Chapter 6: Aerial and satellite images

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Introduction

Aerial and satellite images are a valuable and common source of data for GIS or another software for spatial analysis.

These images are data recorded from a distance; thus, photos and satellite images are often referred to as *remotely sensed data*.

In the GIS context,

- Aerial images: taken from aircraft using film or digital cameras
- Satellite images: recorded with satellite scanners

Sensed images are valuable sources of spatial data for many reasons, including:

Large-area coverage: These kind of images capture data from large areas at a relatively low cost and in a uniform manner.

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Permanent record: An image is fixed in time, so the conditions at the time of the photograph could be analyzed many years hence.

but also have the following problem:

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Example of Large-area coverage:

Figure 1: Left: Northeastern Egypt, illustrates the broad-area coverage provided by satellite data and Right: Pyramids in Egypt illustrates the high spatial detail that could be obtained (courtesy NASA

Basic principles

The most common forms of remote sensing are based on reflected electromagnetic energy.

Different materials reflect different amounts of incoming energy, and this differential reflectance gives objects a distinct appearance. We use these differences to distinguish among objects.

Light is the principal energy form detected in remote sensing for GIS.

Light energy is characterized by its wavelength, the distance between peaks in the electromagnetic stream.

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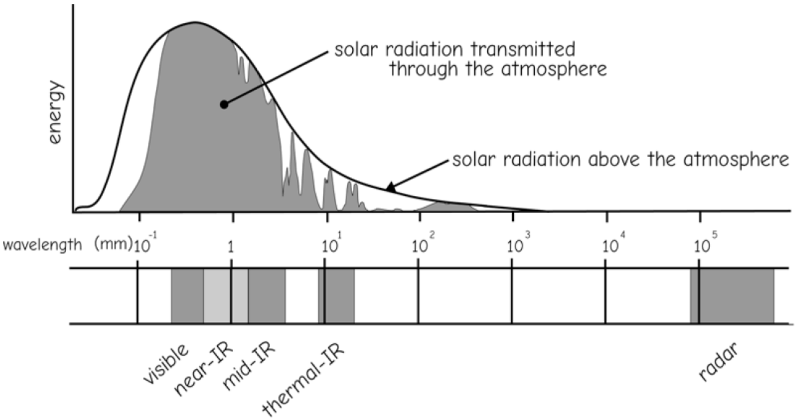

Figure 2: Electromagnetic energy is emitted by the sun and transmitted through the atmosphere (upper). Solar radiation is partially absorbed as it passes through the atmosphere. This results in variable surface radiation in the visible and infrared (IR) wavelength regions (lower) (Bolstad (2016)).

Our eyes perceive light in the visible portion of the spectrum, between 0.4 and 0.7 μm. We typically identify three base colors: blue, from approximately 0.4 to 0.5 μm, green from 0.5 to 0.6 m, and red from 0.6 to 0.7 μm. Other colors are often described as a mixture of these three colors at varying levels of brightness.

Electromagnetic energy striking an object is reflected, absorbed, or transmitted. For example;

- Solid objects absorb or reflect incident electromagnetic energy and transmit none.
- Liquid water and atmospheric gasses are the most common natural materials that transmit light energy as well as absorb and reflect it.

However, energy transmittance through the atmosphere is most closely tied to the amount of water vapor in the air. Water vapor absorbs energy in several portions of the spectrum, and higher atmospheric water content results in lower transmittance.

While we perceive differences in the visible wavelengths, these differences also extend into other portions of the electromagnetic spectrum that we cannot perceive (Fig. 3).

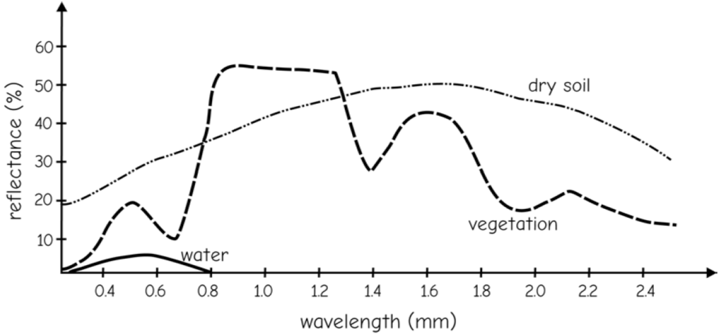

Figure 3: Spectral reflectance curves for some common substances. The proportion of incoming radiation that is reflected varies across wavelengths (Bolstad (2016)).

Most remote sensing systems are *passive*, in that they use energy generated by the sun and reflected off of the target objects ⟶ aerial images and most satellite data are collected using passive systems.

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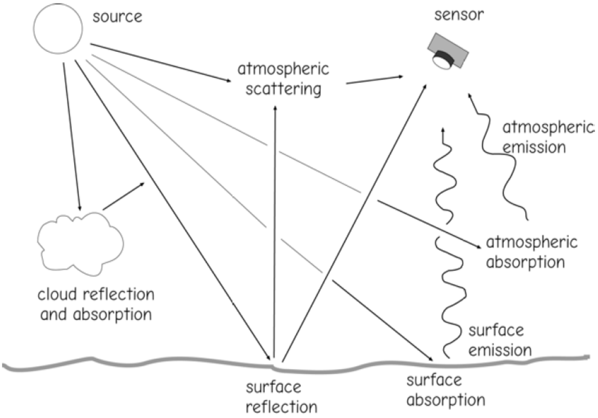

Figure 4: Energy pathways from source to sensor (Bolstad (2016)).

In summary:

Light and other electromagnetic energy could be absorbed, transmitted, or reflected by the atmosphere. Light reflected from the surface and transmitted to the sensor is used to create an image. The image could be degraded by atmospheric scattering due to water vapor, dust, smoke, and other constituents. Incoming or reflected energy could be scattered (Fig. 4).

Another type of remote system are the called *active* and can be used for gathering remotely sensed data under cloudy or nighttime conditions.

Active systems generate an energy signal and detect the energy returned. Differences in the quantity and direction of the returned energy are used to identify the type and properties of features in an image.

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The most common active remote sensing are:

Radar (radio detection and ranging): focuses a beam of energy through an antenna, and then records the reflected energy. These signals are swept across the landscape, and the returns are assembled to produce a radar image.

LIDAR (light detection and ranging): is an optical remote sensing technique that uses laser light to densely sample the surface of the earth, producing highly accurate x, y, z measurements.

Aerial images

Although there are hundreds of applications for aerial images, most applications in support of GIS could be placed into three main categories.

- Are used as a basis for mapping (measuring and identifying the horizontal and vertical locations of objects.)
- Image interpretation could be used to categorize or assign attributes to surface features.
- Images are often used as a backdrop for maps of other features,

Camera aircraft, formats and systems

Aerial camera systems are most often designed for mapping, so the camera and components are built to minimize geometric distortion and maximize the quality of the images.

Mapping cameras are usually carried aboard specialized aircraft designed for photographic mapping projects (Fig. 5)

Figure 5: Aerial photographs are often taken from specialized aircraft, such as this low altitude airplane, or from helicopters or higher-flying, larger aircraft (Bolstad (2016)).

Aerial cameras for spatial data collection are large, expensive, sophisticated devices, but in principle they are similar to simple cameras.

Image scale and *extent* are important attributes of remotely sensed data.

- Image scale, as in map scale, is defined as the relative distance on the image to the corresponding distance on the ground.
- Image extent is the area covered by an image, and depends on the physical size of the sensing area or element.

Image resolution is another important concept. The resolution is the smallest object that can reliably be detected on the image.

Resolution in digital cameras is often set by the pixel size, the size of individual sensing elements in an array.

Digital aerial cameras

Digital aerial cameras are the most common systems used for aerial mapping, and routinely provide high-quality images (Fig. 6)

Figure 6: This figure shows images collected at 15 cm resolution. Extreme detail is visible, including roof vents, curb locations, and street poles (Bolstad (2016)).

Digital aerial cameras provide many advantages,including greater flexibility, easier planning and execution, greater stability, and direct to digital output. While many film cameras are still in use today, camera production has effectively ceased.

The lens of digital cameras focuses light onto charge-coupled devices (CCDs).

CCD is a rectangular array of pixels, or picture elements, that respond to light. It's composed of layers of semiconducting material with appropriate reflective and absorptive coatings, insulators, and conducting electrodes (Fig. 7).

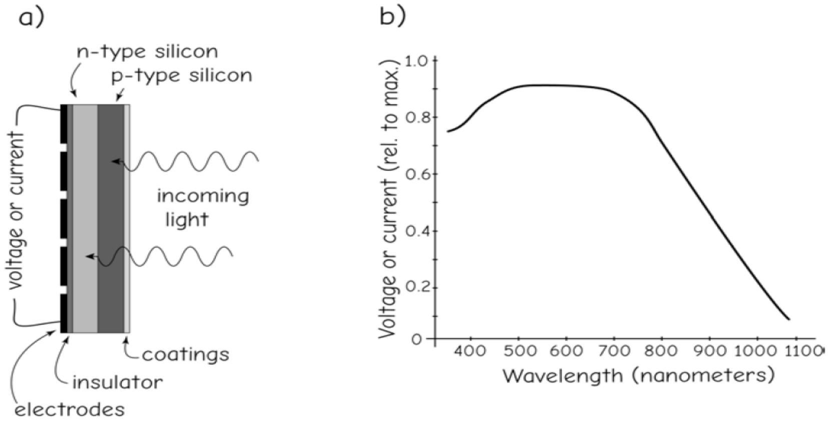

Figure 7: CCD response for a typical silicon-based receptor. The CCD is a sandwich of semiconducting layers (a, on left) that generates a current or voltage in proportion to the light received. Response varies over a wavelength region (b, on right) (Bolstad (2016)).

Since CCDs are typically configured to be sensitive to only a narrow band of light, multiple CCDs could be used, each with a dedicated lens and a specific waveband.

Digital cameras typically have a computer control system:

- Used to specify the location, timing, and exposure
- Record GPS and aircraft altitude and orientation information
- Provide data transfer and storage
- Allow the operator to monitor progress and image quality during data collection

The next Figure (8) shows this system.

Figure 8: An example of the sophisticated system for controlling digital image collection, here with a Leica Geosystems ADS40 digital aerial camera (Bolstad (2016)).

Geometric quality of aerial images

Aerial images are a rich source of spatial information for use in GIS, but most aerial images contain geometric distortion (Fig. 9)

Figure 9: Tilt distortion is common on aerial and some satellite images (Bolstad (2016)).

Most geometrically precise maps are orthographic. An orthographic map plots the position of objects after they have been projected onto a common plane, often called a datum plane (Fig. 10).

Objects above or below the plane are vertically projected down or up onto the horizontal plane. Thus, the top and bottom of a building should be projected onto the same location in the datum plane.

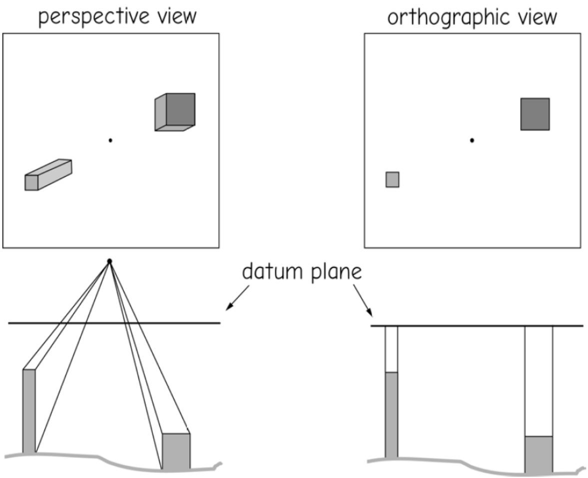

Figure 10: Tilt distortion is common on aerial and some satellite images (Bolstad (2016)).

Unfortunately, most aerial images provide a nonorthographic perspective (Fig. 10), left). Perspective views give a geometrically distorted image of the Earths surface. Some problems of this are:

- Affects the relative positions of objects
- Uncorrected data could not directly overlay data in an accurate orthographic map

However, the amount of distortion in aerial images could be reduced by:

- Selecting the appropriate camera, lens, flying height, and type of aircraft.
- Collecting images under proper weather conditions during periods of low wind and by employing skilled pilots and operators

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An important question arises here:

Is the distortion and geometric error below acceptable limits, given the intended use of the spatial data?

This question is not unique to aerial images; it applies equally well to satellite images, spatial data derived from GPS and traditional ground surveys, or any other data.

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Distortion in aerial images comes primarily from six sources: terrain, camera tilt, film deformation, the camera lens, sensor defects or other camera errors, and atmospheric bending.

Terrain and tilt distortion in aerial images

Terrain variation, defined as differences in elevation within the image area, is often the largest source of geometric distortion in aerial images.

Terrain variation causes *relief displacement*, defined as the radial displacement of objects that are at different elevations (Fig. 11).

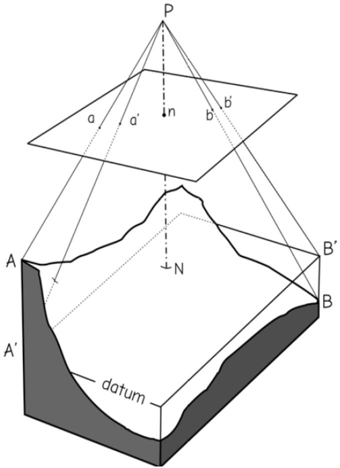


Figure 11: Geometric distortion on an aerial photograph due to relief displacement. P is the camera station, N is the nadir point (Bolstad (2016)).

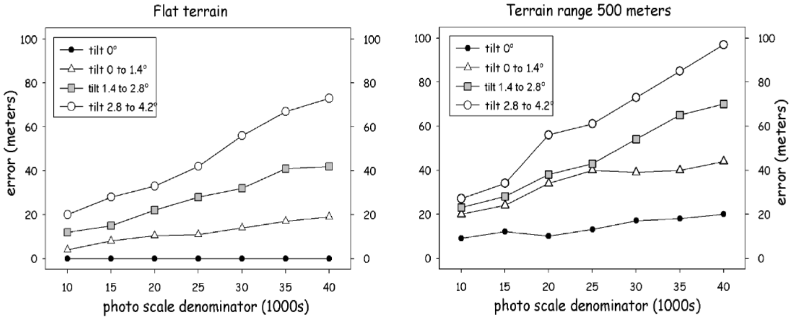
Key characteristics of terrain distortion in vertical aerial images

- Terrain distortions are radial
- Relief distortions affect angles and distances on an image
- Scale is not constant on aerial images
- A vertical aerial image taken over varied terrain is not orthographic

Camera tilt could be another large source of positional error in aerial images. Camera tilt, in which the optical axis points at a nonvertical angle, results in complex *perspective convergence* in aerial images.

Figure 12: An example of tilt convergence. Crop bands of equal width appear narrower towards the horizon in this highly tilted image (Bolstad (2016)).

Figure 13 illustrates the changes in total distortion with changes in tilt, terrain, and image scale.



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Geometric errors can be quite large and will occur when we digitizing from vertical aerial images, even if the digitizing system is perfect and introduces no error.

System errors: media, lens, and camera distortion

The film, camera, and lens system could be a significant source of geometric error in aerial images. One form of distortion commonly caused by the camera system is the *Radial lens displacement*.

Radial lens displacement is typically quite small in mapping camera systems, but it could be quite large in other systems

- Lenses are designed and precisely manufactured so that the image distortion is minimized.
- Films are designed so that there is limited distortion under tension on the camera spools.

Thus, camera and lens distortions in mapping cameras are typically much smaller than other errors, for example, tilt and terrain errors, or errors in converting the image data to forms useful in a GIS.

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Geometric correction of aerial images

Due to the geometric distortions described above, it should be quite clear that uncorrected aerial images should not be used directly as a basis for spatial data collection under most circumstances.

Points, lines, and area boundaries may not occur in their correct relative positions, so length and area measurements could be incorrect.

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Photo interpretation

Once we have determined that the film and camera system meet our spatial accuracy and information requirements, we need to collect the photographs and interpret them.

Photo (or image) interpretation is the process of converting images into information.

In summary, interpreters use the size, shape, color, brightness, texture, and relative and absolute location of features to interpret images. Differences in these diagnostic characteristics allow the interpreter to distinguish among features.

Satellite images

Basic principles of satellite image scanners

Scanners operate by pointing the detectors at the area to be imaged. Each detector has an *instantaneous field of view* (IFOV), that corresponds to the size of the area viewed by each detector (Fig. 14).

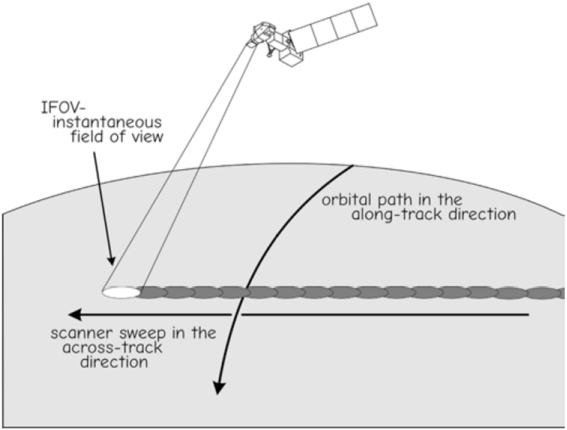

Figure 14: A spot scanning system. The scanner sweeps an instantaneous field of view (IFOV) in an across-track direction to record a multispectral response (Bolstad (2016)).

Satellite data are often nominally collected in a path/row system (Fig. 15).

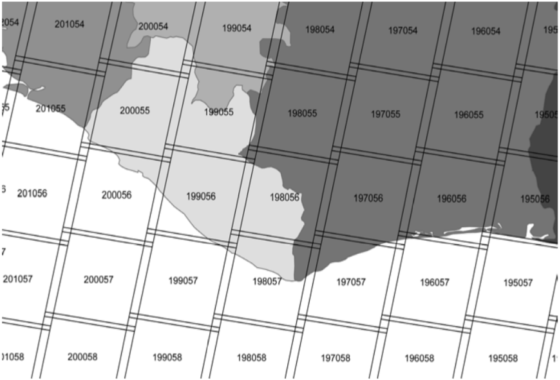

Figure 15: A portion of the path and row layout for the Landsat satellite systems (Bolstad (2016)).

High resolution satellite systems

Images from high-resolution satellite systems could provide a suitable source for spatial data in a number of settings. These images provide substantial detail of different features, and match the spatial resolution and detail of high-accuracy GNSS receivers

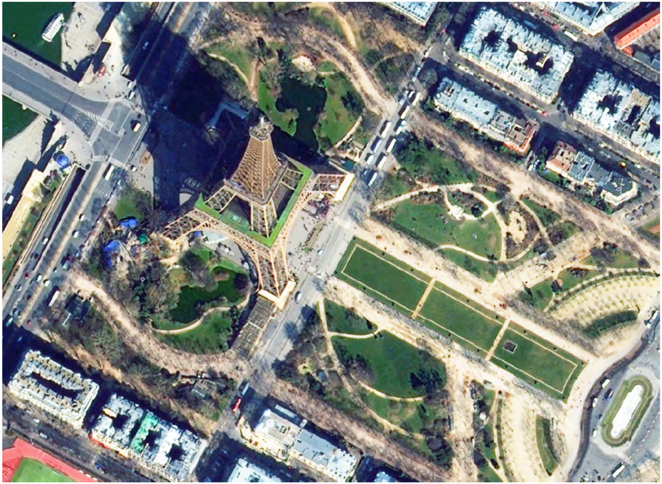

Figure 16: A 0.5 m resolution image from the Worldview satellite (courtesy DigitalGlobe) (Bolstad (2016)).

Mid resolution satellite systems

There are several mid resolution satellite systems, here defined as those providing images with resolutions from 5 m to less than 100 m. SPOT is one of the longest running, uninterrupted satellite imaging systems.

Figure 17: An example of an image from the SPOT satellite system (Bolstad (2016)).

Landsat

Because Landsat was the first Earth observing satellite system and it has operated nearly continuously since 1972, there is an image repository spanning five decades. The majority of these images (Fig. 18) are available free of charge to anyone with an internet connection, allowing long-term monitoring and analysis.

Figure 18: An example of a Landsat-5 image, showing the Mississippi River Delta. Mid-resolution satellites are particularly appropriate for regional or other large-area analysis (Bolstad (2016)).

There are other systems as:

- Resourcesat
- RapidEye
- Coarse-Resolution, Global Satellite Systems
- MERIS

So, important factors to select between aerial images and high-resolution satellite images?

- Spectral range
- Price
- Availability
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Aerial or satellite images : Which to Use?

Aerial images could be preferred when resolutions of a few centimeter are needed, or for smaller areas, under narrower acquisition windows, or with instrument clusters not possible from space.

Satellite data are attractive when collecting data for larger areas, or where it is unwise or unsafe to operate aircraft, or because data for large areas could be geometrically corrected for less cost and time.

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Satellite images in GIS

Satellite images have two primary uses in GIS:

1. Satellite images are often used to create or update landcover data layers.

Satellite image classification involves identifying the reflectance patterns associated with each landcover class, and then applying this knowledge to classify all areas of a satellite image (Fig. 19).

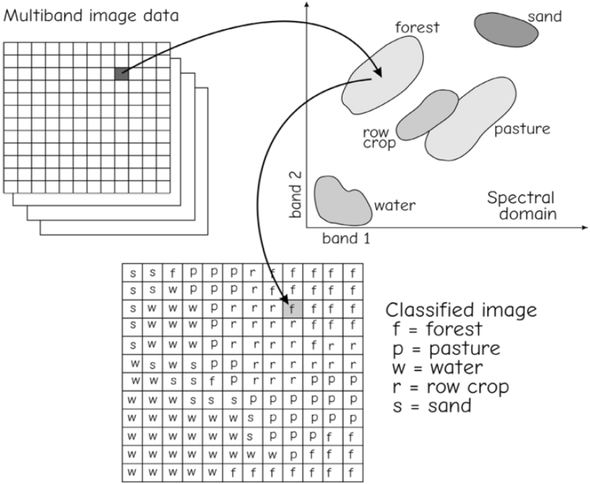


Figure 19: Landcover and land use classification is a common application of satellite images. The spectral reflectance patterns of each cover type are used to assign a unique landcover class to each cell (Bolstad (2016)).

2. Satellite images are also used to detect and monitor change.

The extent and intensity of disasters such as flooding, fires, or hurricane damage may be determined using satellite images (Fig. 19).

Airborne LiDAR

Laser-based, light detection and ranging systems (LiDAR) are becoming common currently. Lasers are pointed at the Earths surface from an aerial or satellite platform, pulses of laser light emitted, and the reflected energy is recorded (Fig 20)

Like radar, laser systems are active because they provide the energy that is sensed.

Pulses may be sent several thousand times a second, so a trace of ground heights may be measured from every few centimeters to a few meters along the ground.

- *Waveform LiDAR* collects a continuous record of the pulse returns (Fig. 20)
- *Discrete-return LiDAR*: is most common, wherein the system records specific values for each laser pulse downward (Fig. 21).

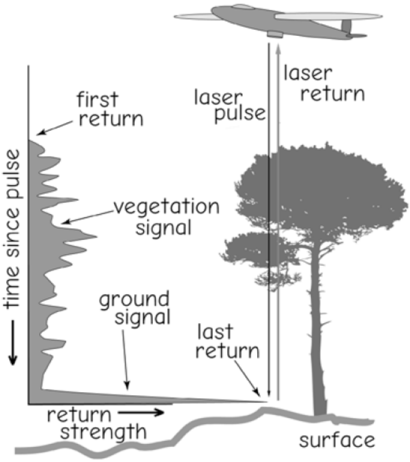
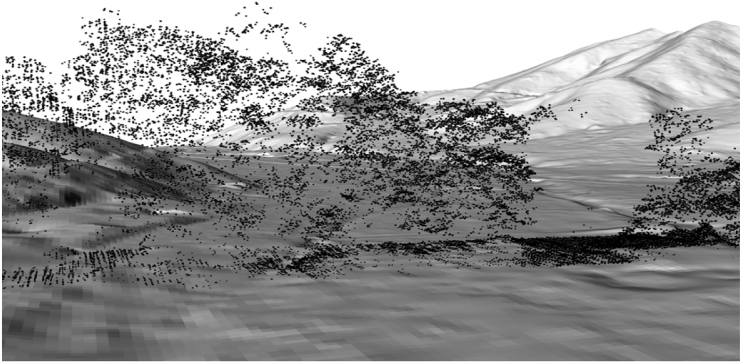


Figure 20: Laser mapping systems operate by generating and then sensing light pulses (Bolstad (2016)).

Discrete-return LiDAR systems produce point clouds, consisting of X, Y, and Z coordinates (Fig. 21)



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Thank You

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