CHAPTER ONE

INTRODUCTION

As a natural resources manager, would you be interested in using aerial photography to reduce costs by up to 35 percent for the mapping, inventorying, and planning involved in the management of forest and rangelands? This was the cost savings estimated by the staff of the Department of Natural Resources, State of Washington (Edwards 1975).

Because of advanced technology and increased availability, this estimate may be low for all natural resources disciplines, as well as for land-use planning (state, urban, and suburban), national defense, law enforcement, transportation route surveys, hydroelectric dams, transmission lines, flood plain control, and the like. With savings of this magnitude, it becomes increasingly important for all agencies, whether county, state, federal, or private, to make maximum use of aerial photography and related imagery.

The study of aerial photography—whether it be photogrammetry or photo interpretation—is a subset of a much larger discipline called remote sensing. *A broad definition of remote sensing would encompass the use of many different kinds of remote sensors for the detection of variations in force distributions (compasses and gravity meters), sound distributions (sonar), microwave distributions (radar), light distributions (film and digital cameras) and lidar (laser light). Our eyes and noses are also considered to be remote sensors. These detectors have one thing in common: They all acquire data without making physical contact with the source. A narrower definition of remote sensing, as used in this book, is the identification and study of objects from a remote distance using reflected or emitted electromagnetic energy over different portions of the electromagnetic spectrum.*

Photogrammetry *is the art or science of obtaining reliable quantitative information (measurements) from aerial photographs (American Society of Photogrammetry 1966). Photo interpretation is the determination of the nature of objects on a photograph and the judgment of their significance.* Photo interpretation *necessitates an elementary knowledge of photogrammetry. For example, the size of an object is frequently an important consideration in its identification. The end result of photo interpretation is* *frequently a thematic map, and mapmaking is the primary purpose of photogrammetry. Likewise, photogrammetry involves techniques and knowledge of photo interpretation. For example, the determination of acres of specific vegetation types requires the interpretation of those types. The emphasis of this book is on image interpretation, but it includes enough information on basic photogrammetry to enable one to become a competent photo interpreter. A good interpreter must also have a solid background in his or her area of interest.*

Because of the introduction of digital technology into remote sensing, the terminology used throughout this book to distinguish between digital and film-based technology is important. This is because: (1) digital sensors (including cameras) produce images, not photographs; and (2) film sensors produce photographs, but it is also correct to call a photograph an image. Therefore, to clarify our terminology, the following scheme will be used:

Terminology

1. *When reference is made to a digital camera, the word* digital *will always be used.*
2. *When reference is made to a film camera,* film *may be used (for emphasis), but in many cases* film *will not be present.*
3. *The term* photograph *will be used only when it is produced by a film camera.*
4. *The term* image *will always be used when reference is made to a digital image, but this term may also be used when reference is made to a photograph.*

OBJECTIVES

After a thorough understanding of this chapter, you will be able to:

1. Write precise definitions to differentiate clearly among the following terms: remote sensing, photogrammetry, and photo interpretation.
2. Fully define the following terms: electromagnetic spectrum, atmospheric window, f-stop, film exposure, depth of field, and fiducial marks.
3. Draw a diagram and write a paragraph to explain fully reflectance, transmittance, absorption, and refraction of light.
4. List the wavelengths (bands) that can be detected by the human eye, film, and terrestrial digital cameras (both visible and photographic infrared bands).
5. Draw complete diagrams of the energy-flow profile (a) from the sun to the sensor located in an aircraft or spacecraft and (b) within the camera.
6. Draw a diagram of a simple frame camera (film or digital), showing the lens shutter, aperture, focal length, and the image captured.
7. Given the first and subsequent photographs taken by a typical, large-format, aerial film camera in the United States, thoroughly explain the meaning of the information printed on the top of most photographs.

8. Given a list of characteristics (or abilities) of various types of cameras discussed in this chapter, state whether each characteristic applies to film cameras only, digital cameras only, or both types of cameras.
9. In a paragraph, briefly discuss the concept of pixel size and the number of pixels associated with digital cameras as related to resolution.

1.1 ELECTROMAGNETIC SPECTRUM AND ENERGY FLOW

All remote-imaging sensors, including the well-known film cameras and the more recently developed digital cameras, require energy to produce an image. The most common source of energy used to produce an aerial image is the sun. The sun's energy travels in the form of wavelengths at the speed of light, or 186,000 miles (299,000 km) per second, and is known as the electromagnetic spectrum (Figure 1.1). The pathway traveled by the electromagnetic spectrum is the energy-flow profile (Figure 1.8).

1.1.1 The Electromagnetic Spectrum

Wavelengths that make up the electromagnetic spectrum can be measured from peak to peak or from trough to trough (Figure 1.2). The preferred unit of measure is the micrometer (mm), which is one-thousandth of a millimeter. The spectrum ranges from cosmic rays (about 10–8 mm), to gamma rays, X-rays, visible light, and microwaves, to radar, television, and standard radio waves (about 108 mm, or 10 km). Different remote sensors are capable of measuring and/or recording different wavelengths. Photographic film is the medium on which this energy is recorded within the film camera and is generally limited to the 0.4 to 0.9 mm

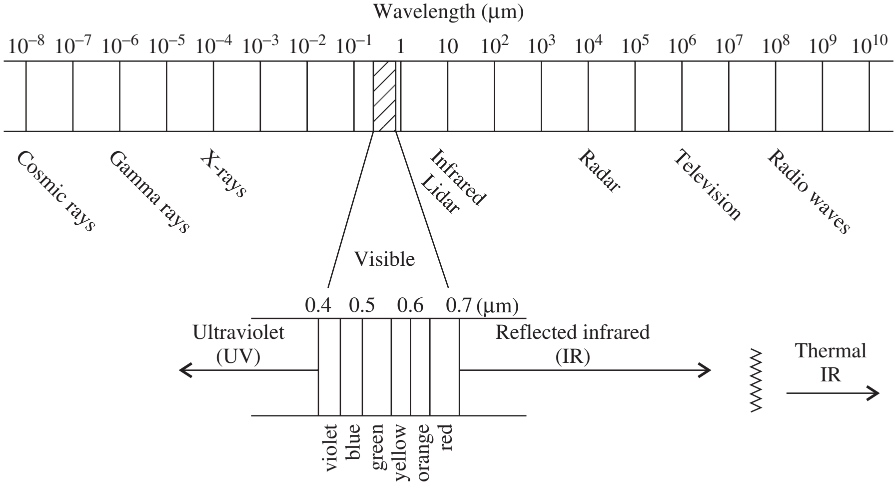

Figure 1.1. The electromagnetic spectrum.

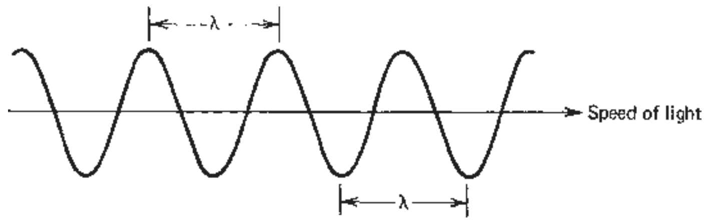

Figure 1.2. Measuring the wavelengths (λ). The preferred unit of measure is the micrometer (μm, or one-thousandth of a millimeter). Wavelengths can also be measured by their frequency—the number of waves per second passing a fixed point.

region, slightly longer compared to human vision, which can detect from 0.4 to 0.7 mm. The recording medium for digital cameras consists of arrays of solid-state detectors that extend the range of the electromagnetic spectrum even farther, into the near infrared region.

1.1.2 Properties of Electromagnetic Energy

Electromagnetic energy can only be detected when it interacts with matter. We see a ray of light only when it interacts with dust or moisture in the air or when it strikes and is reflected from an object. Electromagnetic energy, which we will call rays, is propagated in a straight line within a single medium. However, if a ray travels from one medium to another that has a different density, it is altered. It may be reflected or absorbed by the second medium or refracted and transmitted through it. In many cases, all four types of interactions take place (Figure 1.3).

Reflectance. The ratio of the energy reflected from an object to the energy incident upon the object is *reflectance*. The manner in which energy is reflected

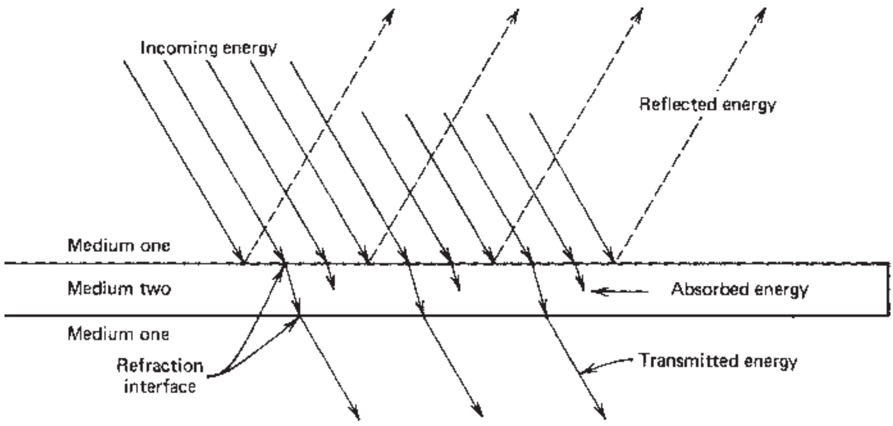

Figure 1.3. The interaction of electromagnetic energy. When it strikes a second medium, it may be reflected, absorbed, or refracted and transmitted through it.

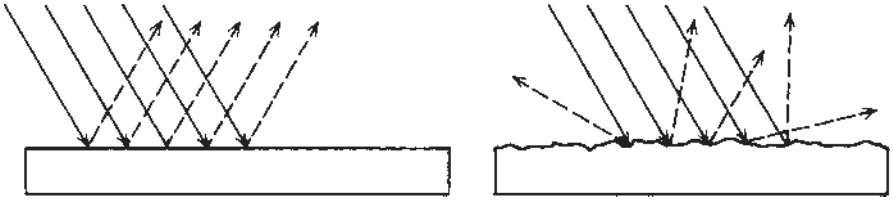

Figure 1.4. Specular reflectance from a smooth surface (*left*) and diffuse reflectance from a rough surface (*right*).

from an object has a great influence on the detection and appearance of the object on film, as well as display and storage mediums for digital sensors. The manner in which electromagnetic energy is reflected is a function of surface roughness.

Specular reflectance takes place when the incident energy strikes a flat, mirrorlike surface, where the incoming and outgoing angles are equal (Figure 1.4, left). *Diffuse* reflectors are rough relative to the wavelengths and reflect in all directions (Figure 1.4, right). If the reflecting surface irregularities are less than one-quarter of the wavelength, we get specular reflectance from a smooth surface; otherwise, we get diffuse reflectance from a rough surface. Actually, the same surface can produce both diffuse and specular reflection, depending on the wavelengths involved. Most features on the Earth's surface are neither perfectly specular nor perfectly diffuse, but somewhere in between.

Absorptance. When the rays do not bounce off the surface and do not pass through it, absorptance has occurred. The rays are converted to some other form of energy, such as heat.

Within the visible spectrum, differences in absorptance qualities of an object result in the phenomenon that we call color. A red glass filter, for example, absorbs the blue and green wavelengths of white light but allows the red wavelengths to pass through. These absorptance and reflectance properties are important in remote sensing and are the basis for selecting filters to control the wavelengths of energy that reach the film in a camera. Absorbed wavelengths that are converted to heat may later be emitted and can be detected by a thermal (heat) detector.

Transmittance and Refraction. Transmittance is the propagation of energy through a medium. Transmitted wavelengths, however, are refracted when entering and leaving a medium of different density, such as a glass window. Refraction is the bending of transmitted light rays at the interface of a different medium. It is caused by the change in velocity of electromagnetic energy as it passes from one medium to another. Short wavelengths are refracted more than longer ones. This can be demonstrated by passing a beam of white light through a glass prism. The refracted components of white light (the colors of the rainbow) can be observed on a white screen placed behind the prism (Figure 1.5).

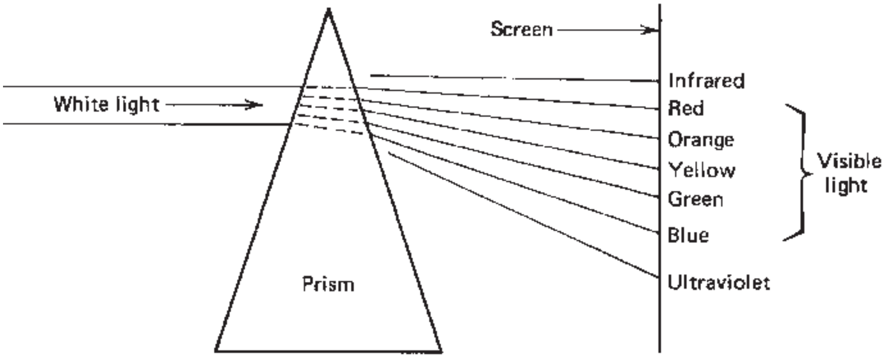

Figure 1.5. Separating white light into its components using a glass prism.

Atmospheric Windows. Fortunately, many of the deadly wavelengths (cosmic rays, gamma rays, and X-rays) are filtered out by the atmosphere and never strike the Earth's surface. *Atmospheric windows* occur in portions of the electromagnetic spectrum where the wavelengths are transmitted through the atmosphere (Figure 1.6). The technology of remote sensing involves a wide range of the electromagnetic spectrum with different sensors (cameras, scanners, radar, lidar, etc.), designed to operate in different regions of the spectrum.

The spectral range of human vision (visible light window) and two of the three image-forming sensors (cameras and scanners) in relation to the atmospheric windows are shown in Figure 1.6. Radar (Section 27.1) operates in the centimeter-to-meter range, where there is practically no atmospheric filtering. Lidar (Section 27.2) operates between approximately 0.5 mm and 1.7 mm.

As mentioned earlier, the human eye can detect wavelengths between about 0.4 and 0.7 mm. Fortunately, this corresponds to an atmospheric window. Without the window, there would be no light. The sensitivity range of photographic film is greater than that of the human eye, ranging from about 0.4 to 0.9 mm. Normal color and panchromatic (black-and-white) film is sensitized to the 0.4 to 0.7 mm range. Recently developed Agfa panchromatic film has extended this range up to 0.75 mm, whereas infrared film (both color and black-and-white) is sensitized to the 0.4 mm to 0.9 mm range. The region between 0.7 and 0.9 mm is called the photographic infrared region. Thus, with the right film and filter combination, the camera can "see" more than the human eye. An interesting example of extended sensitivity range below 0.4 mm is shown in Figure 1.7. Using aerial film with extended sensitivity to include ultraviolet (UV) rays between 0.3 and 0.4 mm and a special camera lens, Lavigne and Oristland (1974) were able to photograph white harp seal pups against their snowy background. The black adult seals are clearly visible on both panchromatic and UV photography while the white pups are visible only on the UV photography. Because of this white-on-white combination, the pups are not visible to the human eye unless one is quite close. Animal fur, whether black or white, absorbs UV wavelengths while snow and

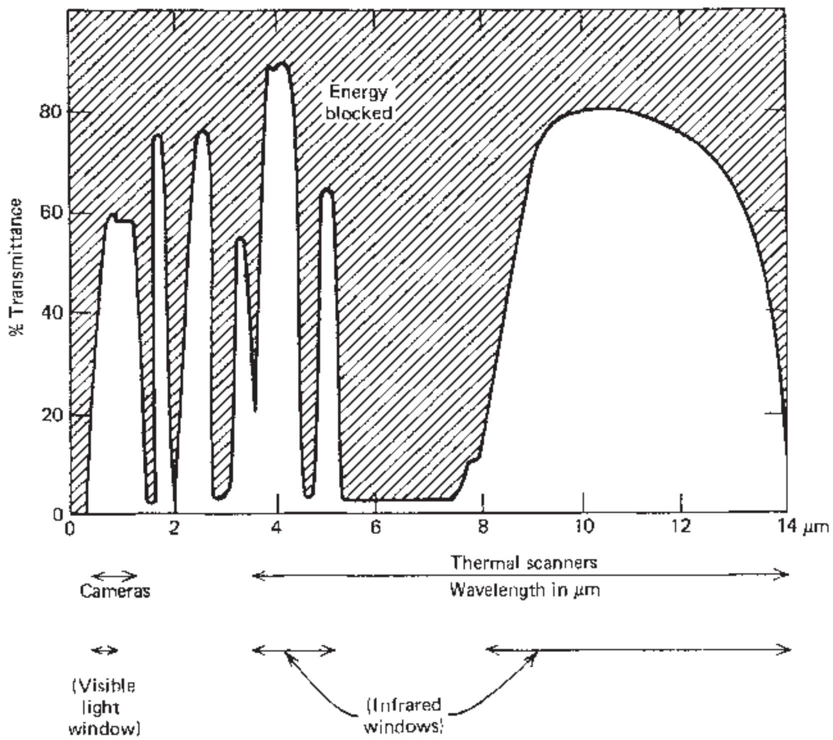

Figure 1.6. Atmospheric windows (not cross-hatched) within the 0 to 14 μm range of the electromagnetic spectrum.

ice reflect UV wavelengths back to the camera. Thus, the images of both the dark adults and white pups become visible on UV photography, as compared to panchromatic photography, which shows only the dark adults.

1.1.3 Energy Flow from Source to Sensor

Contrary to common belief, infrared photography detects *reflected* infrared energy, not heat. *Emitted thermal* infrared energy (heat) is detected by a thermal scanner that uses an entirely different process (Chapter 28). Even though the results of thermal scanning frequently end up on photographic film, the film acts only as a display medium. In the photographic process (see Chapter 14), film acts as both a detector and a display medium.

The energy-flow profile (Figure 1.8) begins at the source (usually the sun), is transmitted through space and the atmosphere, is reflected by objects on the Earth, and is finally detected by a sensor. Not all energy reaches the sensor because of scattering and absorption. Scattering is really reflectance within the atmosphere caused by small particles of dust and moisture.

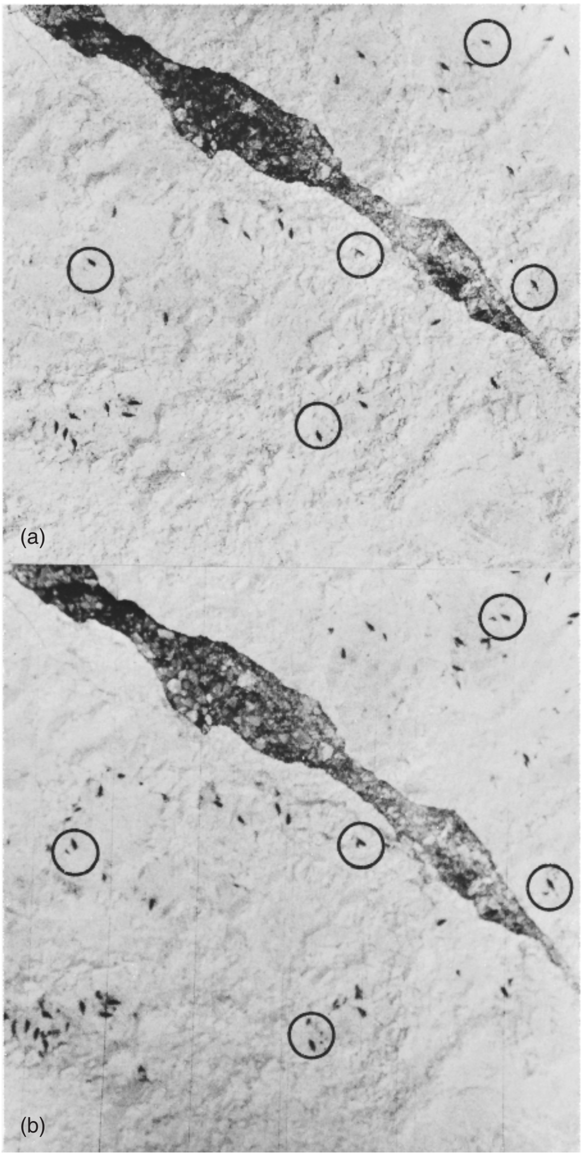

Figure 1.7. Using ultraviolet sensitized film (B) makes it possible to see the white harp seal pups against a white, snowy background. Only black adult harp seals can be seen on standard panchromatic film (A). (Courtesy David M. Lavigne, University of Guelph, Ontario Canada).

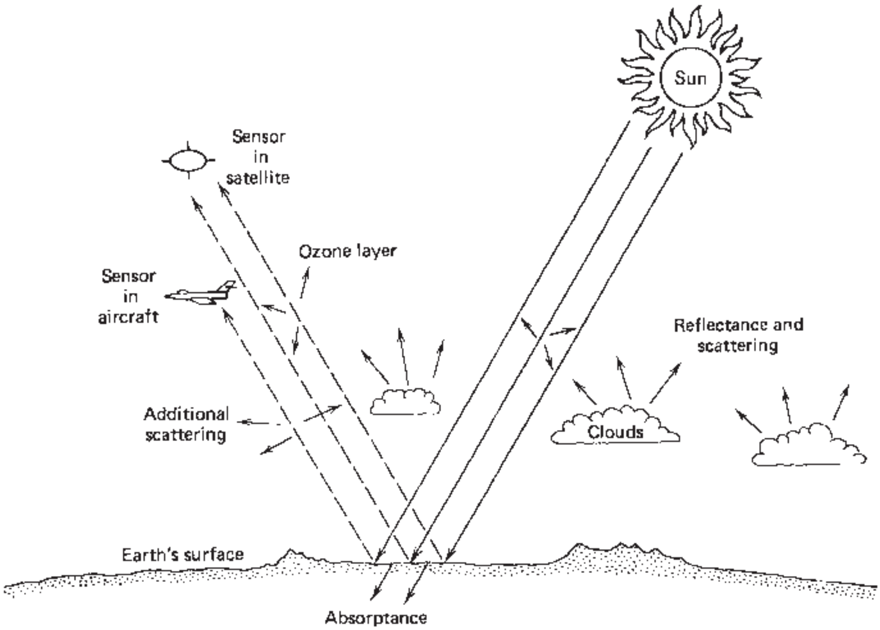

Figure 1.8. The energy-flow profile.

Blue sky is nothing more than scattered blue wavelengths of sunlight. A red sunrise or sunset is the result of additional scattering. During the morning and evening, the solar path through the atmosphere is greatest and the blue and green portions of sunlight are scattered to the point that red is the only portion of the spectrum that reaches the Earth. Small particles within the atmosphere cause more scattering of the blue and green wavelengths than the longer red ones. The ozone layer of the Earth's atmosphere is primarily responsible for filtering out the deadly short wavelengths by absorptance.

Not all energy that reaches the sensor is reflected from terrestrial objects. Some of the rays that are scattered by the atmosphere reenter the energy profile and reach the sensor. Thus, photography from higher altitudes requires the use of filters to filter out the shorter wavelengths. Because the total amount of scattered energy increases with an increase in flying altitude, different filters are used for different flying altitudes. Scattered energy is analogous to static in radio reception and is called background noise (or noise, for short).

1.1.4 Energy Flow within the Camera

The most common source of energy for the camera system is the sun, although electric lights, flashbulbs, flares, or fire can also be used. The following discussion is limited to the sun as the energy source.

Energy that finally reaches the camera detector has navigated several obstacles. It has been reflected, refracted, transmitted, and scattered, and has avoided absorption. The final obstacles before reaching the film are one or more lenses and usually a filter. In addition, many aircraft, especially high-altitude aircraft, are equipped with windows that protect the camera and the photographer from wind pressure and other atmospheric conditions. These windows and camera lenses absorb very little of the visible and photographic infrared portions of the spectrum and are usually of little concern. However, filters do absorb significant portions of the electromagnetic spectrum. Filters (see Chapter 14) are used to control the quantity and quality of energy that reaches the film. The photographer selects the filter or filters based on the altitude, lighting, haze conditions, the type of sensor used, and the final result desired. Finally, a portion of the electromagnetic energy reaches the detector in the camera (film or solid-state detectors) for image capture.

1.2 THE IMAGING PROCESS

Even though images produced by sensors other than the camera are frequently displayed on photographic film, the film camera is the only sensor in which the film is an essential part of the detection system. Photographic film in a camera acts as a detector as well as a display and storage medium, whereas digital cameras, scanners, and radar sensors use photographic film only as a display and storage medium. (See Chapter 14 for more information on photographic film.)

1.2.1 Components of a Simple Film Camera

The film camera (Figure 1.9) can be described as a lightproof chamber or box in which an image of an external object is projected on light-sensitive film through an opening equipped with a lens, a shutter, and a variable aperture. A camera lens is defined as a piece or a combination of pieces of glass or other transparent material shaped to form an image by means of refraction. Aerial camera lenses can be classified according to focal length or angle of coverage (see Chapter 2). The shutter is a mechanism that controls the length of time the film is exposed to light. The aperture is that part of the lens that helps control the amount of light passing through the lens. The design and function of a camera is similar to the human eye. Each has a lens at one end and a light-sensitive area at the other. The lens gathers light rays reflected from objects and focuses them onto a light-sensitive area. Images on the film negative are reversed from top to bottom and from right to left. A second reversal is made when positives are produced, thus restoring the proper image orientation.

Except for the image capture mechanisms, the components of a simple digital camera (Section 1.3.2) are essentially the same as those of the film camera.

1.2.2 Exposing the Film

Film exposure is defined as the quantity of energy (visible light and/or photographic infrared) that is allowed to reach the film and is largely controlled by the

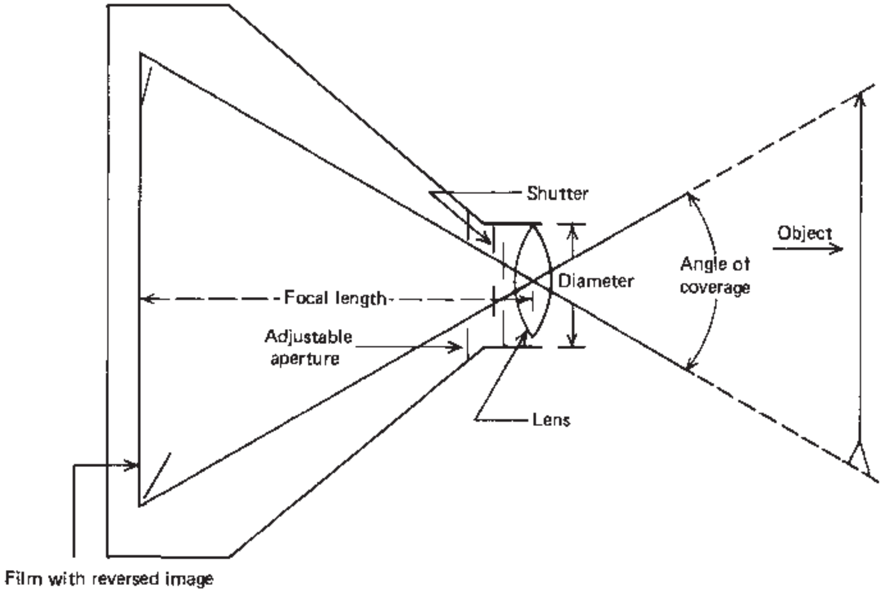

Figure 1.9. Features of a simple film or digital camera.

relative aperture and shutter speed of the camera as well as the energy source. The proper exposure is necessary to produce a good image.

The relative aperture, or lens opening, is called the *f-stop* and is defined as the focal length divided by the effective lens diameter (controlled by the aperture). Some of the more common f-stops, from larger to smaller lens openings, are f/2, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22, and f/32. If the time the shutter remains open is doubled, the lens opening must be decreased by one f-stop to maintain the same exposure. For example, let's assume that a photo is taken with a shutter speed of one-hundredth of a second and a relative aperture of f/11. If the shutter speed is changed to one-fiftieth of a second, the relative aperture must be decreased one f-stop to f/16 in order to maintain the same exposure of the film. The whole idea is to maintain the same total quantity of light energy that reaches the film. Thus, if we want the same exposure and if we increase the size of the opening through which light passes, we must decrease the length of time that light is allowed to pass through the lens to the film.

1.2.3 Depth of Field

As we decrease the size of the lens opening, we increase what is called the *depth of field*, which is the range of distances from the camera in which images are in sharp focus. Depth of field is seldom a consideration with aerial photography because it is only critical for objects relatively close (under 50 feet) to the camera. This same effect can be achieved by squinting our eyes, thus reducing the opening in the lens and sharpening the focus of the object we are viewing.

1.3 TYPES OF CAMERAS

There are two basic types of cameras in use today, film and digital. Most readers are familiar with the popular 35 mm and other small-format film cameras used for everyday terrestrial use. In recent years, small-format digital cameras have joined small-format film cameras and are rapidly becoming popular for amateur and professional use. Both types of cameras are also used in light aircraft for small-format aerial photography (see Chapter 13).

1.3.1 Film Cameras

For many decades, large-format 9 in. × 9 in. (23 cm × 23 cm) or larger cameras have been the backbone of aerial photography for mapping and interpreting purposes. Large-format aerial film cameras are specifically designed for use in aircraft. Some of the more commonly used cameras are the aerial frame camera, panoramic camera, and continuous-strip camera. Most aerial cameras can be classified as frame cameras in which an entire frame or photograph is exposed through a lens that is fixed relative to the focal plane of the camera. Aerial frame cameras (Figure 1.10) are used for reconnaissance, mapping, and interpretation purposes.

The typical aerial film camera has six essential components (Figure 1.11):

1. *Lens assembly:* The focus is fixed at infinity and typically at focal lengths of 6, 8.25 and 12 inches.

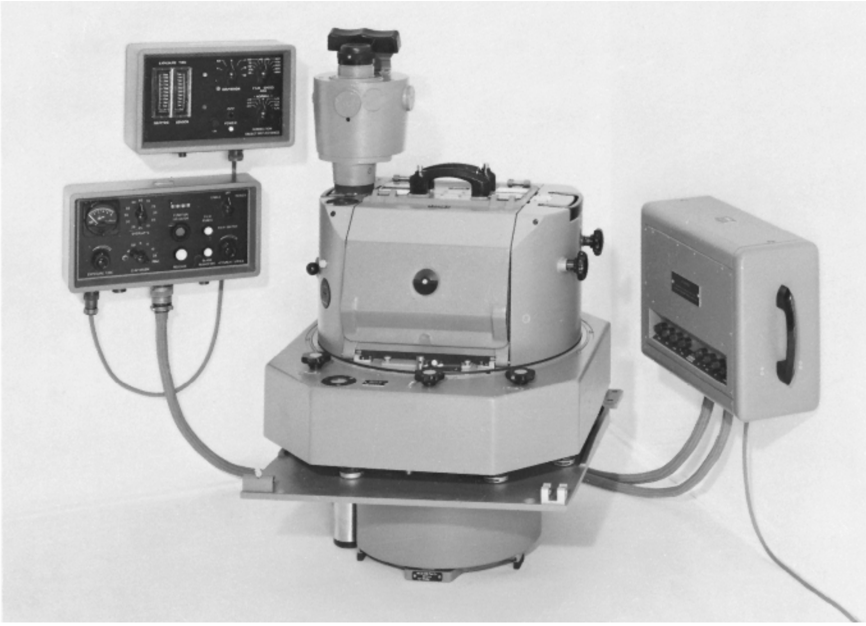

Figure 1.10. A typical large-format aerial (LFA) frame camera (Wild RC 10 Aviophot camera system) primarily used for reconnaissance, mapping, and interpretation. (Courtesy of Wild Heerbrugg Instruments, Inc.).

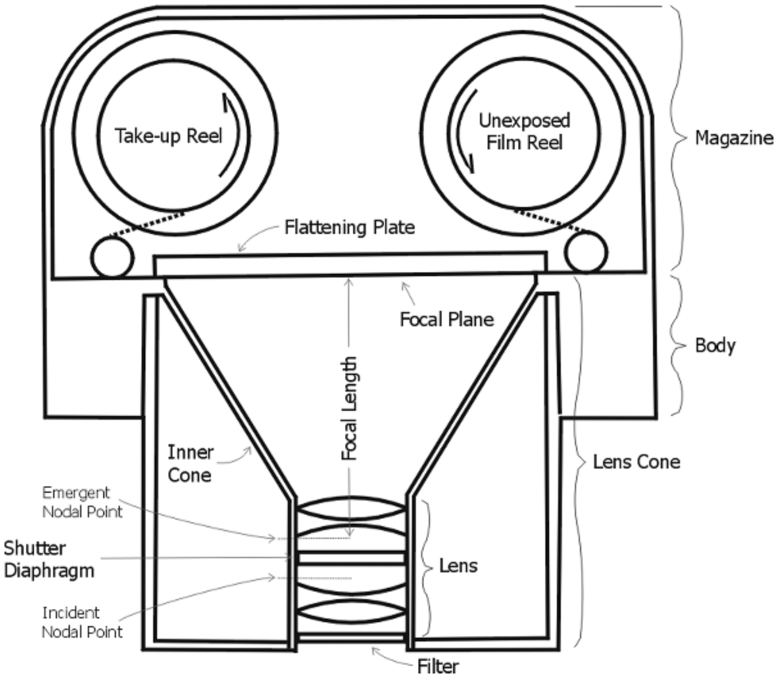

Figure 1.11. A diagram showing the component parts of a typical aerial camera.

2. *Focal plane:* A perpendicular plate aligned with the axis of the lens; it includes a vacuum system to fix the film to the plate.
3. *Lens cone:* A fixed unit holds the lens and filters and prevents extraneous light from entering into the camera body.
4. *Body:* The camera, mounting bolts, and stabilization mechanism are encased in a protective shell.
5. *Drive assembly:* This includes the winding mechanism, shutter trigger, the vacuum pressure system, and motion compensation.
6. *Film magazine:* The magazine secures the roll of unexposed film, advances the film between exposures, holds the film in place, and winds-up the exposed film.

Unlike the frame camera, the panoramic camera takes a partial or complete (horizon-to-horizon) panorama of the terrain. In some panoramic cameras, the film is stationary and the lens scans the film by rotating across the longitudinal axis of the aircraft to produce highly detailed photography (Figure 1.12).

A continuous-strip camera exposes film by rolling the film continuously past a narrow slit opening at a speed proportional to the ground speed of the aircraft (see Figure 1.13). This camera system was developed to eliminate blurred photography caused by movement of the camera at the instant of exposure. It allows for sharp images at large scales obtained by high-speed aircraft flying at low elevations

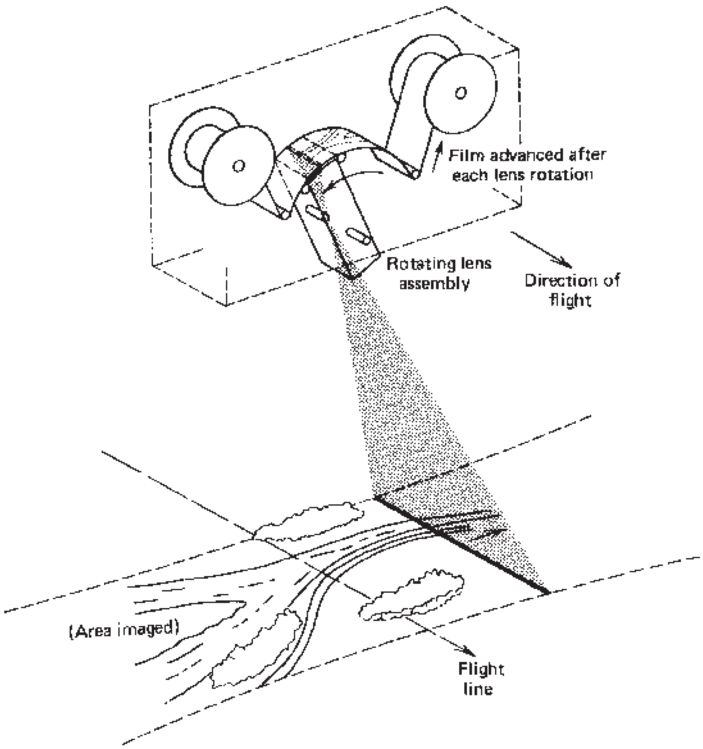

Figure 1.12. Operating principle of a panoramic camera. (Courtesy of T. M. Lillesand and R. W. Kiefer, 2000 *Remote Sensing and Image Interpretation*, copyright 2000, John Wiley & Sons, Inc., reprinted with permission).

and is particularly useful to the military or for research where very large-scale photography is required.

1.3.2 Digital Cameras

The discussion that follows pertains to small-format digital cameras (similar to 35 mm cameras) for terrestrial use, but the same principles apply equally to larger-format cameras (up to 4 in. $\times$ 4 in.) digital aerial imagery. Digital imagery is a direct result of technology developed for imaging from orbiting satellites.

Small-format digital and film cameras have a similar outward appearance and frequently using the same body, lens, and shutter system, but they are totally different on the inside. A film camera uses film on which chemical changes take place when exposed to photographic electromagnetic energy; the film is developed into a negative from which positive prints are made.* Thus, the film in a film camera acts as image capture, display, and storage medium. A digital

*Some films are developed directly into positive transparencies from which prints can be made—35 mm slides, for example.

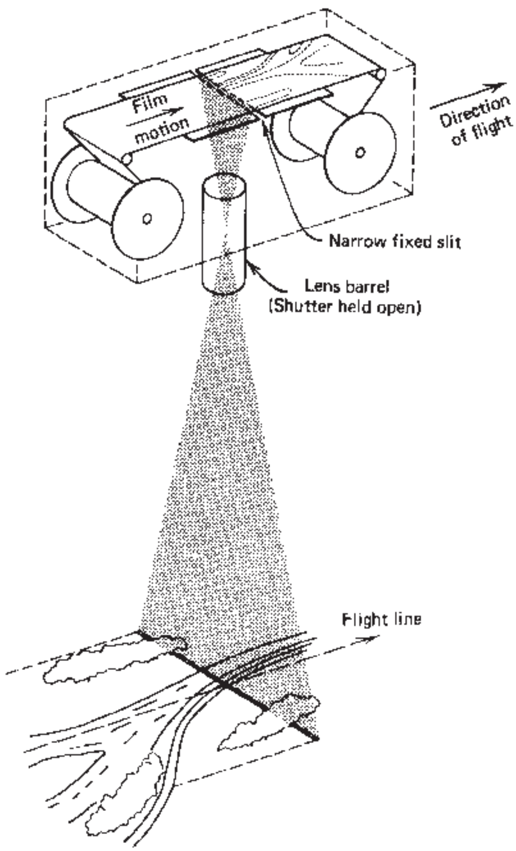

Figure 1.13. Operating principle of a continuous-strip camera. (Courtesy of T. M. Lillesand and R. W. Kiefer, 1979, *Remote Sensing and Image Interpretation*, copyright 1979, John Wiley & Sons, Inc., reprinted with permission.)

image capture, in contrast, is accomplished electronically by solid-state detectors. The detectors in a digital camera are used only for image capture and temporary storage for downloading.

Each digital detector receives an electronic charge when exposed to electromagnetic energy, which is then amplified, converted into digital form, and digitally stored on magnetic disks or a flash memory card. The magnitude of these charges is proportional to the scene brightness (intensity). Currently, there are two types of detectors, charged-coupled devices (CCD) and complementary metal-oxide-semiconductors (CMOS). With the new Faveon chip (see Section 1.4.2) the number of required pixels can be reduced. Most CCD and CMOS detectors are able to differentiate a wider range of the electromagnetic spectrum (e.g., portions of the thermal infrared spectrum) than photographic film or the human eye (see Figure 1.1).

CCD detectors are analog chips that store light energy as electrical charges in the sensors. These charges are then converted to voltage and subsequently into digital information. CMOS chips are active pixel sensors that convert light energy directly to voltage. CCD chips offer better image resolution and flexibility but at the expense of system size, while CMOS chips offer better integration and system size at the expense of image quality. A newer sensor chip called an sCMOS chip (scientific CMOS) has recently been developed that is a hybrid of the advantages of the CCD and CMOS chips.

Digital image data stored in the camera can be transferred to computers or other storage media for soft copy display (digital images displayed on a screen), analysis, and long-term storage. Hard copy display (on film) can then be produced by computer printers. Soft copy data can be electronically transmitted (e-mailed, for example).

Digital frame camera images are captured using a two-dimensional array of detectors composed of many thousands or even millions of individual detectors (see Figure 1.14). Each detector produces one pixel (picture element), analogous to a single silver halide in photographic film. Because silver halides are much smaller than digital detectors, the resolution of a film camera is greater than that of a digital camera. However, this difference in resolution is usually undetectable by the human eye without image enlargement. Modern technology is closing the resolution gap by reducing the size of individual detectors. Currently, CCD detectors can be sensitive to as small as 1.1 μm. Pixels are of uniform size and shape, whereas silver halides have random sizes and shapes. (See Chapter 14 for more about silver halides.)

Because digital image data are computer compatible, images can be manipulated quickly and in a number of ways to detect, analyze, and quantify digital imagery (see color plate VIII [top] and Table 27.2).

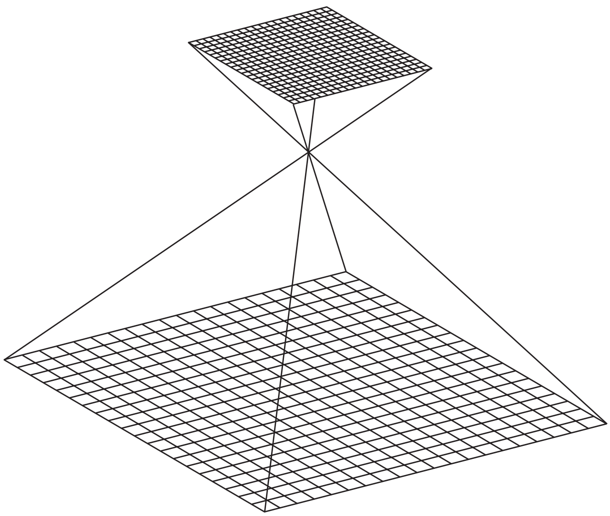

Figure 1.14. Geometry of a digital frame camera—perspective projection.

Digital images can be classified by the number of pixels in a frame. The higher the number of pixels and the smaller their size, the better the resolution. Earlier and cheaper small-format digital cameras had only about 500 rows and 500 columns—or about 250,000 pixels. Newer small-format cameras can have 6 million or more pixels. Slightly larger format aerial frame digital cameras have even more.

1.3.3 Resolution

The resolution of film (Section 14.3.3) and digital cameras is usually handled differently but basically, resolution for both types of cameras is related to the smallest detail (on the ground) that can be distinguished on the imagery and is influenced by several things, especially image scale. The ultimate limitation for photographs for a given scale is the size of the silver halides in the film emulsion and the size of the CCD detectors for digital cameras. A 9 in. × 9 in. format digital camera would require about 400 million pixels to approach the resolution of a typical 9 in. × 9 in. film camera. At present, this capacity does not exist and it probably never will, even though pixel sizes are slowly being reduced (Schnek 1999).

Ground resolution can be optically (in contrast to silver halide or CCD size) improved. Both digital and film cameras can be equipped with telephoto lenses. Thus, with improved optics and the development of smaller solid-state detectors, it is possible that digital cameras may replace film cameras. However, it should be pointed out that as the focal length increases, the amount of light reaching the detector and the angle of coverage are reduced.

1.4 COMPARISON OF FILM AND DIGITAL CAMERAS

Although small-format film and digital cameras have similar outward appearances, their detectors are entirely different. The following list summarizes the ten primary differences:

1. *Image capture:* Film cameras use photosensitive film with silver halides in the film emulsion, whereas digital cameras use photosensitive solid-state CCD or CMOS detectors.
2. *Image storage:* Film cameras use photographic film (negatives, diapositives, or prints), whereas digital cameras use flash memory cards, computer chips, or other solid-state devices. Digital images involve large data files, which create problems when attempting to emulate the massive amount of data held in a conventional aerial photograph. Current technology falls short of being a viable alternative to film for storage purposes. However, it is only a matter of time before a practical solution will be found for storing and processing the vast number of pixels required for digital images (Warner et al. 1996).

3. *Resolution:* At present, film has far better resolution than solid-state detectors. The gap is closing, but the resolution of digital images will probably never equal that of photographs.
4. *Silver halides versus pixels:* Silver halides are of random sizes and shapes, whereas pixels are always uniform (square, rectangular, and sometimes octagonal).
5. *Data transmission:* Photographs must be mailed or faxed, whereas digital data can be sent via phone, computer, or telemetry (from satellites, for example). Note that a photograph may be scanned for transmission, but at that point it becomes a digital image.
6. *Soft copy display:* Diapositives (i.e., 35 mm slides) produced by film cameras can be projected, whereas digital images require computer or television monitors.
7. *Hard copy display:* Film cameras produce film prints, whereas digital hard copy display requires computer printers (standard, inkjet, or laser).
8. *Access time:* Film takes hours (or days) for processing. Digital imagery is almost instantaneous.
9. *Cost:* At present, both digital cameras and soft copy display units cost more than film cameras, but they are rapidly decreasing in price. However, digital cameras eliminate the cost of film purchase and development.
10. *Environmental effects:* Film processing uses an array of chemicals for development. The industry has eliminated most of the highly toxic chemicals, but some are still in use and their disposal remains an issue. Digital processing uses no toxic chemicals.

1.4.1 The Future of Digital Imagery

The future of digital imagery is bright, especially for small-format aerial cameras (Chapter 13) and spaceborne detectors (see Chapters 26, 27, and 28). In fact, sales of digital cameras are increasing for use by the amateur photographer. However, there are problems with aerial-digital imagery that have not been resolved, including the massive amount of digital data required and their permanent storage.

Data Requirements. Because of the massive number of pixels required for good resolution, digital cameras have not yet been developed for aerial use with formats over about 4 in. × 4 in. This format size can require up to 16 million pixels. At this rate, it would require over 80 million pixels for a 9 in. × 9 in. digital image—with resolution inferior to that of a film camera.

Color digital imagery requires even more pixels. If three color bands (red, green, or blue) are used (Section 14.4.2), the image resolution is reduced by a factor of $\sqrt{3} = 1.73$, or increasing the image file size by a factor of 3 over a monochrome (black-and-white) film (Warner et al. 1996).

Permanent Storage. Because temporary data storage space within digital cameras is limited, the data must be frequently downloaded onto computer chips or

CDs. The problem is that long-term magnetic storage begins to deteriorate in as little as two to three years. Compare this to film storage of up to 50 years for color and 100 years for panchromatic (Wilkinson 2002).

One solution is to transfer the digital images onto photographic film for long-term storage. However, the original digital image now becomes a photograph (Wilkinson 2002). A better solution would be for technology to provide a compact, long-term storage system.

1.4.2 A Technological Breakthrough

A major breakthrough in digital image technology occurred in 2002 with a newly developed detector, the Foveon X3, which was said to be the most significant development in digital camera technology since the invention of the CCD array over 30 years ago. The new detector not only improves the resolution of color imagery but also alleviates the problem of file storage size mentioned earlier (Foveon, Inc., 2002). Additional detectors are being designed that are suitable for a wider range of cameras, including digital still cameras, personal digital assistants (PDAs), cell phones, security cameras, and fingerprint recognition systems (Foveon, Inc., 2002).

The new detector increases color resolution so that a 30 in. × 30 in. enlargement can be produced with smaller file size requirements. It also incorporates a variable pixel size (VPS) capability with almost an instantaneous size change. Additional detectors are being designed that are suitable for a wider range of cameras, including digital still cameras, personal digital assistants (PDAs), cell phones, security cameras, and fingerprint recognition systems (Foveon, Inc. 2002).

Improved Resolution. The key to this new technology is the use of a single silicone filter* that allows light to penetrate different depths of layers to photosensitive material embedded within the silicone. The difference between this and CCD detectors is illustrated in Figure 1.15.

Because the three different CCD detectors, each sensitive to a different color, are placed side by side in a checkerboard pattern, complicated algorithms are required to interpolate across unused pixels (for a particular light color). This can result in unpredictable rainbow artifacts that are not present when using the X3 detector. Thus, sharper and truer images are produced when using the newer detector.

Variable Pixel Size. Variable pixel size (VPS) is accomplished by grouping pixels together to produce a full-color "super pixel," creating a new class of still/video cameras. Thus, a single camera can capture a high-resolution still photograph and a full-motion video image that "offers photo quality superior to 35 mm film cameras, and video quality nearly as good as high-end digital image video cameras" (Foveon, Inc. 2002).

*Silicone is a natural filter that filters more light rays the deeper the detector is embedded.

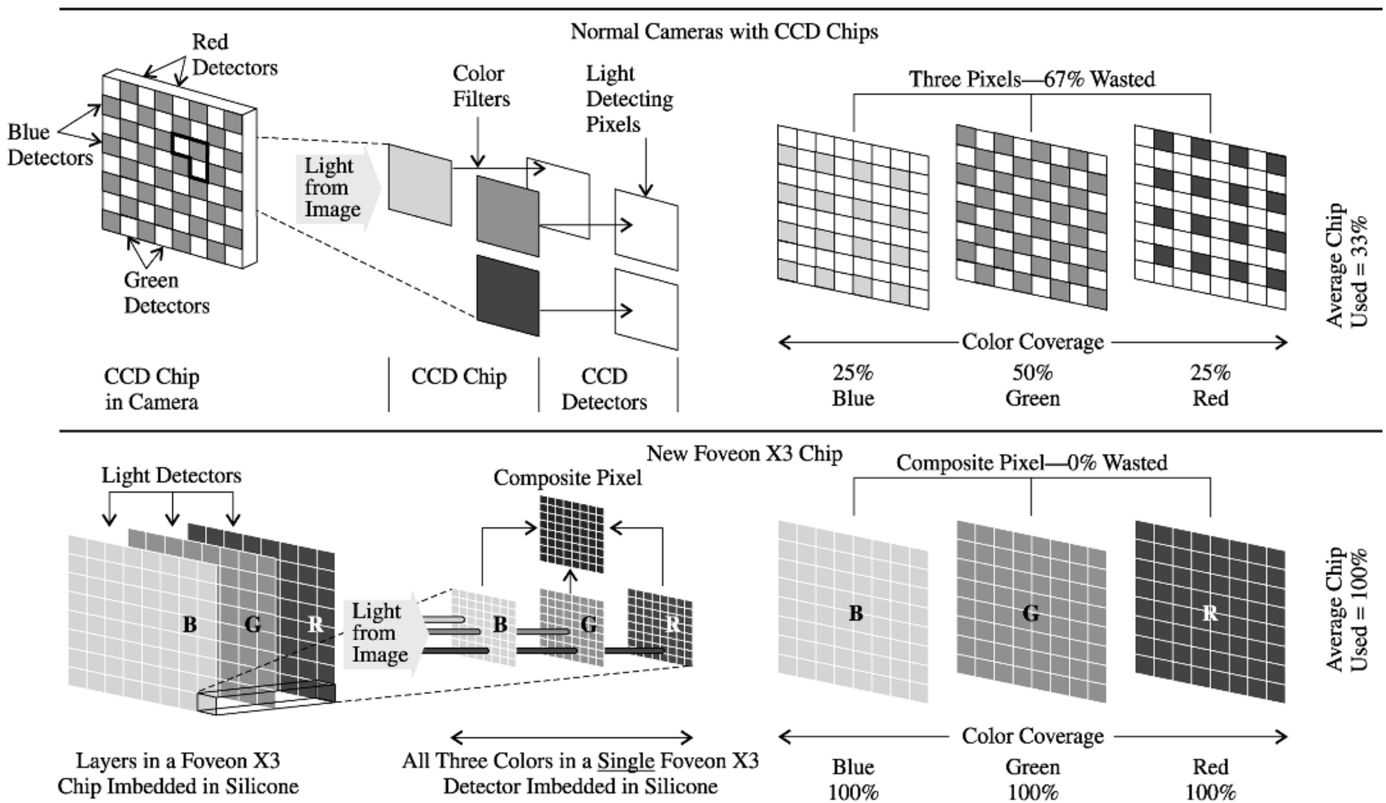

Figure 1.15. A comparison of the light detection capabilities of CCD (*top*) and the Foveon X3 detector (*bottom*). Note the checkerboard pattern when using the CCD detectors. (Adapted from *Newsweek,* March 25, 2002, P. 50.).

Because the VPS feature is instantaneous, one could be a taking a video of a participant in an athletic event, obtain a high-resolution still image merely by pressing the shutter button, and then immediately resume taking the video.

Reduced Storage Space. As discussed earlier, the very large storage space requirements for digital imagery are frequently problematic. The new X3 detector can automatically reduce file storage size up to 66 percent. Because of the VPS capability and the elimination of unwanted artifacts, the detector should reduce the file size even farther.

Additional Advantages. Because larger pixels (like large silver halides in photographic film) require less light, satisfactory digital X3 images can be obtained over a wider range of light intensities than those required for CCD detectors. Due to the relative simplicity, the X3 detector greatly reduces the time delay between exposures, allowing for quicker cycling times as well as faster e-mail transmission of images.

In the long run, the X3 detectors should reduce the cost of digital images because they are less complicated and are not required to eliminate unwanted artifacts. The first cameras (produced by Sigma Corporation) using this technology became available in late 2002. They are designed for professional and advanced amateurs as well as high-end point-and-shoot camera users. They are more expensive than the CCD cameras, but the price should eventually drop. The first camera to be produced will be a single-lens reflex camera with a resolution of 2304 × 1536 pixels that will measure 20.7 mm × 13.8 mm (25 mm diagonal). This is equivalent to a CCD camera of 10.6 million pixels (Foveon, Inc. 2002).

1.5 PRINTED INFORMATION ON LARGE-FORMAT AERIAL PHOTOGRAPHY (LFAP)

During the processing of aerial film in the laboratory, certain important information is printed on each photo. Figure 1.16 shows the first two photographs in a single strip taken over forest and agricultural land. In the United States, the printed information is usually on the north edge for flight lines flown north and south, and on the west edge if the flight lines are oriented east and west. In other countries, or within different geographical areas of the United States, this practice may vary. In British Columbia, Canada, for example, the printed information can be found on the east, west, north, or south edge of the photo regardless of the direction of the flight line. The interpreter needs to know what system was used for the photograph of interest.

On the first photo of each strip, we frequently find the following information (Figure 1.16): date (June 6, 1962), flying height above mean sea level (13,100 feet), lens focal length (12 in.), time of day (13:35, or 1:35 p.m.), project symbol (MF), flight strip number (3), and exposure number (1). On subsequent photos in the same strip, only the date, project symbol, flight strip number, and

Figure 1.16. Information printed at the top of the first two photographs of a flight line.

exposure number are printed. Sometimes, more or less information is provided. For example, many small projects use the film roll number instead of the flight strip number and print the approximate photo scale instead of the flying height above mean sea level. Printing the scale on photos of mountainous terrain can be very misleading to the untrained interpreter because the photo scale changes significantly between and within photos. (This is discussed in detail in Chapters 4 and 5.)

Many cameras are designed to provide similar or additional information in a different manner. Some cameras photograph different instrument dials for each exposure and provide this information on the edge of the photo. These dials can include a circular level bubble to indicate tilt, a clock showing the exact time of exposure (including a second hand), an altimeter reading, and an exposure counter. Unfortunately, this information is frequently cut off and discarded when the photos are trimmed. It is always good practice to request that this information (the header) not be trimmed.

Fiducial marks (Section 2.3) are imaged at the corners and/or midway between the corners of each photo. Examples of side fiducial marks in the form of half arrows can be found in Figure 1.16. Their purpose is to enable the photogrammetrist or photo interpreter to locate the geometric center of the photo.

1.6 UNITS OF MEASURE

When the first edition of this book was published in 1981, the United States was shifting from the English to the metric system of measurement. Highway signs were beginning to include both miles and kilometers to various destinations. This shift, however, has not progressed, and large segments of the population are still not familiar—or at least not comfortable with—the metric system. All-kilometer highway signs have been removed, but the metric system is more visible than it was 20 years ago, and both systems are now used in the United States. For example, modern cars display both systems on their speedometers and odometers. Mechanics find it necessary to use both English and metric tools. Most people are familiar with the 35 mm camera. Both soft and hard drinks are sold in liter containers. Most governmental and private research organizations have shifted to the metric system.

Another problem with units of measure is the use of the chain (a unit of length equal to 66 feet). Even though many are not familiar with the chain (abbreviated ch.), its use is still necessary. For all but the 13 original colonies and a few other exceptions, it is (and probably always will be) the official unit of measure for the U.S. public land survey system (Section 9.3). A square mile is 80 chains on a side. A quarter section (160 acres) is 40 chains on a side, and one acre is 1 ch. × 10 ch. Have you ever heard of an acre being 20.1168 m × 201.168 m?

For these reasons, all units of measure discussed will be used in this second edition. Most chapters will utilize the English system, with metric equivalents frequently in brackets. Other chapters will use only the metric system. Some problems and examples will use one or both systems together, in the same problem. This will provide the reader with needed experience in converting from one measurement system to the other (Appendix G).

QUESTIONS AND PROBLEMS

1. Fully define these terms—remote sensing, photogrammetry, and photo interpretation—in such a manner that clearly illustrates the differences among them.
2. Fully define these terms: electromagnetic spectrum, atmospheric windows, f-stop, exposure, depth of field, fiducial marks, pixels, silver halides, hard and soft copy display, photograph versus an image, focal length, and aperture.
3. Draw a diagram and write a paragraph to explain reflectance, transmittance, absorptance, and refraction.
4. Draw a diagram illustrating a typical energy-flow profile from the sun, or other source of energy, to a sensor located in an aircraft or spacecraft.
5. Draw a diagram of the electromagnetic spectrum showing the human-visible and film-visible portions labeling the wavelengths
6. Draw a diagram of a simple film or digital frame camera showing the lens, shutter, aperture, focal length, and relative position of the image-capturing device.
7. For each of the following characteristics (or abilities) of cameras, place an “F” or a “D” in the blank to indicate if the characteristic pertains to a *film* or *digital* camera. (Some characteristics apply to both types of cameras.)

Silver halide	____	Film storage	____
Sent by fax	____	Computer monitor	____
Lens	____	Best resolution	____
Flash cards	____	Slide projectors	____
Solid-state sensor	____	Electronic storage	____
Produces images	____	Sent over phone lines	____
Pixels	____	Near real-time viewing	____
Chemical detector	____	Lightproof camera box	____
Produces photographs	____	Electronic storage	____
Solid-state sensors	____	Inkjet or laser printers	____
Shutter	____	Widest range of wavelengths sensed	____
Focal length	____		
Sent by mail	____		
Aperture	____		

8. Briefly discuss the concept of pixel size and the number of pixels associated with digital cameras and the size and number of silver halides associated with film cameras as related to resolution.

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