Remote Sensing

Ch. 2 Sensors (Part 2 of 3)

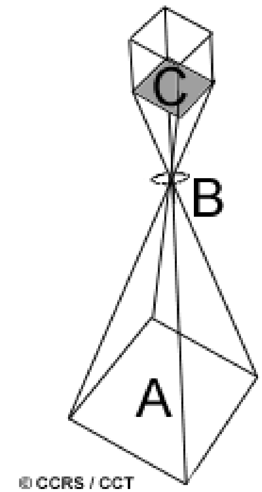
2.7 Cameras and Aerial Photography

Cameras

➔ **the simplest** and **oldest** of sensors used for remote sensing of the Earth's surface.

➔ **framing systems** which acquire a near-instantaneous "snapshot" of an **area (A)**, of the surface.

➔ **passive optical sensors** that use a **lens (B)** to form an image at the focal plane **(C)** where an image is sharply defined.



- **Photographic films** are sensitive to light **0.3 µm ~ 0.9 µm** in wavelength covering the ultraviolet(UV), visible, and near-infrared(NIR).

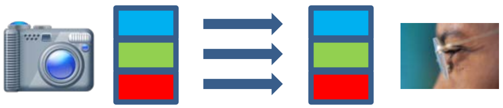
- **Panchromatic films** are sensitive to the UV and the visible portions of the spectrum. ➔ produces **black and white images** and is the **most common type** of film used for aerial photography.

- **UV photography** also uses panchromatic film, but a filter is used to block the visible energy from reaching the film. ➔ is not widely used.
- **Black and white infrared photography** uses film sensitive to 0.3 to 0.9 µm wavelength range and is useful for **detecting differences in vegetation cover**, due to its sensitivity to IR reflectance.

2.7 Cameras and Aerial Photography

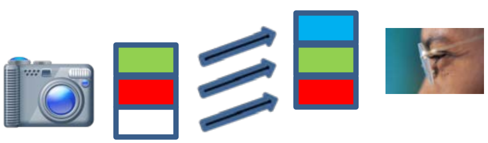
Color & **false color (or color infrared, CIR) photography**

- **Normal color photograph :** sensitive to **blue**, **green**, and **red** light - the **same as our eyes**. These photos appear to us the same way that our eyes see the environment (i.e. trees appear green, etc.).



- **False color (or color infrared, CIR) photograph** : sensitive to **green**, **red**, and the photographic portion of **near-infrared radiation**, which are processed to appear as *blue*, *green*, and *red*, respectively. In a false color photograph,
  targets with high **near-infrared** reflectance appear **red**,
  those with a high **red** reflectance appear **green**, and
  those with a high **green** reflectance appear **blue**,

thus giving us a "false" presentation of the targets relative to the color we normally perceive them to be.



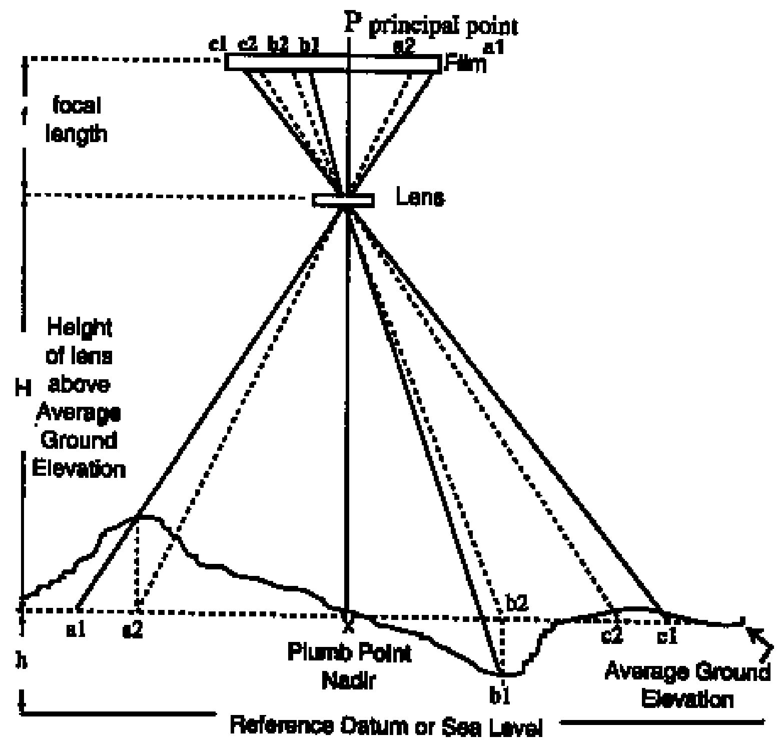
2.7 Cameras and Aerial Photography

- Cameras can be used on **a variety of platforms** including ground-based stages, aircraft, and spacecraft. Very **detailed photographs** taken from aircraft are useful for many applications where identification of detail or small targets is required.

- The ground coverage of a photo depends on several factors, including the **focal length** of the lens, the platform **altitude**, and the format & **size of the film**.

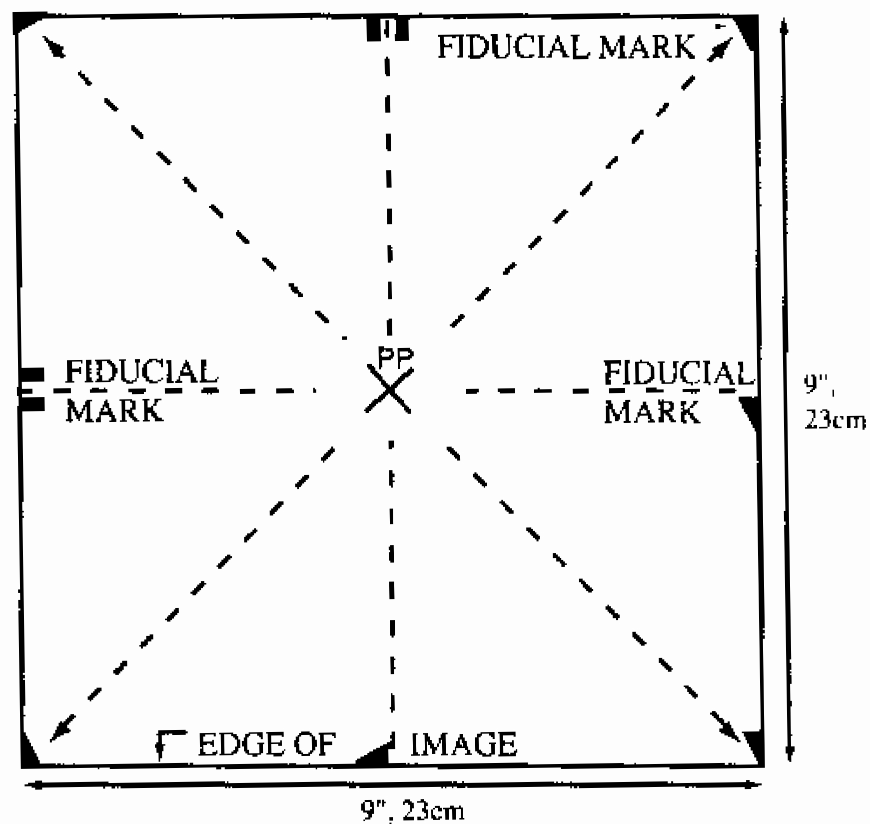
- **Focal length** : The focal length controls the **angular field of view** of the lens (similar to the concept of IFOV) and determines the area "seen" by the camera. Typical focal lengths : 90mm, 210mm, & most commonly, 152mm. **The longer the focal length, the smaller the area covered** on the ground, but with greater detail (i.e. larger scale).

- **Altitude** : At high altitudes, a camera will "see" a larger area on the ground than at lower altitudes, but with reduced detail (i.e. smaller scale). Aerial photos can provide fine detail down to spatial resolutions of less than 50 cm.



2.7 Cameras and Aerial Photography

- In order to identify the location of the **Principal Point** on an airphoto, **Fiducial Marks** are photographed each time an image is recorded. The location of the Principal Point can then be determined by **the intersection of straight lines between opposite fiducial marks.**

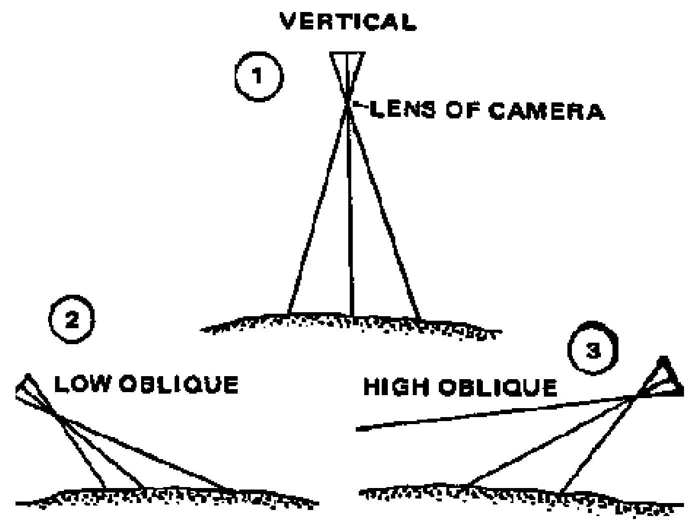


2.7 Cameras and Aerial Photography

Oblique vs **Vertical photograph** : depending on the orientation of the camera relative to the ground during acquisition.

Oblique aerial photographs

- with the camera **pointed to the side** of the aircraft.
- useful for covering very large areas in a single image and for depicting terrain relief and scale.
- distortions in scale from the foreground to the background preclude easy measurements of distance, area, and elevation.



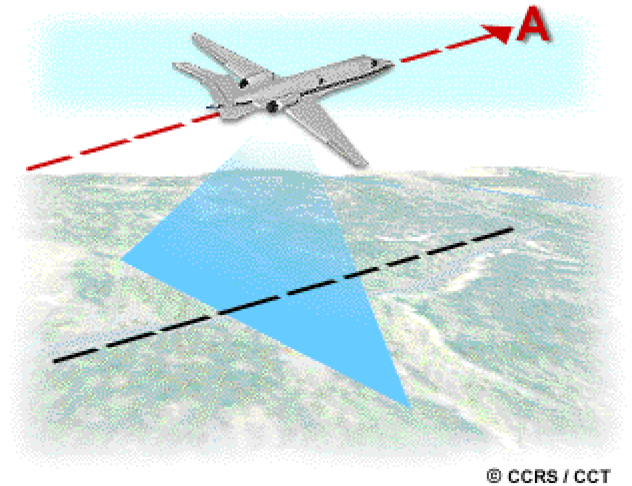
Vertical aerial photographs

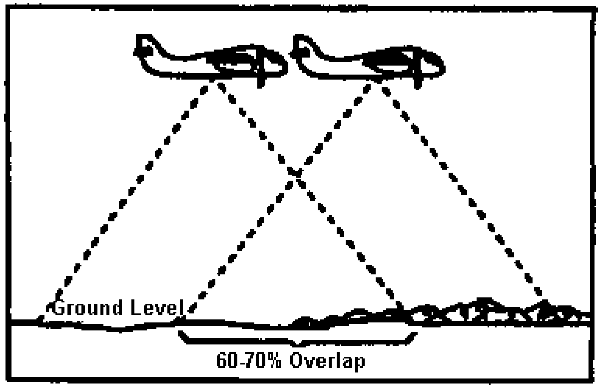
- the **most common** use of aerial photography for RS and mapping purposes.
- These cameras are specifically built for **capturing a rapid sequence of photographs** while limiting geometric distortion. They are often linked with navigation systems onboard the aircraft platform, to allow for accurate geographic coordinates to be instantly assigned to each photograph.

2.7 Cameras and Aerial Photography

- When obtaining vertical aerial photographs, the aircraft normally flies in a series of lines, each called a **flight line**.

- Photos are taken in rapid succession looking straight down at the ground, often with a **50-60 percent overlap** (A) between successive photos. The overlap ensures **total coverage** along a flight line and also facilitates **stereoscopic viewing**. Successive photo pairs display the overlap region from different perspectives and can be viewed through a device called a **stereoscope** to see a three-dimensional view of the area, called a **stereo model**. Many applications of aerial photography use stereoscopic coverage and stereo viewing.



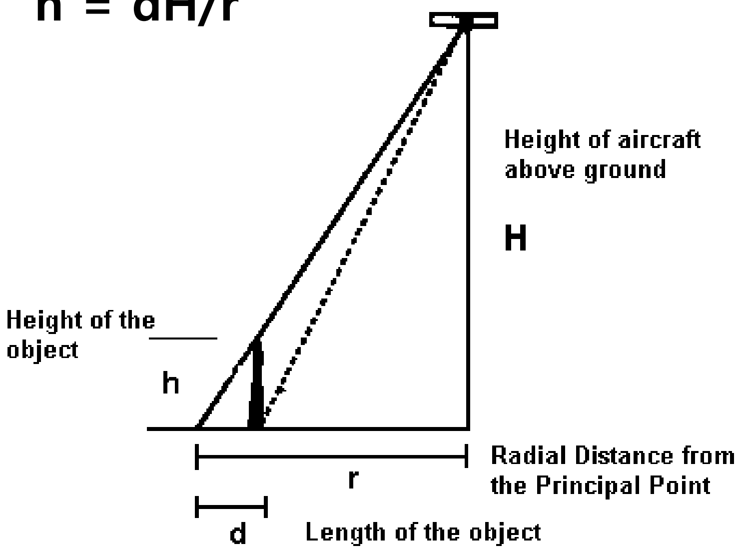


2.7 Cameras and Aerial Photography

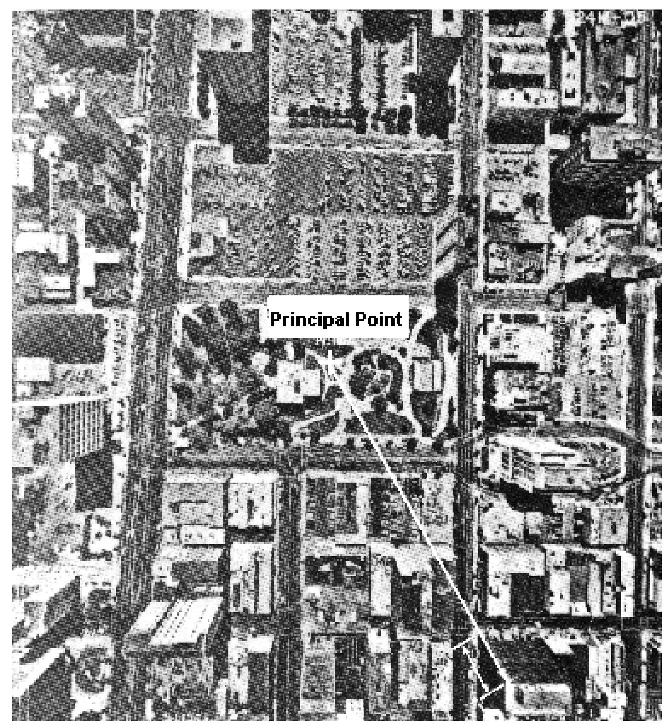
Height Determination from Airphotos : two methods to determine the height of objects - the **Single Photo Method** & the **Stereopair Parallax Method.**

Single Photo Method : The simplest to use, but generally applicable only to vertical features where the top an bottom of the feature can be observed. The method uses the principle that the radial displacement of a feature varies proportionately with the height of the aircraft and is determined by the formula:

$$h = dH/r$$



$$H:h = r:d \qquad H/h = r/d \qquad h = dH/r$$

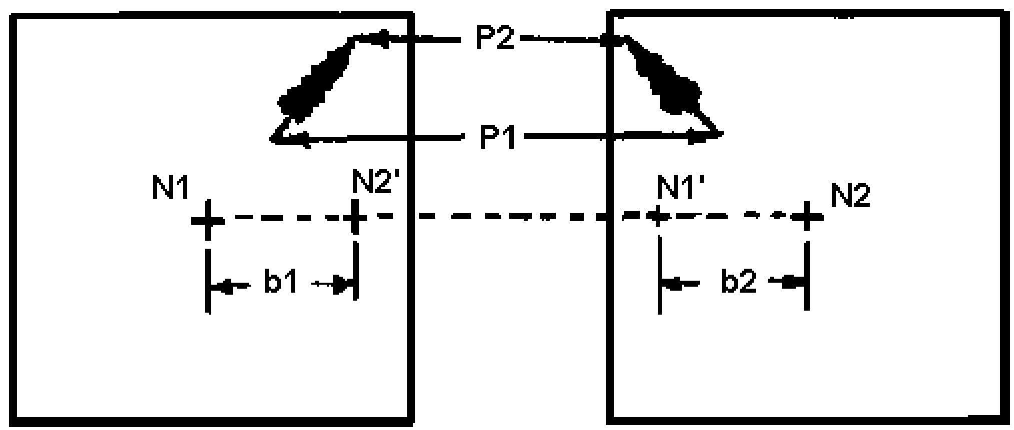


2.7 Cameras and Aerial Photography

Parallax Method of Height Determination

This method requires **two overlapping airphotos** on the same flight line, the **height of the aircraft** above the ground, and the **average photo base length**. The photo base length is the distance from the geometric center (or Principal Point) of one airphoto to the other.

The method uses the principle that the **radial displacement** of a feature varies proportionately with the **height of the aircraft**, but takes into account measurements from **two airphotos** thereby providing greater accuracy in the result.



Differential Parallax: $dP = P1 - P2$

Photo base length: $b = \frac{b1 + b2}{2}$

Object Height: $h = H \frac{dP}{b + dP}$

H = Aircraft Height

2.7 Cameras and Aerial Photography

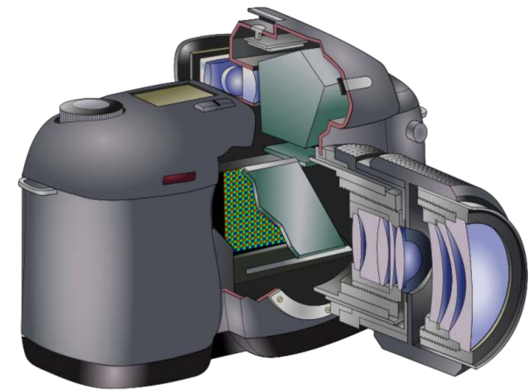
- Aerial photographs are **most useful when fine spatial detail is more critical than spectral information**, as their spectral resolution is generally coarse when compared to data captured with electronic sensing devices.

- **photogrammetry** (The science of making measurements from photographs**) :** The geometry of vertical photographs is well understood and it is possible to make very accurate measurements from them, for a variety of different applications (geology, forestry, mapping, etc.). Photos are most often interpreted manually by a human analyst (often viewed stereoscopically). They can also be scanned to create a digital image and then analyzed in a digital computer environment.

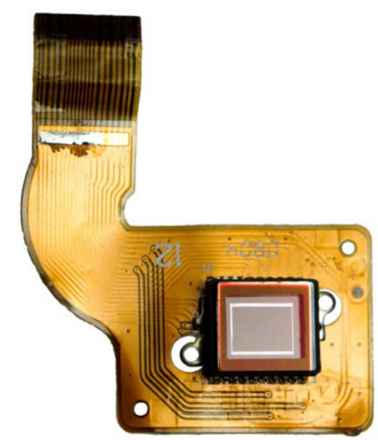
- **Multiband photography** uses multi-lens systems with different film-filter combinations to acquire photos simultaneously in a number of different spectral ranges. **Advantage** : their ability to record reflected energy separately in discrete wavelength ranges, thus providing potentially better separation and identification of various features. However, simultaneous analysis of these multiple photographs can be problematic.

2.7 Cameras and Aerial Photography

Digital cameras



- record EM radiation electronically, differ significantly from their counterparts which use film. Instead of using film, digital cameras use a gridded array of silicon coated CCDs (charge-coupled devices) that individually respond to electromagnetic radiation.
- Energy reaching the surface of **the CCDs** causes the generation of **an electronic charge** which is proportional in magnitude to the "brightness" of the ground area. **A digital number** for each spectral band is assigned to each pixel based on the magnitude of the electronic charge.
- Digital cameras also provide **quicker turn-around** for acquisition and retrieval of data and allow greater control of the spectral resolution.
- Although parameters vary, digital imaging systems are capable of collecting data with **a spatial resolution of 0.3m**, and with **a spectral resolution of 0.012 μm to 0.3 μm**. The size of the pixel arrays varies between systems, but typically ranges between 512 x 512 to 2048 x 2048.

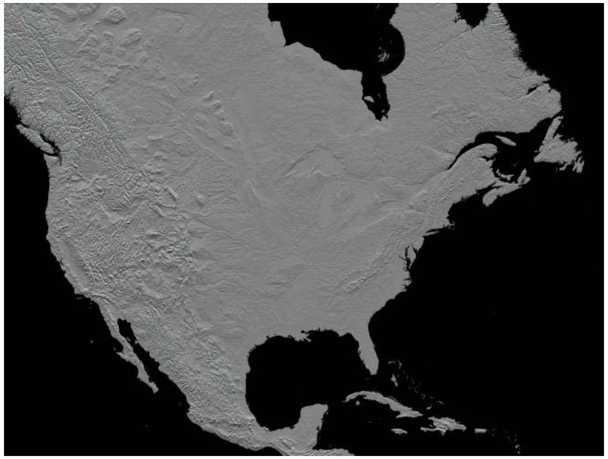


2.7 Cameras and Aerial Photography

Did You Know?

The U.S. Space Shuttles have used cameras mounted in the shuttle's cargo bay, called **Large Format Cameras (LFCs)**. LFCs have **long focal lengths (305 mm)** and take high quality photographs covering several hundreds of Km in both dimensions. Photos from these passive sensors need to be taken when the Earth's surface is being illuminated by the sun and are subject to cloud cover and other attenuation from the atmosphere.

The shuttle has also been used several times to image many regions of the Earth using a special active **microwave sensor** called a **RADAR**. The RADAR sensor can collect detailed imagery during the night or day, as it provides its own energy source, and is able to penetrate and "see" through cloud cover due to the long wavelength of the electromagnetic radiation.



2.7 Cameras and Aerial Photography

Did You Know?

Taking photographs in the UV portion of the spectrum can be very useful where other types of photography are not.

An interesting example in **wildlife research** and management has used UV photography for detecting and counting **harp seals** on snow and ice. Adult harp seals have dark coats while their young have white coats. In normal panchromatic imagery, the dark coats of the adult seals are readily visible against the snow and ice background but the white coats of the young seals are not. However, **the coats of both the adult and infant seals are strong absorbers of UV energy**. Thus, both adult and young appear very dark in a UV image and can be easily detected. This allows simple and reliable monitoring of seal population changes over very large areas.

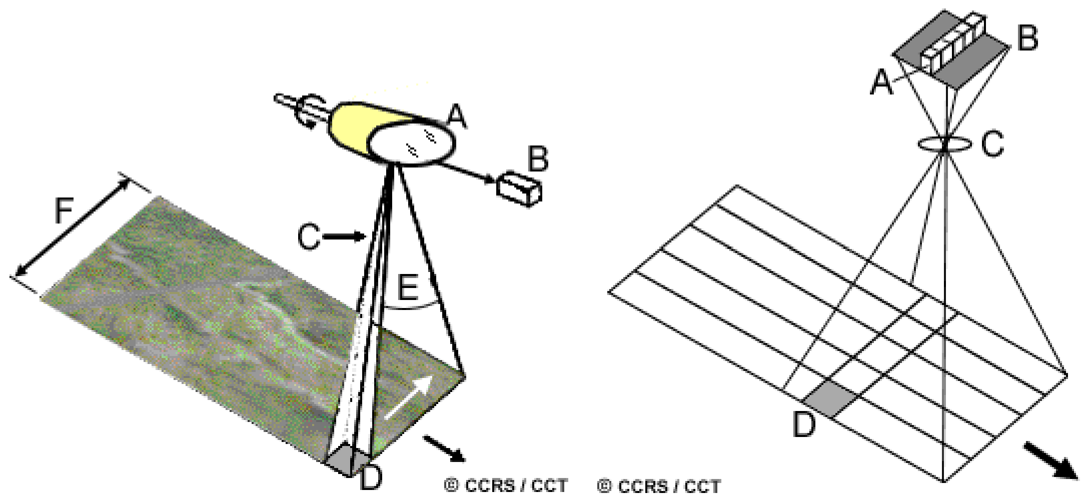
2.8 Multispectral Scanning

- Many electronic remote sensors acquire data using **scanning systems**, which employ a sensor with a narrow IFOV that sweeps over the terrain to build up and produce a two-dimensional image of the surface.

- Scanning systems can be used on both aircraft and satellite platforms.

- A scanning system used to collect data over a variety of different wavelength ranges is called a **multispectral scanner (MSS)**, and is the most commonly used scanning system.

- There are two main modes or methods of scanning employed to acquire multispectral image data - **across-track scanning**, and **along-track scanning**.

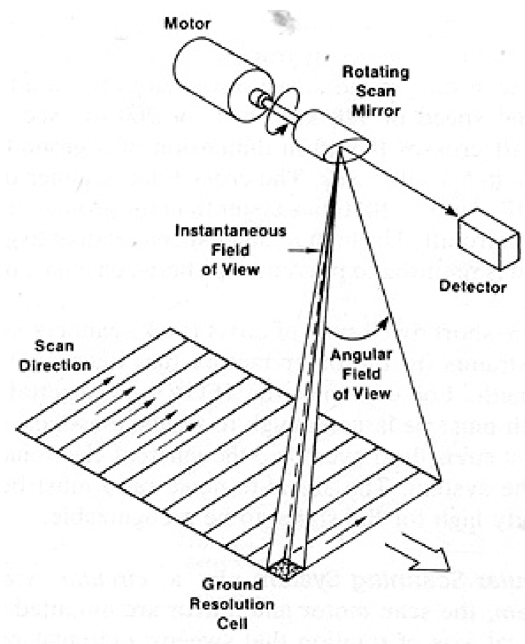


2.8 Multispectral Scanning

Across-track scanners

• scan the Earth in a series of lines. The lines are oriented perpendicular to the direction of motion of the sensor platform (i.e. across the swath). Each line is scanned from one side of the sensor to the other, using a **rotating mirror (A)**. As the platform moves forward over the Earth, successive scans build up a two-dimensional image of the Earth´s surface.

• The incoming reflected or emitted radiation is separated into several spectral components that are detected independently.

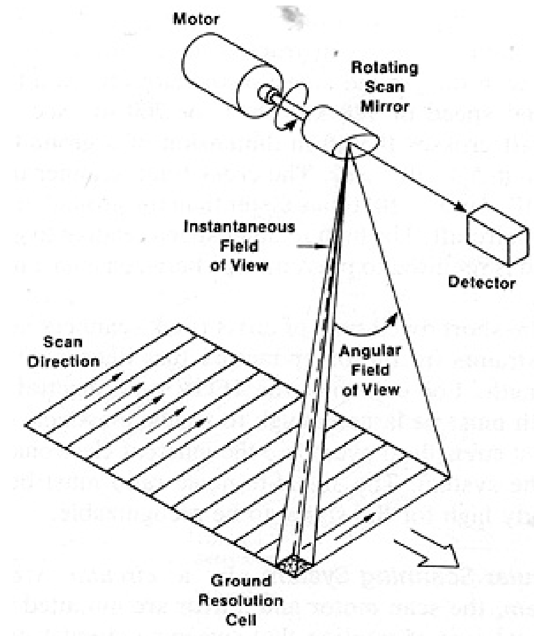


A. CROSS–TRACK SCANNER.

• The UV, visible, near-infrared, and thermal radiation are dispersed into their constituent wavelengths. A bank of internal **detectors (B)**, each sensitive to a specific range of wavelengths, detects and measures the energy for each spectral band and then, as an electrical signal, they are converted to digital data and recorded for subsequent computer processing.

2.8 Multispectral Scanning

- The **IFOV (C)** of the sensor and the altitude of the platform determine the **ground resolution cell viewed (D)**, and thus the spatial resolution.
- The **angular field of view (E)** is the sweep of the mirror, measured in degrees, used to record a scan line, and determines the width of the imaged **swath (F)**.
- **Airborne scanners** typically sweep **large angles** (between 90º and 120º), while **satellites**, because of their higher altitude need only to sweep fairly **small angles** (10-20º) to cover a broad region.



A. CROSS–TRACK SCANNER.

- Because the distance from the sensor to the target increases towards the edges of the swath, the ground resolution cells also become larger and introduce **geometric distortions** to the images.
- Also, the length of time the IFOV "sees" a ground resolution cell as the rotating mirror scans (called the **dwell time**), is generally quite short and influences the design of the spatial, spectral, and radiometric resolution of the sensor.

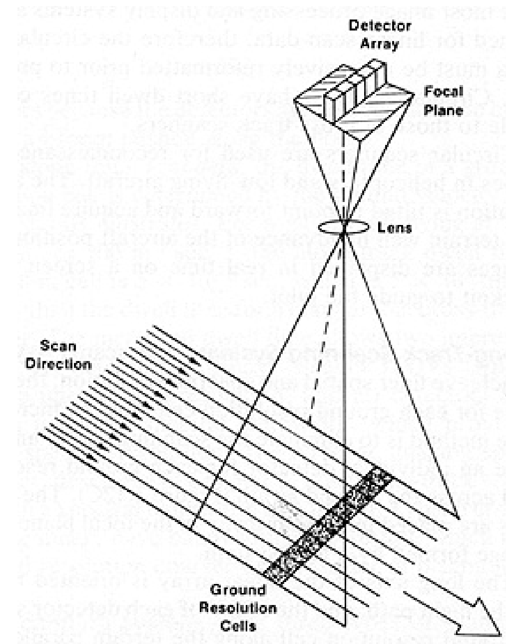
2.8 Multispectral Scanning

Along-track scanners

• use the forward motion of the platform to record successive scan lines and build up a 2-D image, perpendicular to the flight direction.

• However, instead of a scanning mirror, they use **a linear array of detectors (A)** located at the focal plane of the image (B) formed by lens systems (C), which are "pushed" along in the flight track direction (i.e. along track).

• also referred to as **pushbroom scanners**, as the motion of the detector array is analogous to the bristles of a broom being pushed along a floor.



C. ALONG–TRACK SCANNER.

• Each individual detector measures the energy for a single ground resolution cell (D) and thus **the size and IFOV of the detectors** determines the **spatial resolution** of the system.

• **A separate linear array** is required to measure each **spectral band** or channel. For each scan line, the energy detected by each detector of each linear array is sampled electronically and digitally recorded.

2.8 Multispectral Scanning

Advantages of along-track scanners with linear arrays over across-track mirror scanners.

- The array of detectors combined with the pushbroom motion allows each detector to "see" and measure the energy from each ground resolution cell for **a longer period of time (dwell time)**. This allows more energy to be detected and **improves the radiometric resolution**.

- The increased dwell time also facilitates **smaller IFOVs and narrower bandwidths** for each detector. Thus, **finer spatial and spectral resolution** can be achieved without impacting radiometric resolution.

- Because detectors are usually solid-state microelectronic devices, they are generally smaller, lighter, require less power, and are **more reliable** and last longer because they have no moving parts.

- On the other hand, cross-calibrating thousands of detectors to achieve uniform sensitivity across the array is necessary and complicated.

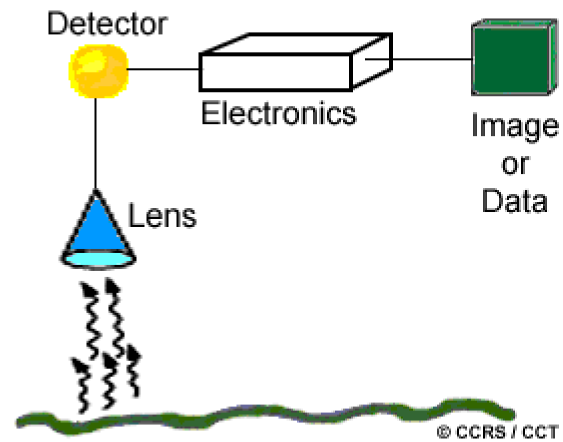
2.8 Multispectral Scanning

Advantages of the scanning system over photographic systems.

- The spectral range of photographic systems is restricted to the visible and near-infrared regions while MSS systems can extend this range into the thermal infrared. They are also capable of **much higher spectral resolution** than photographic systems.
- Multi-band or multispectral photographic systems use separate lens systems to acquire each spectral band. This may cause problems in ensuring that the different bands are comparable both spatially and radiometrically and with registration of the multiple images. MSS systems **acquire all spectral bands simultaneously** through the same optical system to alleviate these problems.
- Photographic systems record the energy detected by means of a photochemical process which is difficult to measure and to make consistent. Because MSS data are recorded electronically, it is **easier to determine the specific amount of energy measured**, and they can record over a greater range of values in a digital format.
- Photographic systems require a continuous supply of film and processing on the ground after the photos have been taken. The digital recording in MSS systems facilitates transmission of data to receiving stations on the ground and immediate processing of data in a computer environment.

2.9 Thermal Imaging

Remote sensing of the **thermal infrared (3 µm to 15 µm)** energy is different than the sensing of reflected energy. **Thermal sensors** use photo detectors sensitive to the direct contact of photons on their surface, to detect emitted thermal radiation. The detectors are cooled to temperatures close to absolute zero in order to limit their own thermal emissions.



Thermal imagers are typically **across-track scanners** that detect emitted radiation in the thermal portion of the spectrum. Thermal sensors employ one or more internal temperature references for comparison with the detected radiation, so they can be related to absolute radiant temperature. The data are generally recorded on film and/or magnetic tape and **the temperature resolution** of current sensors can reach **0.1 °C**.

2.9 Thermal Imaging

- For analysis, an image of relative radiant temperatures (**a thermogram**) is depicted in grey levels, with warmer temperatures shown in light tones, and cooler temperatures in dark tones. Imagery which portrays relative temperature differences in their relative spatial locations are sufficient for most applications.

- Because of the relatively long wavelength of thermal radiation (compared to visible radiation), atmospheric scattering is minimal. However, absorption by atmospheric gases normally restricts thermal sensing to two specific regions - **3 to 5 μm** and **8 to 14 μm**.

- Because energy decreases as the wavelength increases, thermal sensors generally have **large IFOVs** to ensure that enough energy reaches the detector in order to make a reliable measurement. Therefore the **spatial resolution of thermal sensors is usually fairly coarse**, relative to the spatial resolution possible in the visible and reflected infrared.

- Thermal imagery can be acquired during the day or night (because the radiation is emitted not reflected) and is used for a variety of applications such as military reconnaissance, disaster management (forest fire mapping), and heat loss monitoring.

2.9 Thermal Imaging

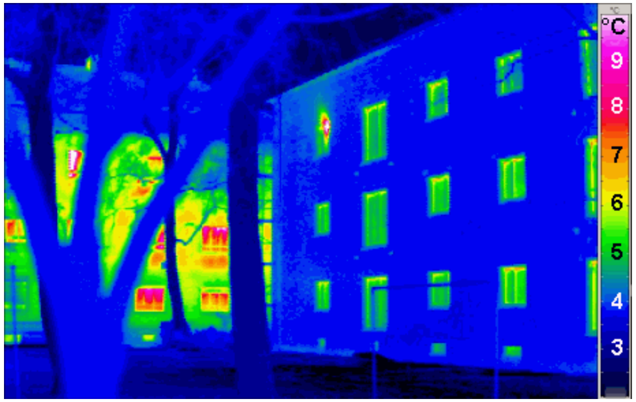
Quiz How would thermal imagery be useful in an urban environment?

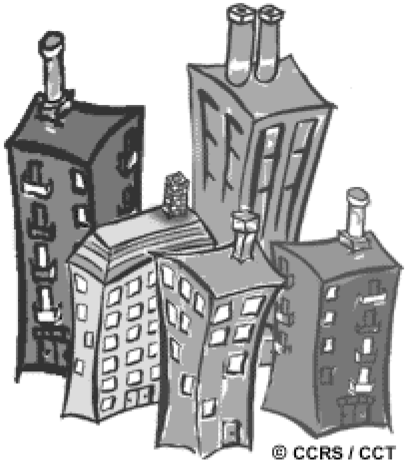
ANS

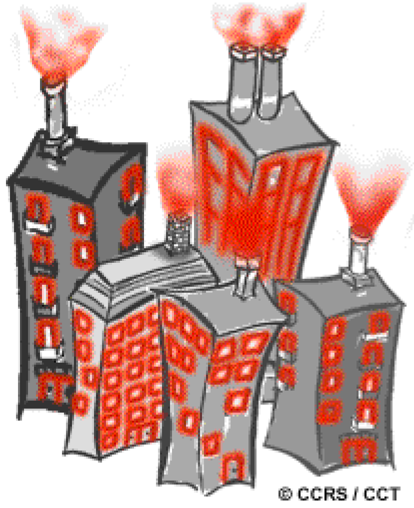
2.9 Thermal Imaging

Quiz How would thermal imagery be useful in an urban environment?

ANS Detecting and monitoring heat loss from buildings in urban areas is an excellent application of thermal remote sensing. Heating costs, particularly in northern countries such as Canada, can be very expensive. Thermal imaging in both residential and commercial areas allows us to identify specific buildings, or parts of buildings, where heat is escaping. If the amount of heat is significant, these areas can be targeted for repair and re-insulation to reduce costs and conserve energy.







2.10 Geometric Distortion in Imagery

- Any remote sensing image will have various **geometric distortions**.

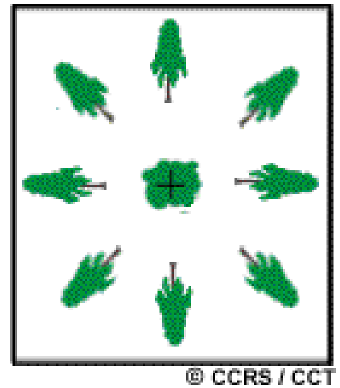
- This **problem is inherent** in remote sensing, as we attempt to accurately represent the 3-D surface of the Earth as a 2-D image.

- Geometric distortions may be due to **a variety of factors**, including one or more of the following, to name only a few:

    - the perspective of the sensor optics,
    - the motion of the scanning system,
    - the motion and (in)stability of the platform,
    - the platform altitude, attitude, and velocity,
    - the terrain relief, and
    - the curvature and rotation of the Earth.

2.10 Geometric Distortion in Imagery

geometric distortion in images from **framing systems**.



- **Relief displacement :** The primary geometric distortion in vertical aerial photographs is due to **relief displacement**. Objects directly below the center of the camera lens (i.e. at the **nadir**) will have only their tops visible, while all other objects will appear to **lean away from the center** of the photo such that their tops and sides are visible. If the objects are tall or are far away from the centre of the photo, the distortion and positional error will be larger.

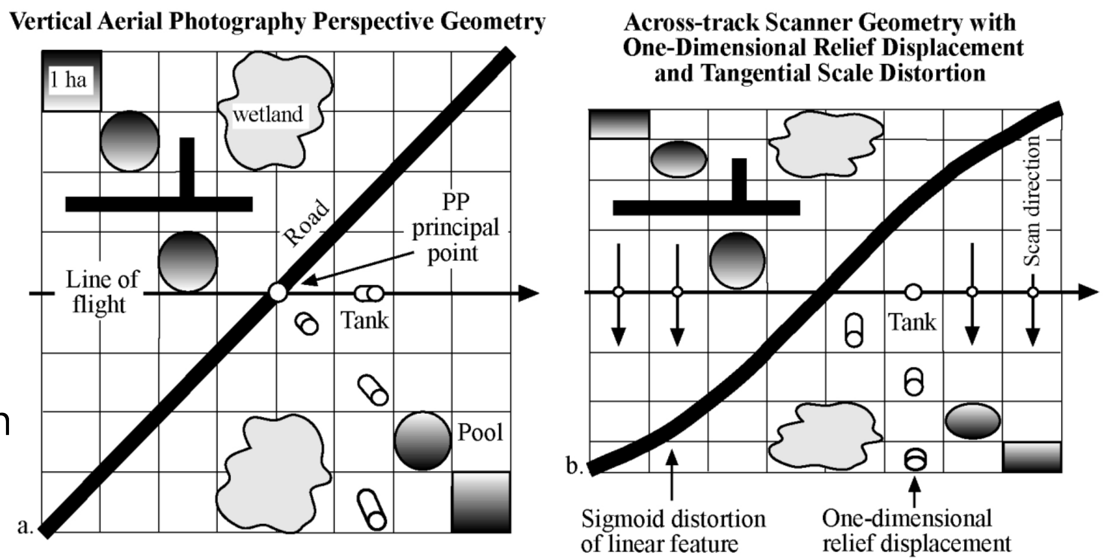
geometric distortion in images from **along-track scanning systems**.

- The geometry of along-track scanner imagery is similar to that of an aerial photograph **for each scan line** as each detector essentially takes a "snapshot" of each ground resolution cell. Geometric variations between lines are caused by random variations in platform altitude and attitude along the direction of flight.

2.10 Geometric Distortion in Imagery

Two main types of **geometric distortion** in images from **across-track scanning systems**.

- **Relief displacement (A)**: similar to aerial photographs, but in only one direction parallel to the direction of scan. There is no displacement directly below the sensor, at nadir. As the sensor scans across the swath, the top and side of objects are imaged and appear to lean away from the nadir point in each scan line. Again, the displacement increases, moving towards the edges of the swath.



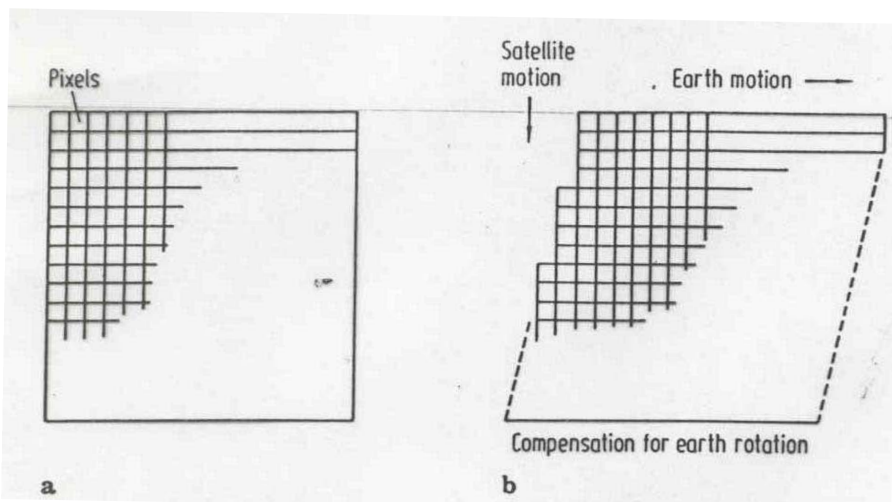
- **Tangential scale distortion (B):** occurs due to the rotation of the scanning optics. As the sensor scans across each line, the distance from the sensor to the ground increases further away from the centre of the swath. Although the scanning mirror rotates at a constant speed, the IFOV of the sensor moves faster (relative to the ground) and scans a larger area as it moves closer to the edges. This effect results in the compression of image features at points away from the nadir.

2.10 Geometric Distortion in Imagery

- All images are susceptible to **geometric distortions** caused by variations in platform stability including changes in their speed, altitude, and attitude during data acquisition. These effects are most pronounced when using aircraft platforms and are alleviated to a large degree with the use of satellite platforms, as their orbits are relatively stable.

- However, the **eastward rotation of the Earth during a satellite orbit** causes the sweep of scanning systems to cover an area slightly to the west of each previous scan. The resultant imagery is thus skewed across the image. This is known as **skew distortion** and is common in imagery obtained from satellite multispectral scanners.

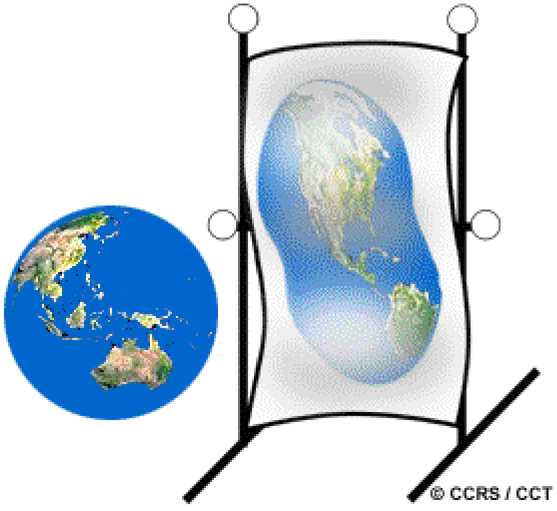
- The sources of geometric distortion and positional error vary with each specific situation, but are inherent in remote sensing imagery. In most instances, we may be able to remove, or at least reduce these errors.



2.10 Geometric Distortion in Imagery

Did you know?

...many **systematic**, or predictable, geometric distortions can be accounted for in real-time (i.e. during image acquisition). As an example, skew distortion in across-track scanner imagery due to the Earth's rotation can be accurately modeled and easily corrected. Other random variations causing distortion cannot be as easily modeled and require **geometric correction** in a digital environment after the data have been collected.



2.10 Geometric Distortion in Imagery

Quiz If you wanted to map a mountainous region, limiting geometric distortions as much as possible, would you choose a satellite-based or aircraft-based scanning system? Explain why in terms of imaging geometry.

ANS

2.10 Geometric Distortion in Imagery

Quiz If you wanted to map a mountainous region, limiting geometric distortions as much as possible, would you choose a satellite-based or aircraft-based scanning system? Explain why in terms of imaging geometry.

ANS Although an aircraft scanning system may provide adequate geometric accuracy in most instances, **a satellite scanner would probably be preferable** in a mountainous region.

1. Because of the large variations in relief, geometric distortions as a result of **relief displacement** would be amplified at aircraft altitudes much more than from satellite altitudes.

2. Also, given the same lighting conditions, **shadowing** would be a greater problem using aircraft imagery because of the shallower viewing angles and would eliminate the possibility for practical mapping in these areas.