

Chapter 1

Overview of imaging GIS

Imaging GIS, a term used in the medical imaging community (Wang 2012), is adopted here to describe a geographic information system (GIS) that displays, enhances, and facilitates the analysis of Earth images from satellites, aircraft, and, most recently, unmanned aerial systems (UAS). Earth imaging has roots in aerial photogrammetry, which is the “science or art of obtaining reliable measurements by means of photography” (American Society of Photogrammetry 1952). Photogrammetry expanded in the 1960s to include images from the thermal infrared and microwave regions of the electromagnetic spectrum. Orbiting satellites were also being considered as platforms for imaging sensors during these years. As a result, the term *remote sensing* was coined to replace the more limiting terms *aerial* and *photograph* and embrace these developments (Colwell 1960). Remote sensing continued to develop in the 1970s and 1980s with active, microwave radar, which greatly expanded the range of wavelengths used to create images (Slama, Theurer, and Henriksen 1980). More recently, laser scanners (lidar systems) have been employed to create three-dimensional point clouds, a very different kind of “image” that facilitates three-dimensional modeling of the Earth’s surface (Renslow 2012).

Earth images provide photo-realistic representations of the Earth’s surface that increase the interpretability and usefulness of GIS in unique ways. The human eye recognizes many surface features from the wealth of detail present in Earth images, often more easily than from cartographic representations of those features. For example, maps often contain only building footprint symbols for a single-family residential house. An image often contains sufficient detail to not only recognize the building as a single-family residence, but enough to assess the approximate value of the property by inference from landscaping, driveway type, and other clues. Figure 1-1 shows the difference in the level of detail that can exist between an aerial photo and a computer-generated map.

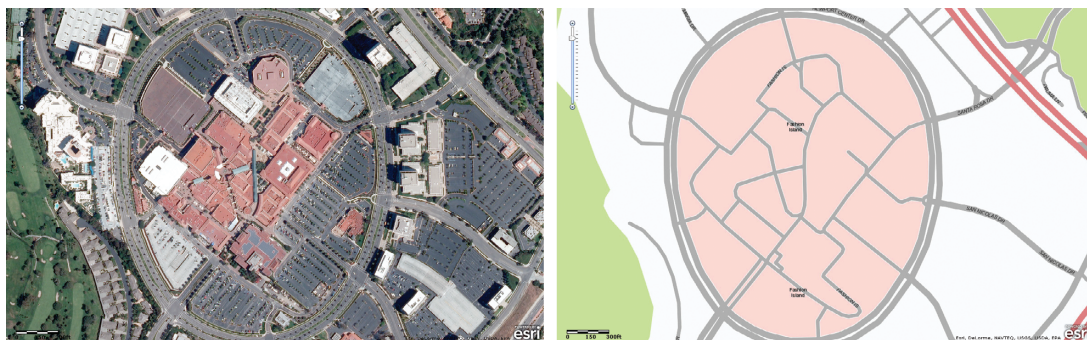


Figure 1-1. Two views of Fashion Island shopping center in Newport Beach, California, in 2009. The image on the left is an aerial photograph, and the image on the right is a typical computer-generated map.

Map courtesy of US Geological Survey. Topographic Mapping Program provided by Esri ArcGIS Online; Esri, DeLorme, NAVTEQ, USGS, USDA, EPA. Image courtesy of National Agriculture Imagery Program, US Department of Agriculture, Farm Service Agency, California Department of Fish and Wildlife, Biogeographic Data Branch.

The myriad recognizable features in the photograph in figure 1-1 would add to the visual information of any map layer in which the photograph was used. In addition, features not shown on the map in figure 1-1 could be identified and delineated from the photograph using a GIS, which creates even more information.

Structure of a two-dimensional digital image

Images are traditionally displayed as raster layers in a GIS, a data structure that most GIS professionals understand. However, images can be more complex than other types of raster data, which can make it challenging for those without remote sensing training to effectively display and enhance them. To review, the raster data structure consists of grid cells arranged in rows and columns. Each cell has associated attributes. The rows and columns provide a coordinate system to locate any grid cell. These image coordinates may be coregistered with a number of Earth coordinate systems such as latitude/longitude, universal transverse Mercator (UTM), or state plane coordinates, as appropriate for specific applications.

The grid cells in an image raster represent picture elements (pixels) of a specific size and shape on the ground (normally square). The key difference between an image raster and other raster grids (such as a digital elevation model) is that the cell attributes of an image are not associated with any specific descriptive variable such as elevation or land cover. The cell values in an image represent brightness. These cell values have a large range of levels (traditionally 256 levels, but recently ranges of up to 2,048 levels have been introduced). Brightness is more analogous to a continuous variable than a categorical variable because it can contain so many levels.

The brightness values contained within the grid cells of an image are seldom displayed as numbers. Rather, shades of gray are sometimes applied by the GIS software to form the classic black-and-white (grayscale) image display (figure 1-2).

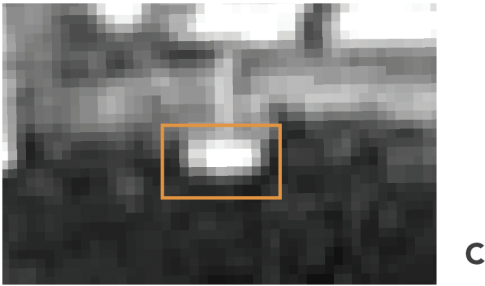
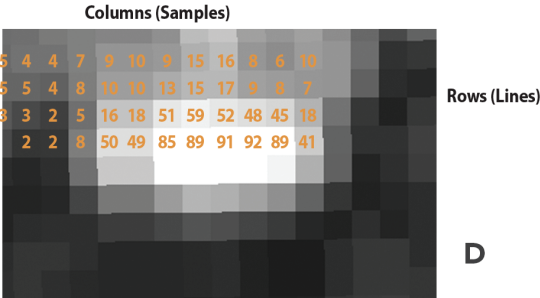


Figure 1-2. The raster data structure of an image showing the relationship between numerical brightness values and shades of gray in a simple gray-scale rendition. *A*, A digital image of a small boat harbor is shown. *B*, An enlargement of the area in the rectangle is shown. *C*, An enlargement of one pier and floating dock shows individual pixels of 1 × 1 meter on the ground. *D*, An enlargement of the end of the dock displays the digital brightness values of the pixels as numbers.

Photograph courtesy of US Geological Survey,
DOQQ, Clear Lake, California, 1993.



The numerical brightness value of any single pixel is usually not informative to the image interpreter. However, the interpreter can use the geographic pattern of relative brightness values to help correctly interpret Earth features that are much larger than a single pixel. The exception is *quantitative remote sensing*, in which environmental variables (such as surface temperature) are inferred from upwelling radiation (further explained in chapter 2).

Another factor that makes image data more complicated than other raster layers is color. Digital color photographs are managed in most general-purpose computer systems as one file in familiar formats (such as picture.tif or picture.jpg). As a result, the casual user may be unaware of the tristimulus theory of color vision, which states that all colors can be formed from various shades of three additive primary colors: red, green, and blue. Every color image is actually three images superimposed in various shades of those three colors (explained in detail in chapter 5). The information contained within color images is best exploited when the three primary additive colors are separated into three raster layers. Images are displayed as three separate layers in most GIS software packages rather than as one layer in common image formats. This three-layer display allows the analyst to manipulate each additive color separately, increasing interpretability of the image. Advanced sensors provide wavelength bands in addition to the visual range, thus providing more information about the Earth's surface than the spectral sensitivity of consumer-grade color photography. The most information is extracted from imagery when false-color combinations are used in which invisible radiation is made visible on screen (Campbell and Wynne 2011). This process is further explained in chapter 5.

Three-dimensional data

GIS software is increasingly able to produce realistic three-dimensional visualizations of terrain from digital elevation models. These perspective views are enhanced when imagery is displayed as an overlay on an elevation model (figure 1-3).

Pairs of aerial images acquired in an overlapping flight pattern can be used to create elevation models through the measurement processes of photogrammetry. Although traditionally the domain of specialized image processing software, photogrammetric functionality is increasingly being incorporated into GIS (Esri 2014a; further explained in chapter 6).



Figure 1-3. A grayscale image draped over a digital elevation model of Sausalito, California, in 1991.

Image and elevation data courtesy of US Geological Survey. Visualization created by the author.

Three-dimensional data may also be represented by *point clouds* in some GIS software. Each data point has three attributes in this data model: an x-coordinate and a y-coordinate for the horizontal position and a z-coordinate for the vertical position. Point cloud data may be displayed in perspective view with visualization software embedded in GIS (figure 1-4). The visualizations provide a reasonably realistic representation of the scene, depending on the number of points in the cloud.

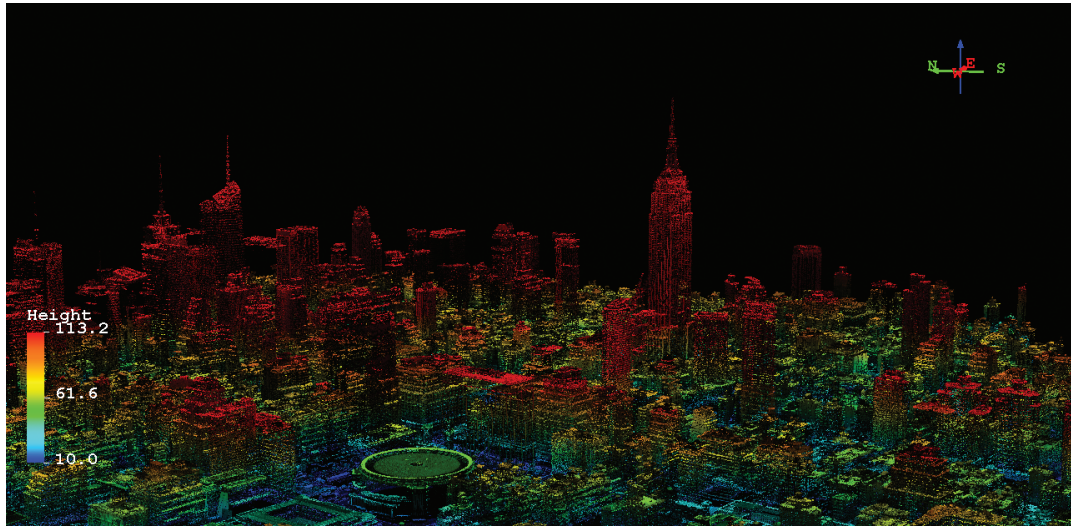


Figure 1-4. An example of point cloud data for New York City, color-coded by elevation.

New York City lidar image courtesy of The Sanborn Mapping Company, Inc. Data acquired and created through a sustainable City University of New York (CUNY) project on behalf of the NYC Solar America City Partnership. Used by permission.

The generation of point clouds has been facilitated by the recent development of laser scanning devices (lidar) that provide millions of geographically registered points very rapidly (Vosselman and Maas 2010). The point cloud structure provides detailed information using very large amounts of data, compared with traditional two-dimensional raster grids. GIS software is rapidly being developed to incorporate point cloud data for the visualization and detailed measurement of features that range from individual structures to entire landscapes (further explained in chapter 6).

Chapter 2

The physical basis and general methods of remote sensing

Knowing how images are formed by sensors will help you effectively use the images created by them. In this chapter, you will learn the principles of electromagnetic (EM) radiation, the engine of image formation in virtually all Earth imaging systems. Underwater acoustic sonar is a well-known example of using sound to generate images, but this form of remote sensing requires specialized software for image display, beyond GIS. Knowing what EM radiation is and how it interacts with the environment will help you interpret the variety of digital image and elevation data available today and planned for tomorrow. In this chapter, you will also learn about current imaging systems and the capabilities and limitations of various remote sensing methods. You will learn about aerial and spaceborne platforms and how their characteristics influence the attributes of the imagery collected from them. Further detail on how sensors generate images is provided in chapter 4 for two-dimensional images and in chapter 6 for three-dimensional point clouds.

How remote sensing works

In order to remotely sense features on the Earth's surface, information must be conveyed from the feature to the sensor. Information about the size, shape, texture, color (or tone), and sometimes the temperature of a feature is conveyed to the sensor by EM radiation. The EM radiation can come from the sun or the Earth and be detected passively by the sensor. The EM radiation can also be generated by the sensor itself to accomplish active remote sensing.

The diagram in figure 2-1, the energy flow profile, illustrates the process of image formation and how remote sensing works. The profile has three components that indicate the flow of EM radiation: the source, the scene, and the sensor. Figure 2-1 illustrates the profile of energy flow when the source of the EM radiation is the sun and the radiation reflects from an object in the scene to be sensed passively by the sensor. Aerial photography and most satellite sensing are done in this way with optical instruments. The diagram is modified to show passive thermal remote sensing and active microwave remote sensing later in this chapter.

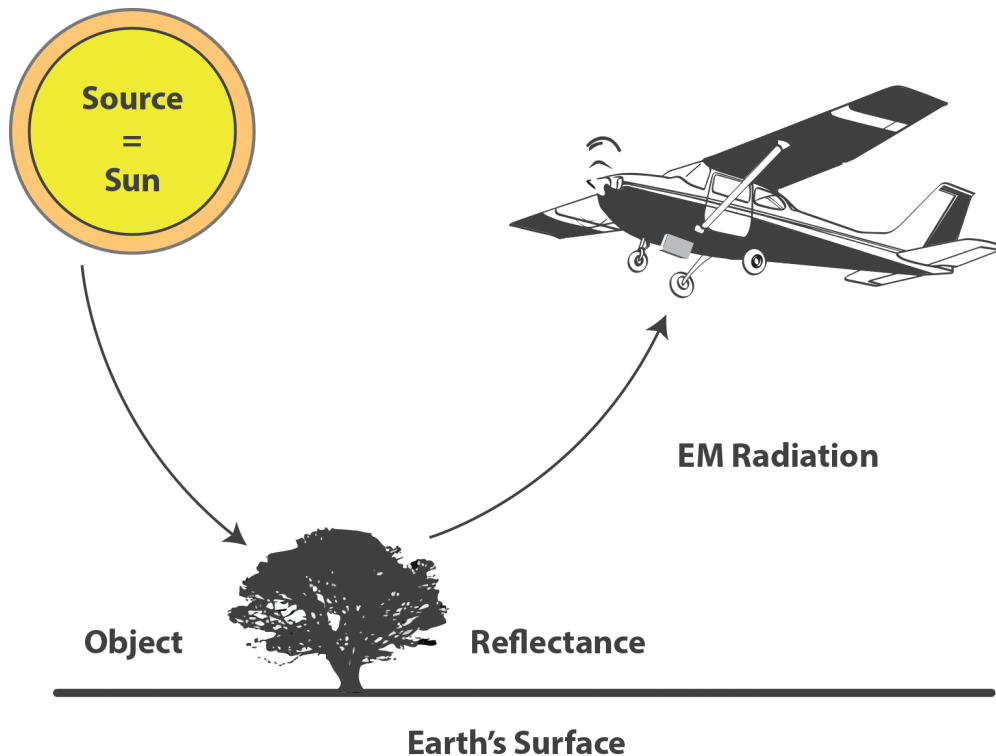


Figure 2-1. The energy flow profile shows the sensor at some distance from the objects of interest. The sun is the source of electromagnetic radiation that creates the image.

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Remote sensing precludes direct (in situ) measurement by field observation. However, a percentage of remotely sensed information is commonly evaluated on the ground using a scientific sampling plan, a procedure called *ground truthing*.

Electromagnetic radiation

Remote sensing systems use EM radiation to form images of Earth features. To understand the remote sensing process, you must know a little about EM radiation.

All matter with a temperature above absolute zero produces EM radiation (Waldman 1983). EM radiation travels at a rapid and constant velocity: the speed of light, or 186,000 miles per second. Some experiments show that EM radiation has wave properties, and others show that it behaves as if it were composed of particles (photons). Both the wave and particle nature of EM

radiation are helpful to understanding image formation. Waves allow the separation of radiation into separate wavelength intervals (wavelength bands), which adds greatly to the information content of images. The particle nature of EM radiation provides the energy that forms the image.

Remote sensing is accomplished with EM radiation emitted by the sun (light) and by the Earth (heat). The sun is extremely hot (6,000°C at the surface) and emits tremendous amounts of light (400 trillion terawatts at the sun's surface, about 1,360 watts per square meter arriving at the Earth). The radiation is produced over a range of wavelengths between about 0.1 and 3.0 micrometers, with a peak wavelength of about 0.5 micrometers (figure 2-2).

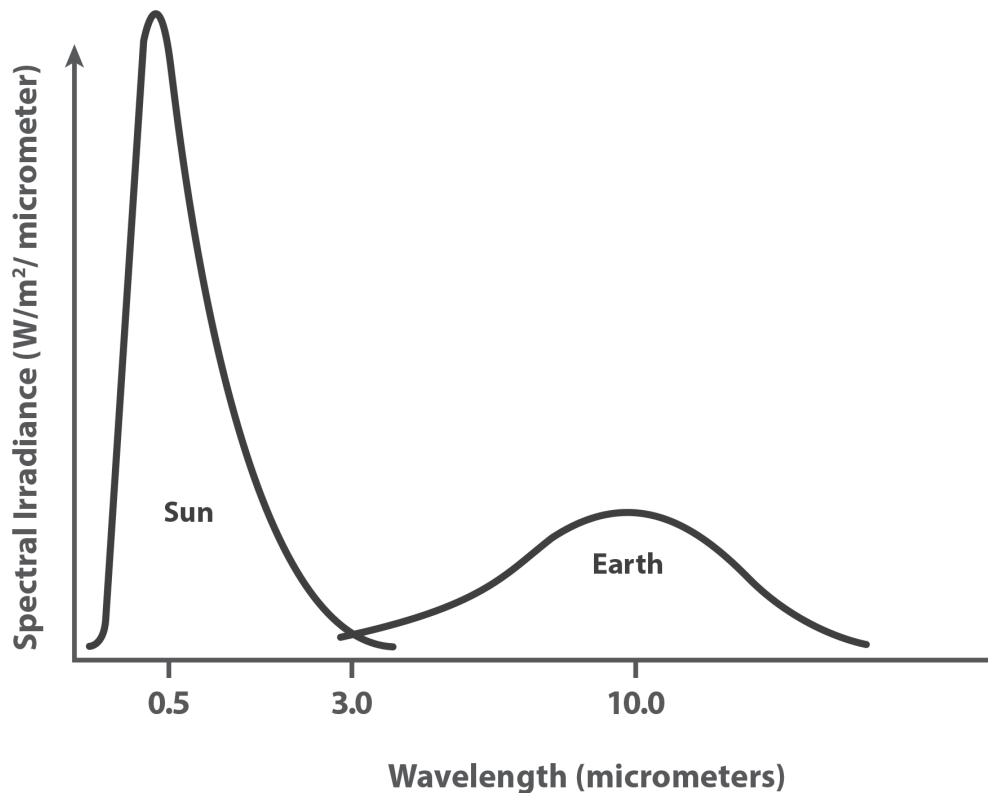


Figure 2-2. The spectral range of electromagnetic radiation emitted by the sun as it arrives at the top of Earth's atmosphere and the spectral range of radiation emitted by the Earth itself.

The Earth, by contrast, is cool (average surface temperature of about 15°C) and emits smaller amounts (an average of about 235 watts per square meter) of heat radiation over a broader range