in 2000, the Lidar Specifications for Flood Hazard Mapping requires a DEM point spacing of 5 m or less and a vertical accuracy of 30 cm. Adherence to the standards are an important aspect of becoming a FEMA Cooperating Technical Partner (CTP), the advantages of which include potential funding benefits. The American Society for Photogrammetry and Remote Sensing (ASPRS) is another common reference; their Guidelines for Vertical Accuracy Reporting for Lidar Data was produced in 2004 and incorporates relevant sections of the National Digital Elevation Program's Guidelines for Digital Elevation Data.

Project Considerations. Questions to consider when designing projects include:

- What is the ideal point spacing and point density for the given application(s)?
- How will the flight design account for the different types of terrain or changes in the elevation?
- What deliverables should be requested (bare-earth DEM, point cloud data, reflective surface DEM, intensity images, ground survey and acquisition reports, lidar-derived land cover)?
- What methodology is desired for removing vegetation and above-ground features to generate a bare-earth DEM (fully- or partially-automated removal)?
- What vertical accuracy is needed for the given application(s)?
- What is the preference between data licensing and data ownership?

Costs. Lidar project costs vary based on project specifications. A 500 sq mi project area with 3 m point spacing over flat to moderate terrain may cost $200-300 per sq mi. The same type of project with a 1 m point spacing over an area of 100-500 sq mi may cost $350-450 per sq mi. These rough estimates assume a contiguous, roughly rectangular project block. The location, type of terrain, vegetation cover, and time of year can dramatically affect pricing.