Image from NASA:
https://commons.wikimedia.org/wiki/File:Earth_Western_Hemisphere_transparent_background.png#filelinks

Remote Sensing

Aerial Imagery

AmericaView
Empowering Earth Observation Education
AmericaView.org - Est. 2003

The goal of this module is to introduce key concepts associated with the collection of imagery data using digital sensors from an aerial platform. We will also provide a general introduction to photogrammetry.

Module Topics

1. Cameras and optics
2. Exposure considerations
3. Color theories
4. Film emulsions
5. Digital sensors
6. Aerial camera systems
7. Orthophotography
8. Basics of photogrammetry

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These are the topics covered in this module.

Cameras and Optics

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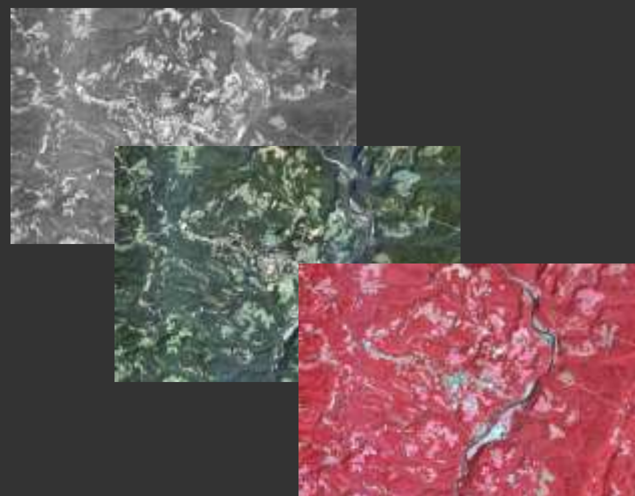
Types of Aerial Photography

- ❖Panchromatic = black-and-white aerial photograph with wide spectral range
- ❖True Color = Red, Green, and Blue (visible spectrum)
- ❖Color Infrared (CIR) = Visible (RGB) + Near Infrared (NIR)



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Panchromatic images are black-and-white, single-band images that do not provide separate channels or bands. A wide range of wavelengths are sensed and recorded as a single gray-scale image. Although this is a bit limiting, panchromatic images are still used. In fact, panchromatic images are commonly collected along with multispectral data. The panchromatic image is generally collected at a higher spatial resolution and can be used to pansharpen multispectral data, which will be discussed in a later module.

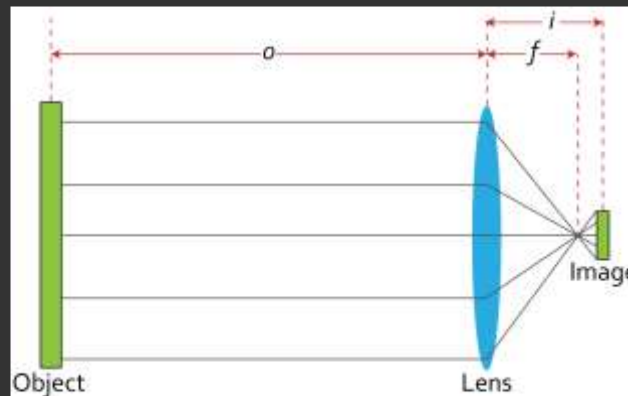
True color images are designed to mimic or simulate human vision. Our eyes contain red, green, and blue cones. Our visual system can then combine the primary colors to create a color view of the world. A true color camera works similarly: the red, green, and blue channels are collected separately and stored in separate bands. They are then combined to produce a color at each pixel. Most of the images we collect on a daily basis, such as pictures taken with a cell phone, are true color images.

Color infrared, or CIR, images collect visible bands and a near infrared band. Near infrared wavelengths are useful for differentiating and mapping vegetation and vegetation health. So, collecting this information can be of value. Older film-based methods were able to collect green, red, and near infrared data. Modern digital sensors can collect four bands of data: blue, green, red, and near infrared.

It is very common for modern aerial surveys to collect 4-band CIR data.

Focusing an Image

- ❖The lens collects light rays that are being reflected at multiple angles and makes them converge on a focal point so that a sharp image is produced
- ❖Focal length = distance from lens surface to focal point (mm)
- ❖Telephoto = longer focal length/more “zoomed in”
- ❖Wide angle = shorter focal length/more “zoomed out”



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Optical camera systems rely on a lens to focus incoming light on an imaging plane to create a sharp, focused image.

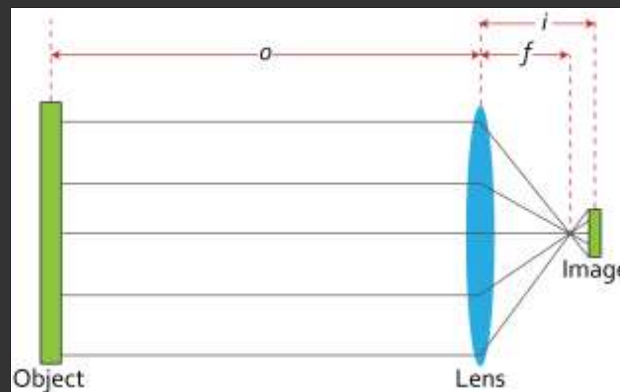
The diagram on this slide describes this process. The object represents the feature being photographed. Light rays that reflect off the object travel through space. Rays that reach the lens are focused to a focal point. The image is produced on an image plane, such as the surface of the digital sensor.

Focal length specifically relates to whether the lens is “zoomed-in” or “zoomed-out”. It is specified as the distance from the lens surface to the focal point in millimeters.

A 250 mm lens would be telephoto or “zoomed-in” whereas a 20 mm lens would be wide angle or “zoomed-out”.

Focusing an Image

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$



- *f* = focal length
- *o* = distance between lens and object
- *i* = distance between lens and image plane
- Depth of Field = range of distances where focus is acceptable

*As *o* approaches infinity, 1/*o* approaches zero, and *i* = *f*

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The equation on this slide represents the relationships between the focal length (*f*), object distance (*o*), and image distance (*i*). As mentioned in the prior slide, the focal length (*f*) is the distance from the lens to the focal point. Object distance (*o*) represents the distance from the object being photographed to the lens whereas the image distance (*i*) represents the distance from the generated image, on the surface of the sensor, to the lens.

As the distance between the lens and the object being photograph increases, *o* approaches infinity, 1/*o* approaches 0, and the focal length becomes equivalent to the image distance. This is a common occurrence when collecting aerial imagery or satellite imagery, since the sensor is very far from the ground surface.

A related concept is the depth of field. This represents the range of distances that are in acceptable focus. This property is used to blur the background relative to the foreground or the foreground relative to the background in photographs and movies.

Aperture

- Determines how much light can pass through
- Focal ratio (*f*-numbers) = ratio of the diameter of the lens aperture to the length of the lens (f/1.4, f/2.0, f/2.8, f/4.0, f/5.6, f/8.0)
- Lower *f*-number = aperture is more open/more light passes through
- Higher *f*-number = aperture is more closed/less light passes through
- Lower *f*-number = shallow depth of field
- Higher *f*-number = greater depth of field

https://commons.wikimedia.org/wiki/File:Lenses_with_different_apertures.jpg

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We will now discuss how to control the exposure of an image so that it is neither too bright (overexposed) nor too dark (underexposed).

Photographers and filmmakers partially control exposure and shadows using artificial lighting in their studios and sound stages. Unfortunately, we don't generally have this option when collecting aerial imagery. However, there are some general rules for when to collect aerial images. For example, to make sure there is adequate lighting and that shadow length is reduced, it is common to collect images between the hours of 10 AM and 2 PM. However, during the winter months, it can be difficult to avoid shadows since the Sun is lower in the sky.

When it is not possible to control the lighting conditions, then exposure can be controlled within the camera by adjusting the aperture, shutter speed, and/or ISO. On this slide, we will explore aperture.

Aperture relates to how much light is allowed to pass to the sensor. This generally works similar to the pupil in your eye. When you are in a dark environment, your pupil will dilate to let in more light. When in a bright environment, you pupil will contract to let in less light. In a camera, the aperture can similarly open and close to change the amount of light passed to the sensor.

Aperture is generally quantified with the focal ratio, or *f*-number, which is a ratio of the diameter of the lens aperture to the length of the lens. Lower values indicate that the aperture is more "open" and more light is allowed to pass through. In contrast, high numbers mean that the aperture is more "closed" to allow less light to pass through.

Aperture also impacts the depth of field. When the *f*-number is lower, or the aperture is more open, the depth of field decreases. In other words, a smaller range of distances will be adequately focused.

Aperture

- Determines how much light can pass through
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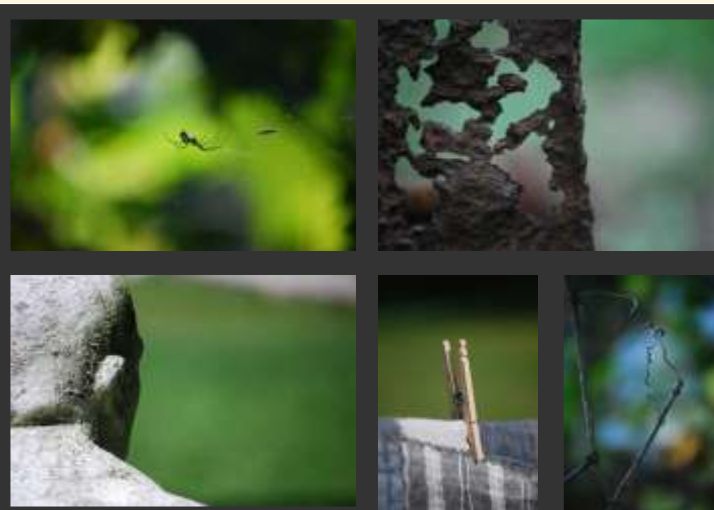

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The images on this slide show some examples of shallow depth of field, which is again impacted by the aperture.

What if you want to collected an image with a shallow depth of field when outside on a bright sunny day? Wouldn't this cause the image to be over exposed? The answer here is yes. However, other exposure settings can be altered to compensate.

Shutter Speed

- Controls how long light is able to collect
- How long shutter remains open
- Measured as fraction of second
- 1/30 = shutter is open for 1/30th of a second
- Leaving shutter open can cause blurring of motion

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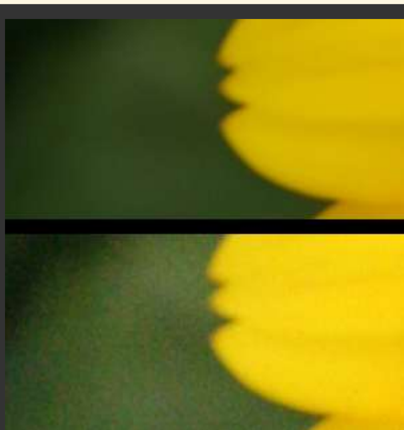
Shutter speed controls how long the sensor is able to collect light. This was traditionally controlled by a gate or shutter that opened and closed to control how long light could expose film. With modern, digital sensors, the shutter speed equates to how long the sensor collects incoming energy.

Shutter speed is commonly reported as seconds or fractions of a second. For example, a shutter speed of 1/30 means that light is collected for 1/30th of a second.

When collecting images at night, opening the aperture might not provide enough exposure. So, the shutter speed can be decreased so that light is collected longer and an adequate exposure is obtained. However, letting the sensor collect light for an extended period of time can cause motion blur as objects move within the frame and/or the camera moves during the time of exposure. This can produce an interesting artistic effect, but can also be undesirable.

Shutter speed is also useful for dealing with bright conditions. If an image is overexposed, even when the aperture is vary narrow, reducing the shutter speed can further reduce the exposure. Opening the aperture while decreasing the shutter speed can allow you to control the depth of field for collecting shallow depth of field images in bright settings.

ISO



https://commons.wikimedia.org/wiki/File:ISO_comparison.jpg

- ❖Level of sensitivity of sensor or film to light
- ❖Low numbers = low sensitivity to light
- ❖High numbers = high sensitivity to light
- ❖High ISO = increased grain/noise

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A third option is to change how sensitive the sensor is to light. When using film, this is controlled by using different film stocks that are more or less sensitive to light. With modern sensors, this is controlled by a digital gain.

The trade-off of increasing the digital gain is that it will also create noise in the image, as demonstrated in the example images. I generally prefer to keep the ISO as low as possible to reduce this noise. However, it is sometimes necessary to increase it if (1) you cannot increase the amount of light, (2) you can't open the aperture any further or are struggling with a depth of field that is too shallow, or (3) you cannot decrease the shutter speed without unwanted motion blur.

Vignetting

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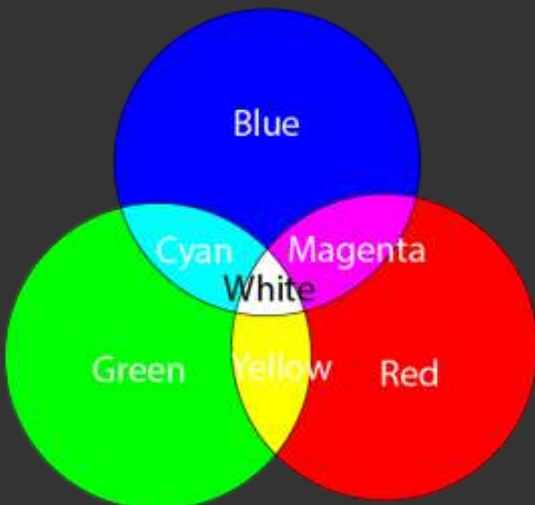
A common issue with film and digital sensors is the issue of vignetting. This occurs as a result of reduction in exposure near the margins of the frame in comparison to the center. Although this can be a desired artistic or stylistic effect, it is often undesired in photographs, and analytical imagery specifically. This can be more or less of an issue depending on the sensor and/or optics.

Fortunately, modern digital cameras are generally able to compensate for this reduced exposure to minimize vignetting. If necessary, the edges of an image can be cropped.

Color Theory

Additive Colors



- Blue + Red = Magenta
- Blue + Green = Cyan
- Green + Red = Yellow
- Blue + Green + Red = White

- This model is useful for explaining human vision and how monitors work

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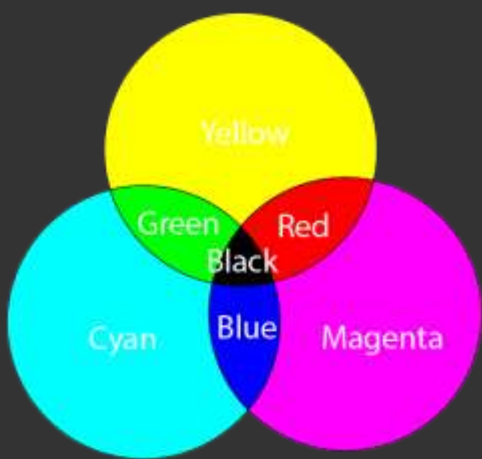
Before moving on to discussing film and sensors, I want to provide a brief introduction to color theory as it applies to remote sensing.

In this class, we will primarily work with additive colors. The additive primaries (red, green, and blue) can be combined in different combinations to produce unique colors. This color space is generally used when dealing with projected light, such as reflected sunlight, computer monitors, TVs, and digital projectors.

Subtractive Colors



- Yellow + Cyan = Green
- Yellow + Magenta = Red
- Cyan + Magenta = Blue
- Yellow + Cyan + Magenta = Black

- Used to explain dyes
- Dyes subtract from white
- Commonly used in printing

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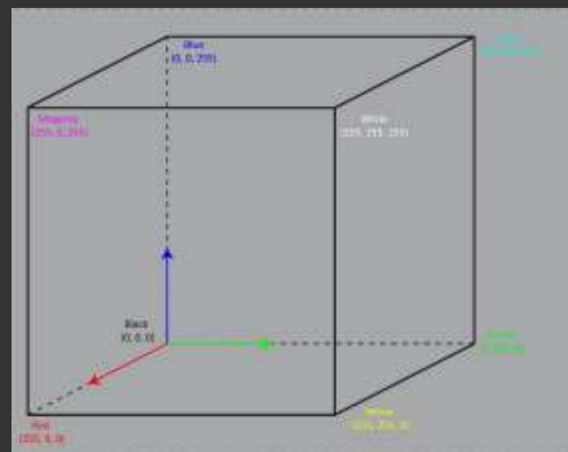
Subtractive color space is commonly used for printing. There is some value in understanding this color space, since it impacts how film is exposed and processed. However, we will not use it much in this class.

The important concept here is that the subtractive primaries (Yellow, Cyan, and Magenta) sum to black and are used when dealing with dyes and printing. The dyes are effectively subtracting from the white paper or canvas.

In contrast, the additive primaries sum to white.

RGB

Example from ArcGIS Pro



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Additive colors are generally defined based on relative proportions of the additive primaries: red, green, and blue.

It is common to define colors using 8-bit color space where 256 gray or brightness levels are available for each primary color. By mixing relative proportions of these 0 to 255 values, a large number of colors can be defined (256 X 256 X 256 = more than 16 million!).

This is also related to radiometric grain. When an image is 8-bit, 256 gray levels can be distinguished in each band. Or, 256 values of blue, green, and red for a true color image. In contrast, a 16-bit image can differentiate more that 65,000 brightness levels in each band. In other words, smaller changes in brightness can be differentiated and subsequently recorded.

Color Composites

❖Simulated True Color Composite

Red = Red

Green = Green

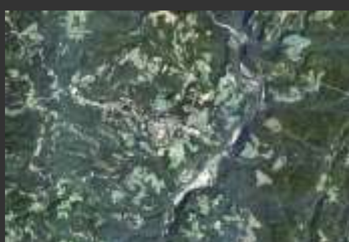
Blue = Blue

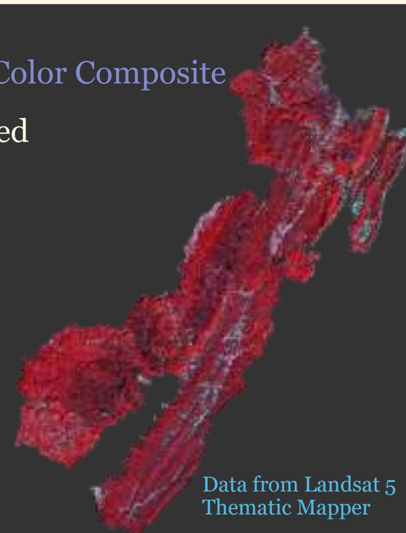
❖Standard False Color Composite

Red = Near Infrared

Green = Red

Blue = Green





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As opposed to a simulated true color composite, a false color composite can be used to symbolize or visualize data or bands outside of the visible spectrum. For example, a standard false color composite uses the red channel to show near infrared, the green channel to show red, and the blue channel to show green.

In the image provide, red areas show up as red because they are reflecting a lot of near infrared radiation. So, using color channels to show different wavelength ranges can help us visualize the information made available in multispectral images.

Human Vision

Rods

- ~ 130 million
- 1000x more sensitive to light than cones
- Same wavelength sensitivity
- Monochromatic

Cones

- ~ 7 million
- Blue, green, and red
- Allows for color vision

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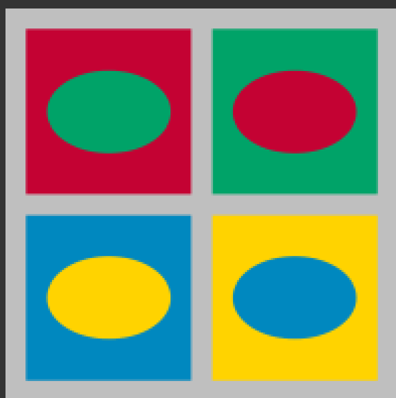
It is worth taking a moment to discuss human vision. Color vision is supported by our cones, of which we have more than 7 million. Some cones are sensitive to blue, while other as sensitive to green or red. Our rods are more abundant and sensitive to light. They allow for low-light, monochromatic, or black-and-white vision. Having both rods and cones allow us to see in a variety of lighting conditions. In low light, colors cannot be differentiated. You can think of rods as your panchromatic camera and cones as your RGB camera.

Human Vision



https://commons.wikimedia.org/wiki/File:Color_opponent_process_theory_contrast_of_complementary_colors.svg

Trichromatic Theory

- A color is perceived by combining the signals obtained from red, green, and blue cones

Opponent Process Theory

- Color vision is produced by processing of opposite pairs
  - white-black
  - red-green
  - Blue-yellow

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There are two theories of human vision that each explain different aspects of color perception.

Trichromatic theory relates to the additive color space. Signals from cones that are sensitive to different wavelengths, red, green, or blue, are combined to yield a perception of color. With digital images, we mimic this process by storing true color images as separate red, green, and blue channels. Digital, true color sensors effectively mimic trichromatic human vision.

However, this theory does not explain all visual phenomenon. For example, if you stare at the images on the left side of the slide for an extended period, when you look away you should see an after image of the opposite color. Trichromatic theory cannot explain this. The Opponent Process Theory offers an alternative explanation. This theory suggests that colors vision is created by processing pairs of opposite colors: white and black, red and green, and blue and yellow. After images are caused by an over stimulation of a certain color and a rebound effect that causes its opponent color to occur as an after image.

Which theory is correct? It turns out that both theories are necessary to explain human vision. So, both theories still play a role. In other words, our understanding of human vision is incomplete.

Importance to Remote Sensing

- Trichromatic theory is most important
- Film or digital sensors generally mimic human vision

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The mixing of colors to generate images is best explained by the trichromatic theory. So, we will rely on this model for the remainder of the class.

Again, this theory suggests that our visual system generates a sensory response associated with a color by the mixing of signals from red, green, and blue cones. We can mimic this with RGB images, in which each primary color is stored as separate bands. Mixing these primaries at different intensities produces a wide range of colors.

Filters

Absorption Filters

- Absorb certain wavelengths, allow others to transmit
- Example: Blue filter absorbs green and red but transmits blue

Bandpass Filters

- Only allow a narrow wavelength range to pass through

Antivignetting Filters

- Reduce vignetting

Polarizing Filters

- Only allows a certain polarization of light to pass through

UV Filters

- Block UV light/reduce haze

Neutral-Density Filters

- Reduces intensity of all wavelengths/reduces brightness uniformly

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Before we move on, I want to mention how filters are used in photography. A variety of different filter types are available, as outlined on this slide.

Absorption filters absorb certain wavelengths and let others pass. For example, an image can be made bluer by filtering out the red and green components. Only the blue wavelengths will pass to the sensor while the red and green radiation are partially absorbed or fully blocked by the filter. This is how tinted sunglasses work. A bandpass filter is even more limiting: it only allows a narrow range of wavelengths to pass through.

Antivignetting filters are used to reduce vignetting. This effectively reduces the transmission of light near the center of the lens to match the reduced exposure caused by vignetting nearer the margins of the frame. Polarizing filters only allow light rays with a certain orientation to pass and are commonly used to reduce glare. Also, polarized light is used in some 3D viewing technologies. In this case, one filter will allow light to pass into one eye with a certain polarization. The other eye will only receive light that is polarized differently. This effectively allows for different images to be sensed by each eye. If the perspectives are different, this mimics stereo viewing and generates a 3D effect.

UV filters block UV radiation. Since these wavelengths are scattered substantially, this can reduce glare and increase contrast. It is common for aviator or driving sunglasses to be amber tinted to block the UV wavelengths along with some of the blue and violet light. Again, the goal here is to reduce glare and increase contrast, since blue light is scattered in the atmosphere. I tend to keep a UV filter on my camera just to protect the lens from being scratched.

Lastly, neutral-density filters reduce the transmission of all wavelengths equally. The goal here is to homogenously reduce the amount of incoming light without altering the tone. This can be used to offer further control of exposure. For example, if you want to obtain a shallow depth of field in a bright environment, neutral density filters can be used to reduced exposure with less decrease in shutter speed to compensate for the large aperture.

Film and Digital Sensors

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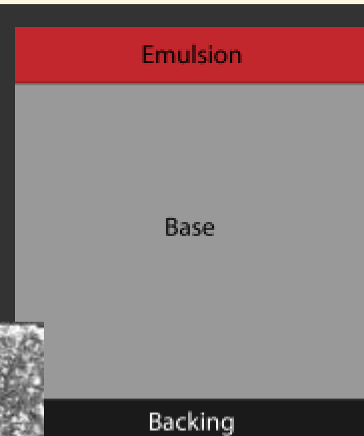
Monochromatic Film

- Negative film
- Positive prints
- Emulsion contains silver halide crystals
- Emulsion is coated on a base
- Silver halide darkens with more light exposure
- After development, silver salts are reduced to silver grains that appear black
- Results in a negative image
- Contact printing results in a positive print



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We will not spend a lot of time discussing film in this course since modern systems make use of digital sensors. However, a broad overview is merited.

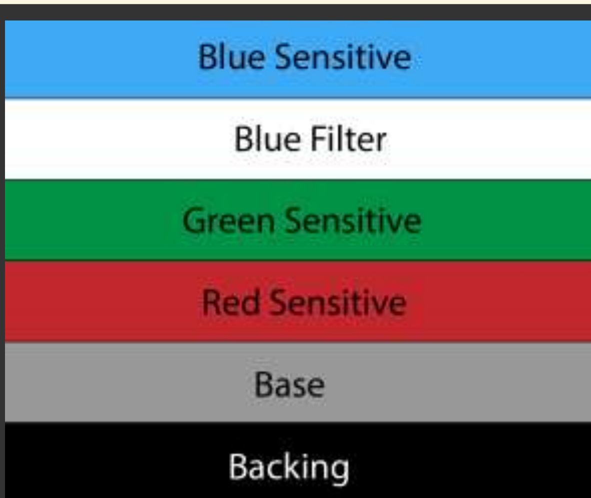
Film uses chemicals and a development process to produce images. Monochromatic film, in which a single layer is sensitive to a wide range of wavelengths, is simplest to understand.

Black-and-white or monochromatic film consists of an emulsion containing silver halide crystals. This emulsion is then coated onto a base and attached to a backing. When exposed to light, silver halide crystals darken. The greater the amount of exposure, the more they darken. This will result in a negative image, where bright areas appear dark and dark areas appear bright.

The film must then be developed to create a positive print. This process involves reducing the silver halide to silver grains, which appear black. This is accomplished through the process of contact printing.

This process generates a singe-band, or monochromatic, image. Such images are also called panchromatic images.

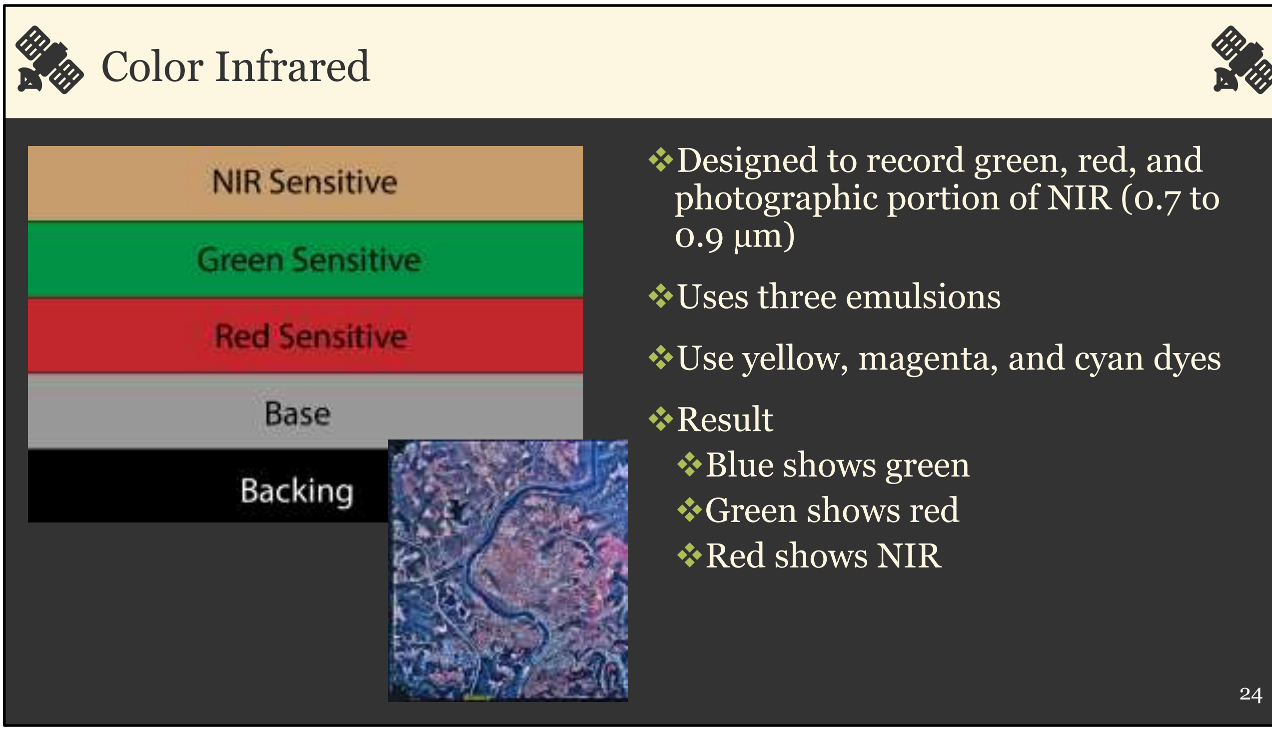
Color Film



- Layers sensitive to different colors
- Generally use a UV/haze filter
- After processing
  - Blue = yellow dye
  - Green = magenta dye
  - Red = cyan dye
- Composited to produce a color image

Color film will include different layers that are sensitive to different wavelength of light. In the example, the first emulsion layer is sensitive to blue light, so only blue wavelengths will expose this layer. Next, a blue filter blocks any blue wavelengths from penetrating to the subsequent emulsion layers. Beneath this filter, green and red sensitive emulsions are exposed by these wavelengths. The emulsion and filter layers are attached to a base and backing.

When the film is developed, blue will yield yellow dye, green magenta, and red cyan. These subtractive pigments are used in the printing process to produce colors.



It is also possible to produce film that is sensitive to NIR, red, and green light. This allows for the generation of a false color composite where blue represents green, green represents red, and red represents NIR.

These early color infrared images were very important for monitoring and mapping vegetation. It was common for foresters to learn to differentiate forest types from such film prints.

Digital Imaging with Frame-Based Systems

- Charged Coupled Device (CCD)
  - Senses light, converts to electrical signal
  - Each square of 4 pixels = 1 red, 1 blue, 2 green
  - Data combined to create RGB image using interpolation
- 3 CCD
  - Separate CCDs for each primary color
  - Light split using a prism
- Complementary Metal Oxide Semiconductors (CMOS)

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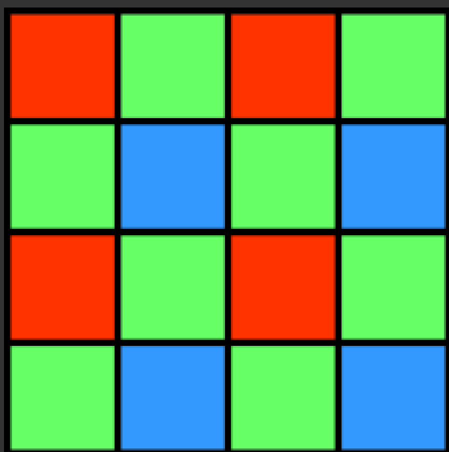
We now rely on digital sensors to collect our spectral measurements. These include analytical devices, such as multispectral sensors, along with consumer-level imaging devices, such as cell phones, web cams, video cameras, and digital cameras.

Different types of digital sensors have been developed. Charged Coupled Devices (CCDs) are very common. In these devices individual detectors, or pixels, are sensitive to red, blue or green light. They are stored in an array to generate a rectangular image. A square of 4 pixels will contain 2 green, 1 red, and 1 blue pixel. Gaps in the color channel data are filled using spatial interpolation and the nearby pixel values. The pixels sense light, which generates an electrical signal that is processed and stored as digital data.

Some sensors incorporate three separate CCDs for each primary color. This requires that incoming light is split by a prism so that the red, green, and blue wavelengths can be sensed separately.

Another type of digital sensor is the CMOS, or Complementary Metal Oxide Semiconductors, sensors. Again, these sensors rely on light energy generating an electrical current that is processed to generate an image.

Bayer Array



- Each pixel collects one color channel
- Green most common
- Interpolation to fill gaps

https://commons.wikimedia.org/wiki/File:GRGB_filter_array.png

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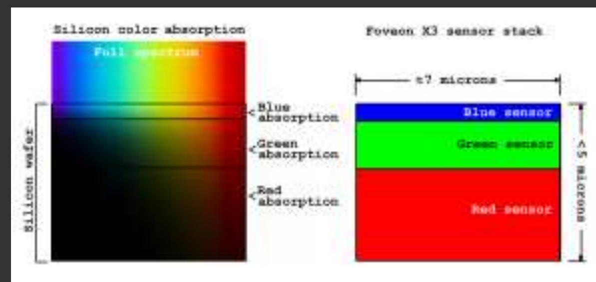
The Bayer array is used in CCD systems. A square of 4 cells consist of 2 green, 1 red, and 1 blue sensitive pixel. Gaps in the color channels are filled using spatial interpolation.

Foveon Chip

- ❖Each pixel has three sensors
- ❖Uppermost sensors transmit light to lower sensors
- ❖No interpolation necessary
- ❖Thus, number of sensors is 3x the array size
- ❖Limited adoption



https://commons.wikimedia.org/wiki/File:Absorption-X3.png

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As an alternative to the Bayer array, a foveon chip allows for each color channel to be sensed at each pixel location. Three sensors are aligned vertically, with the first sensor sensitive to blue, the next sensitive to green, and the last sensitive to red. Between the sensor layers, blue, green, and red filters are placed.

This design results in 3X the number of pixels as a Bayer array since each position in the array contains a stack of three sensors. Also, there is no need for interpolation since no data gaps exist in the color channels.

Despite these positive attributes, foveon chips have not been widely adopted at the time of this writing.

Aerial Camera Systems

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Film-Based

- Single-Lens Frame
  - Collects a single frame for each shutter opening or exposure
- Panoramic
  - Film is exposed along a curved surface located at the focal distance from the rotating lens assembly

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We will now discuss common aerial camera systems.

Film based cameras were commonly either single-lens frame or panoramic. Single-lens frame cameras collect a single frame of film for each shutter opening or exposure. In contrast, panoramic film exposed along a curved surface at the focal distance from a rotating lens assembly.

Again, film is currently rarely used to collected aerial imagery.

Small-Format Digital Cameras

- Similar to 35 mm film camera
- Generally lighter payload
- Digital SLRs (Canon EOS 5D, Nikon D200)

https://www.nikonusa.com/en/nikon-products/product-archive/dslr-cameras/d200.html

https://www.usa.canon.com/internet/portal/us/home/products/details/cameras/eos-dslr-and-mirrorless-cameras/dslr/eos-5d-mark-iv

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Small format digital cameras are basically the same as cameras used by photographers. They are generally smaller and lighter than medium- or large-format digital cameras, so are a smaller payload. They can even be attached to UAVs.

Small-format cameras have replaced traditional 35mm film. They are generally much more affordable than medium- and large-format digital cameras.

Small-Format Digital Cameras

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The images on this slide show a small-format camera being attached to the window of a small airplane.

Small Format Cameras

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This is an image produced using a small-format digital camera mounted to an airplane. This image is of the downtown PRT station and Brooks Hall on the WVU downtown campus.

Large-Format Digital Cameras

- Replacing 230 mm format film cameras
- Integraph Z/I Imaging Digital Mapping Camera (DMC)
- Vexcel UltraCam-X
- DiMAC (Digital Modular Aerial Camera)
- Leica DMC III

https://leica-geosystems.com/products/airborne-systems/imaging-sensors/leica-dmciii

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Large-format digital cameras are generally used by commercial contractors for collecting large volumes of aerial imagery, such as entire counties or states. They have generally replaced 230 mm format film.

These sensors are generally much larger than small-format sensors. So, they cannot be mounted on UAVs. Instead, they are generally mounted on airplanes. Operating these types of cameras generally requires a trained technician. It is possible to collect both true color data, and 4-band color infrared data depending on the sensor specifications. Some devices will collect each channel using a separate lens and sensor system. These channels must then be co-registered.

This slide lists some common large-format digital camera models.

Orthophotography and Photogrammetry

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Types of Aerial Photography

- Vertical Photographs = viewed straight down
- Oblique Photographs = not viewed straight down
- Nadir = spot on ground directly beneath camera

https://commons.wikimedia.org/wiki/File:Elk_Mountain_(Wyoming)_oblique_aerial.jpg

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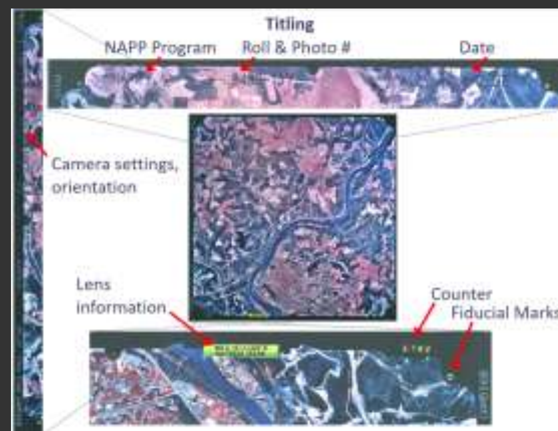
Aerial images that look roughly straight down are commonly used to provide a map view or plan view of the ground surface. These are called vertical photographs. Although vertical photographs are most commonly used in GIS and remote sensing, oblique images that provide a side view perspective can also be collected. Such imagery is valuable for creating 3D models.

The nadir point in an image is the spot on the ground directly below the plane or camera. This is not necessarily the center of the image. In an oblique photograph, the nadir point is not likely to even be in the image.

Here, we will primarily focus on vertical photographs.

Some Terminology

- Altitude Above-Ground-Level (AGL) = height of aircraft above the ground
- Field of View = area being viewed at one time
- Principal Point = the middle of the image
- Nadir = point directly below plane
- Vertical Photograph = camera axis directed as vertically as possible
- Oblique Photograph = intentionally side-looking
- Flight Line = flight path as a strip
- Nadir Line = line traced on the ground directly beneath the aircraft



Example from Dr. Tim Warner

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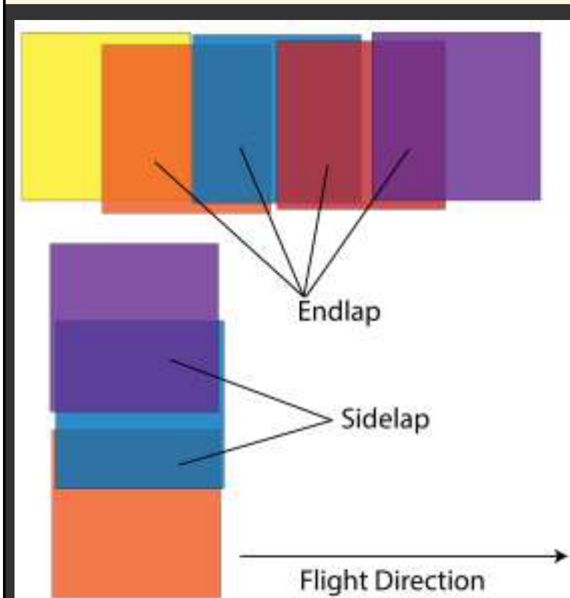
This slide describes some key terminology associated with aerial photography and aerial photographs.

To elaborate on some key points, the principal point of an image is not the same as the nadir point. They can co-occur; however, this would only be the case when the viewing geometry is such that the center of the image is the point directly below the aircraft.

Flight Lines



- An endlap of at least 50% is required for stereoscopic coverage
- To ensure this, 55% to 60% is commonly used
- Airbase = distance between successive photograph centers
- Vertical Exaggeration = exaggeration of vertical component relative to horizontal
- Ratio between the airbase and flight height determines the vertical exaggeration
- Larger base-height ratio = greater vertical exaggeration

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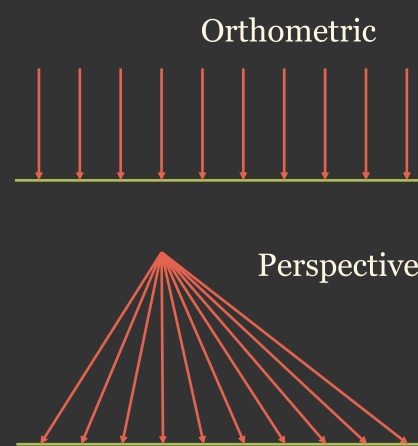
When collecting aerial imagery as individual frames, especially if photogrammetric methods will be used to derive digital terrain information, it is important to include overlap between images both along the flight line (endlap) and between adjacent flight lines (sidelap). In fact, an endlap of at least 50% is required for full stereoscopic coverage of the entire mapped area. Generally, 55% to 60% overlap is recommended.

The airbase represents the distance between successive photograph centers along a flight line. This impacts the amount of vertical exaggeration when using the images for stereoscopic viewing. Vertical exaggeration relates to how exaggerated elevation is in comparison to horizontal distance. The ratio between the airbase and the flight height determines the vertical exaggeration. Decreasing the distance between photo centers will increase the vertical exaggeration.

Vertical Relief/Elevation Displacement

- All points on a map are depicted in their true relative horizontal (planimetric) position
- Points on a photo taken over varying terrain are displaced from their true "map position"
- Map = Orthometric projection
- Photo = Perspective projection
- Tall objects lean away from the principal point of the image.



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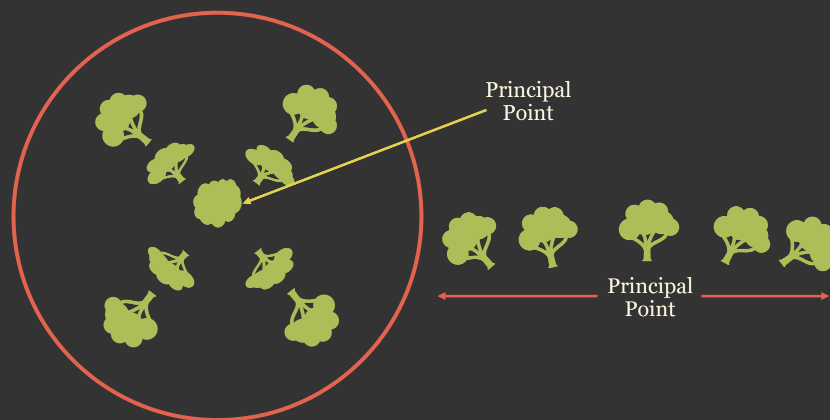
Images represent a perspective view of the landscape as opposed to an orthometric view; the data are collected from a vantage point as opposed to directly above each individual location in the extent.

This results in a perspective projection as opposed to an orthographic projection, as demonstrated by the graphics on this slide. Practically, this viewing geometry results in some impacts on representation of the landscape in the resulting images.

Most notable, is the impact of terrain. Points on a photo taken over varying terrain are displaced from their true map position. Also, tall objects tend to lean away form the center of the image, or image principal point.

Orthophotography

- An aerial photograph with uniform scale that has been corrected for relief displacement
- Tall objects bend outward or away from center of image (Principal Point)
- There are also distortions because of terrain and variable distance from the camera



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This slide further discusses the concept of vertical relief displacement resulting from the perspective view.

Again, tall objects, such as buildings and trees, will bend or lean away from the center or principal point of the image.

Also, variability in the terrain surface means that the actual landscape surface will occur at different distances from the sensor. So, the location and scale of the landscape surface is also impacted or distorted.

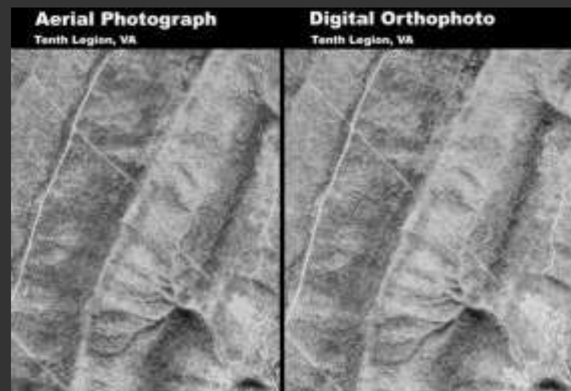
Orthophotography

Orthorectification = A process used to remove vertical relief displacement and give image uniform scale

To do this, you need to know information about:

- The flight
- The camera
- The terrain

Only orthophotography should be used as reference information to digitize and make maps



https://www.usgs.gov/media/images/aerial-photograph-vs-orthoimage

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Orthorectification is the process used to remove vertical relief displacement and give an image uniform scale. The goal here is to transform the image from a perspective to orthometric projection, which will alleviate the impact of topography, height, and viewing geometry. The resulting orthophotograph will have consistent scale throughout.

In order to perform orthorectification, you need to have information about the flight, camera, and terrain.

Once orthorectification has been performed, the image has been converted to an orthophotograph.

The difference is highlighted in the provided images. The first image is the raw image with scale distortions. Note that the long, linear clearing seems to “zig-zag” as it goes up and down the topography. This is because the ground surface-to-sensor distance varies due to the terrain. Once orthorectification has been performed, the linear feature appears to be straighter. This is because the scale distortion was removed.

The most important point here is that only orthophotography should be used as reference information to digitize and make maps in a GIS. If orthorectified imagery is used, the scale distortions will be incorporated into the products.

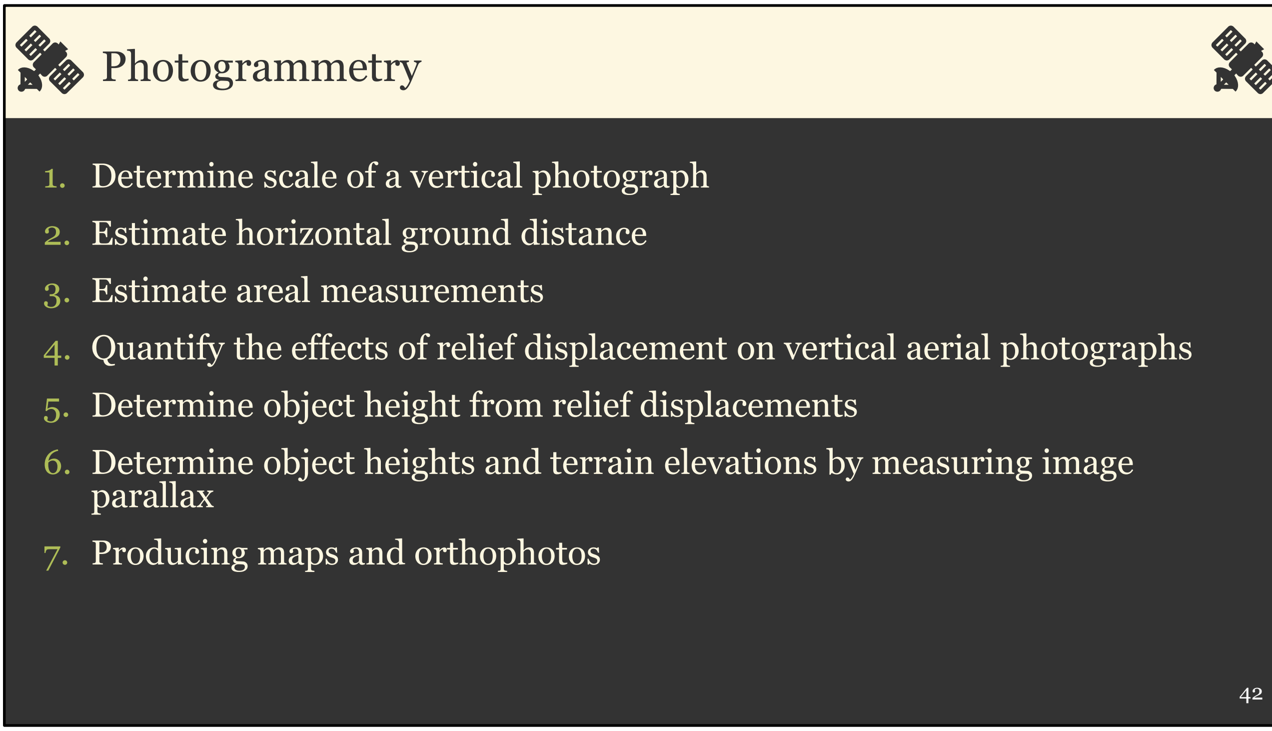
If you have spent any time viewing aerial imagery, such as in Google Earth, you may have noticed that many buildings still appear to lean in the orthophotography. That is because a terrain surface or digital elevation model is commonly used in the orthorectification process. Since no above ground features are represented in the elevation surface, only relief displacement associated with the topography is fixed. Above ground features, such as buildings, are still distorted.

Photogrammetry

- "The science and technology of obtaining spatial measurements and other geometrically reliable derived products from photographs."
- Unique mathematical and geometric relationships exist between image or stereo image pairs and the ground surface.
- We can exploit these relationships to make measurements and extract information.

Photogrammetry is the science and technology of obtaining spatial measurements and other geometrically reliable derived products from photographs.

In contrast to the generation of orthophotography, which attempts to remove the impacts of a perspective projection, photogrammetry makes use of these relationships and distortions to derive measures from images.



A variety of measures can be derived using imagery and derived products, as outlined on this page. In the remaining slides, I will provide some examples.

Photograph Scale

$$S = \text{photo scale} = \frac{\textit{photo distance}}{\textit{gound distance}} = \frac{d}{D}$$

Problem: Assume that two road intersections shown on a photograph can be located on a 1:25,000 scale topographic map. The measured distance between the intersections is 47.2 mm on the map and 94.3 mm on the photograph.

(a) What is the scale of the photograph?

(b) At that scale, what is the length of a fence line that measures 42.9 mm on the photograph?

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It is possible to determine the scale of a photograph based on the relationship between the distance between objects on the ground and the distance between the objects on the photograph.

This relationship is described in the provided equation where d = photo distance and D = ground distance.

Using this equation, we can solve the problem stated on this slide as follows:

1. Calculate the ground distance using the topographic map and associated measurements: (47.2 mm X 25,000)/1000 = 1,187.5 meters.
2. Calculate scale from the ground distance and image distance. (94.5/1000)/(1187.5) = 7.96e-7 (Invert to get a scale of 1:12,566). This is the answer for (a).
3. Use the calculated scale to answer (b): 42.9 X 12,566 X 1/1000 X 1/1000 = 0.54 km

Photograph Scale

$S = \frac{f}{H - h}$

S = scale, f = camera focal length, H = flight height, h = elevation height

Problem: A camera equipped with a 152 mm focal length lens is used to take a vertical photograph from a flight height of 2780 m above ground level. If the terrain is flat and located at an elevation of 500 m, what is the scale of the photograph?

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The scale of a photograph can also be calculated from the flight and camera characteristics, as shown in the provided equation. The provided problem can be solved as follows:

1. Calculate S: (152/1000)/(2780-500m) = 6.67e-5 (Invert to get a scale of 1:15,000).

Photograph Scale

$S = \frac{f}{H - h}$

S = scale, f = camera focal length, H = flight height, h = elevation height

Problem: Assume that a vertical photograph was taken at a flight height of 5000 m above sea level using a camera with a 152 mm focal length lens

(a) Determine the photo scale at points A and B, which lie at elevations of 1200 m and 1960 m.

(b) What ground distance corresponds to a 20.1 mm photo distance measured at each of these elevations?

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The scale of the image will change based on the distance from the surface of the earth to each location in the image. This highlights the impact of a perspective view.

The examples on this slide, which calculate scale at a specific location, can be solved as follows:

1. For (a), calculate the scale at each location using the same method as the prior example: (152/1000)/(5000-1200m) = 4e-5 (Invert to get a scale of 1:25,000) and (152/1000)/(5000-1960m) = 5e-5 (Invert to get a scale of 1:20,000)
2. For (b), use the calculated scales to find the ground distance: 20.1/1000 X 25,000 X 1/1000 = 0.50 km and 20.1/1000 X 20,000 X 1/1000 = 0.40 km

Photograph Scale (Average)

$$S_{avg} = \frac{f}{H - havg}$$

S_{avg} = average scale, f = camera focal length, H = flight height, h_{avg} = average elevation height

Problem: A camera equipped with a 120 mm focal length lens is used to take a vertical photograph from a flying height of 2800 m above ground level. If the average elevation of the terrain is 800 meters, what is the average scale of the photograph?

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Since scale varies based on elevation and distance between the sensor and the ground, it is common to calculate an average scale using an average elevation in the image. The problem on this slide can be solved as follows:

1. Use the equation, the camera focal length, the flight height, and the average elevation to estimate the average scale: (120/1000)/(2800-800) = 6e-8 (Invert to get a scale of 1:16,667).

Measuring Object Height Using Vertical Relief Displacement

$$h = \frac{dH}{r}$$

h = feature height

d = relief displacement

H = flying height

r = radial distance on the photograph from the principal point to the displaced image point

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It is also possible to estimate the height of an above ground object based on the associated vertical relief displacement. In the provided equation, h represents the height of the object, d represents the relief displacement, H represent the flight height, and r represents the radial distance on the photograph from the principal point to the displaced image point. Remember that there is more relief displacement the further an object is from the principal point.

Measuring Object Height Using Vertical Relief Displacement

$$h = \frac{dH}{r}$$

Problem: Assume the relief displacement for a tower is 2.01 mm, and the radial distance from the center of the photo to the top of the tower is 56.43 mm. If the flying height is 1220 m above the base of the tower, find the height of the tower.

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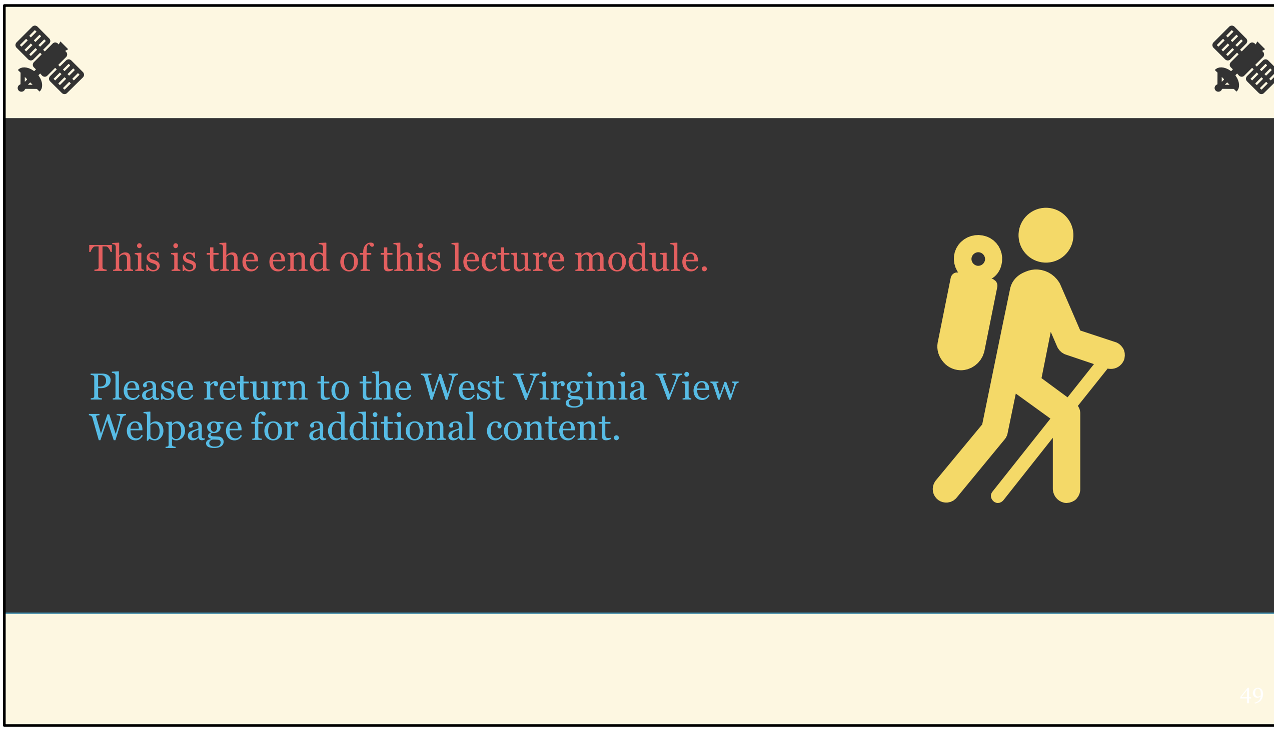
Here is how the question on this slide could be answered:

h = (2.01 X 1220)/(56.43) = 43.5 meters



Thanks! Hope you found this useful.