Chapters 1-3

- Chapter 1: Introduction and applications of photogrammetry
- Chapter 2: Electro-magnetic radiation
  - Radiation sources
  - Classification of remote sensing systems (passive & active)
  - Electromagnetic radiation wavebands
- Chapter 3: Basic optics
  - Definitions
  - Factors affecting the precision and the accuracy of the image coordinate measurements
  - Resolving power of an optical system

CE59700: Chapter 4

Film Development & Digital Cameras

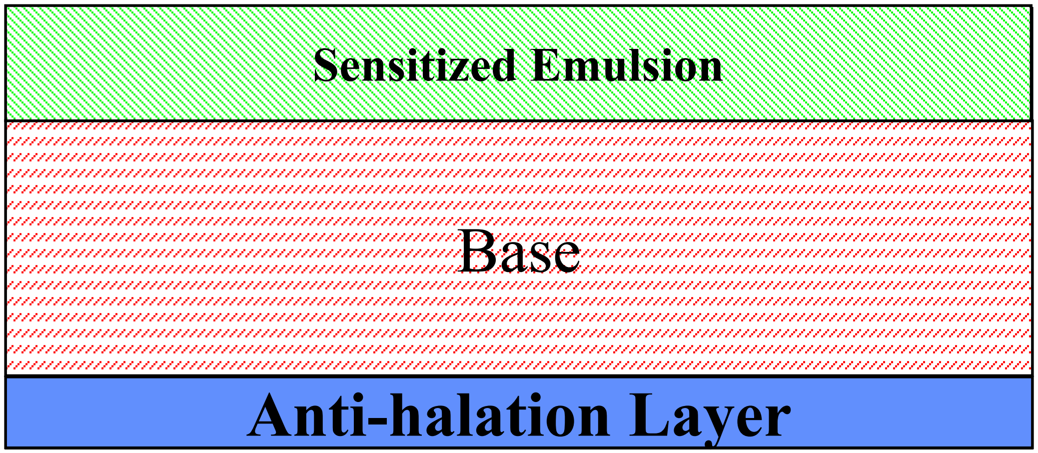
Overview

- Photographic film components
- Processing of Black and White (B/W) film
  - Negative film
  - Inverse film
- Nature of color
- Processing of color film
  - Negative film
  - Inverse film
- Sensitometric properties of the emulsion
- Analog versus digital cameras
- Frame versus line cameras

Photographic Film Development

B/W and Color Film Development

B/W Photographic Film



B/W Photographic Film

- Emulsion:
  – Micro-thin layer of gelatin in which light-sensitive ingredients (silver bromide crystals) are suspended.
- Base:
  – Transparent flexible sheet on which light sensitive emulsion is coated.
- Anti-halation layer:
  – Prevents transmitted light through the base from reflecting back towards the emulsion.

B/W Photographic Film

- Negative film:
  - Bright areas in the object space appear dark and dark areas appear bright.
  - Directions are inverted.
- Diapositive:
  - Bright areas in the object space appear bright and dark areas appear dark.
  - Image and object space directions are compatible.

Negative Film

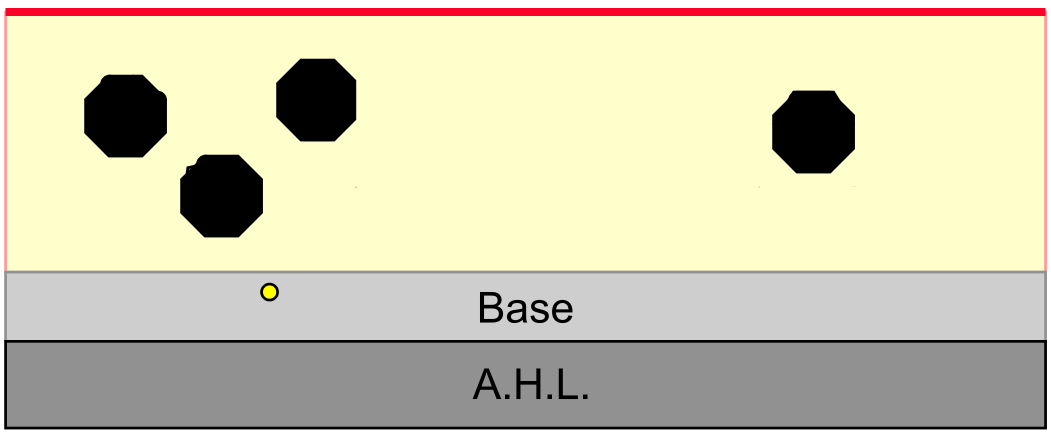
Diapositive

Processing of Black and White Negative Film

development process:

crystals with speckle reduced to silver

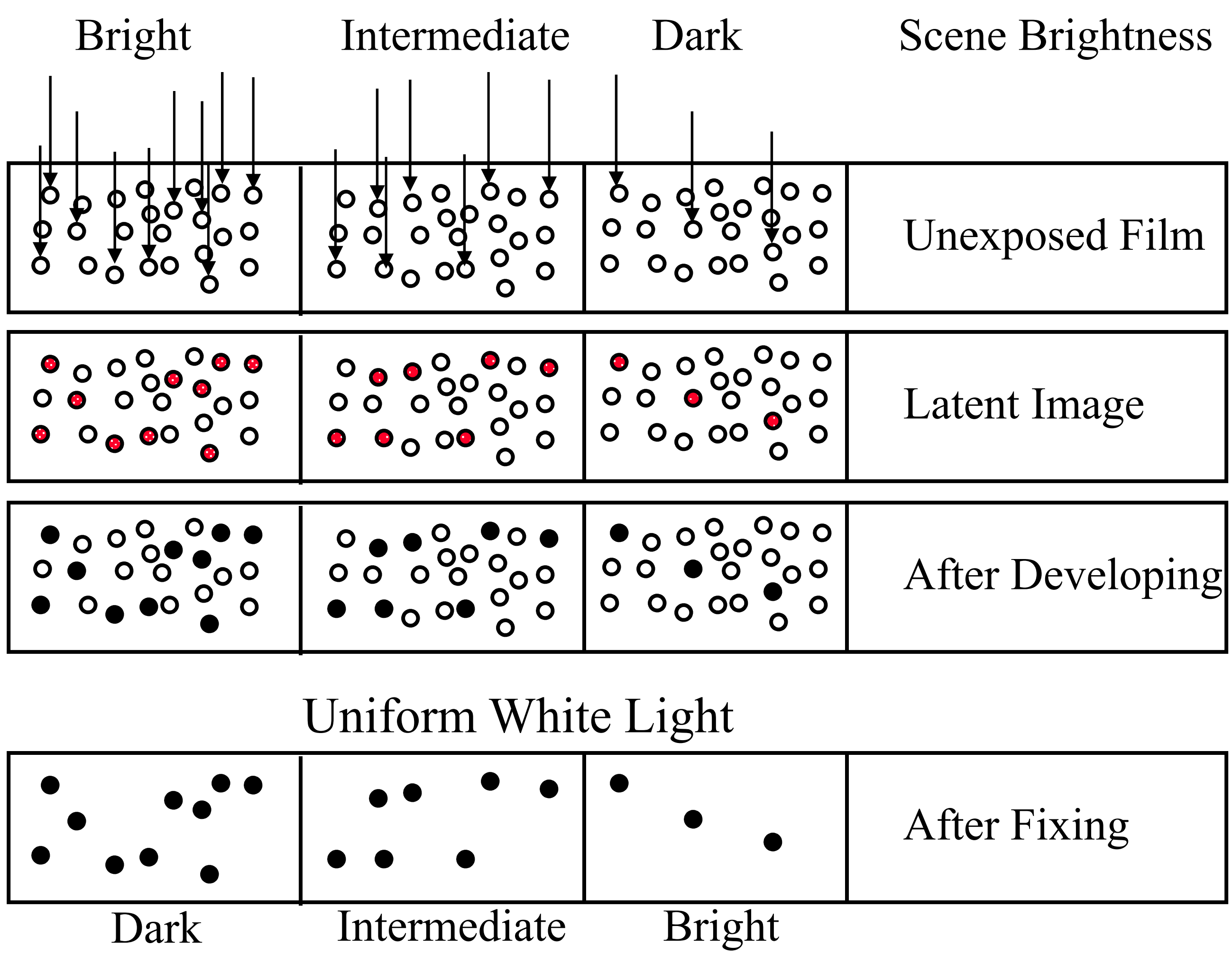
other crystals washed out



Processing of Black and White Negative Film

- Exposure of film to light → Latent image
- Latent Image:
  - The bond between the silver and the bromide is broken.
- Development of latent image:
  - The silver (in the affected crystals) is separated from the bromide. We get rid of the bromide.
- Fixing:
  - We get rid of the unaffected crystals. They are converted into salt, which can be dissolved into water and released.

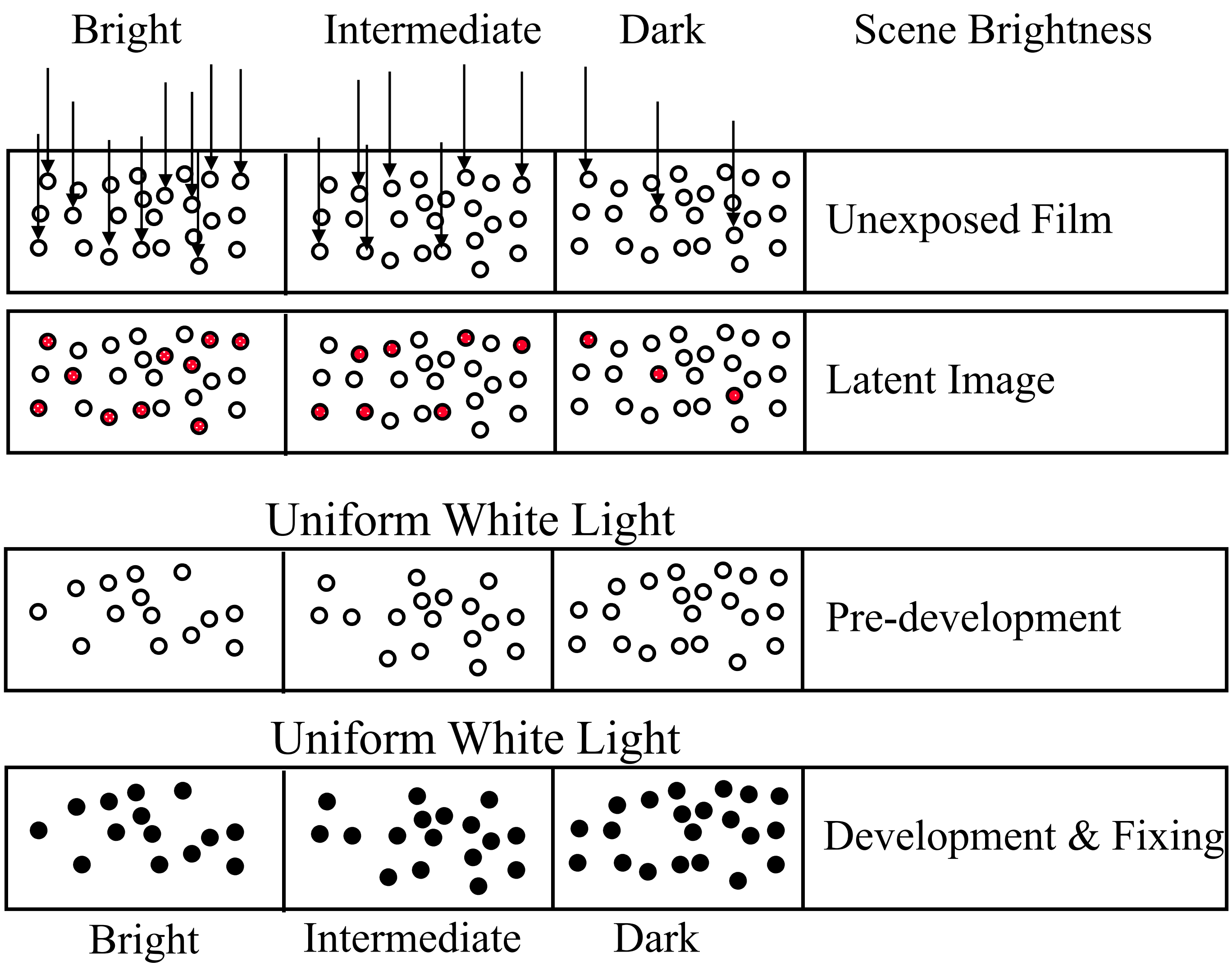
Negative Film Development



Processing of Black and White Inverse Film

- Exposure of film to light → Latent image
- Latent Image:
  - The bond between the silver and the bromide is broken.
- Pre-development (bleaching) of latent image:
  - The affected silver bromide crystals are released. Only, unexposed silver bromide crystals remain.
- Exposing the film to uniform white light, development, and Fixing:
  - The film is uniformly exposed to white light. This is followed by development (where we get rid of the bromide) and fixing stages.

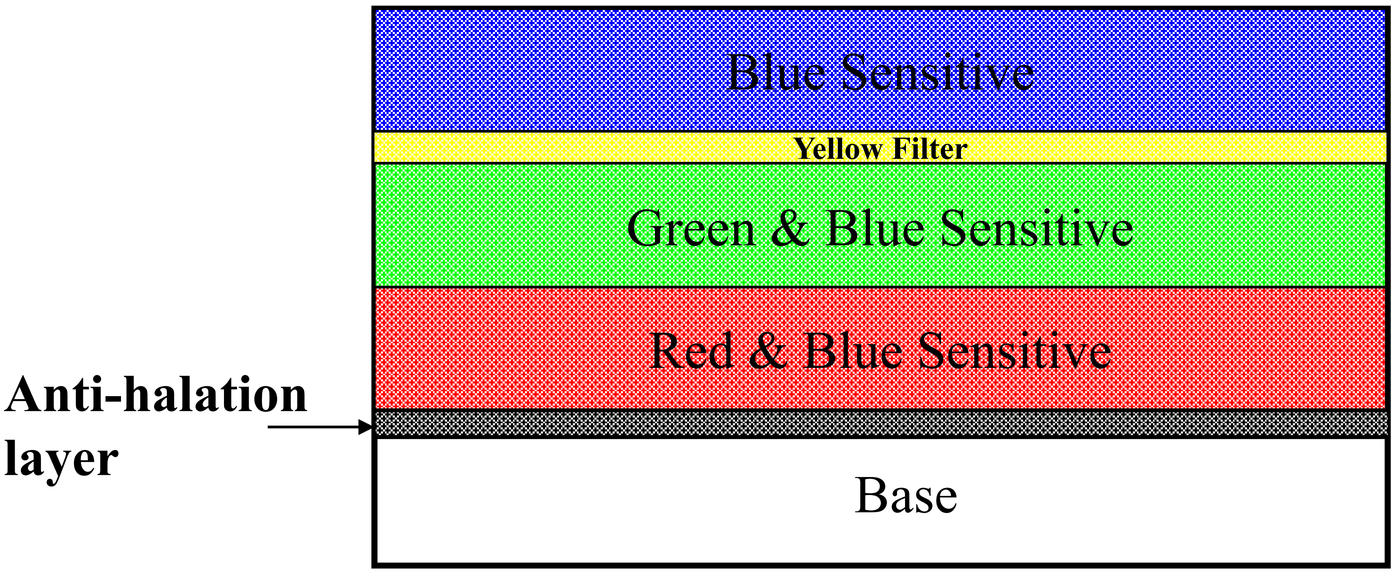
Development of Reversal (Inverse) B/W Film



Nature of Color

- Primary Colors:
  - Colors that cannot be derived from other colors.
  - Red, Green, and Blue
  - Red + Green + Blue → White
  - Green + Blue → Cyan
  - Red + Green → Yellow
  - Red + Blue → Magenta
  - Cyan filter subtracts Red (passes Green and Blue).
  - Yellow filter subtracts Blue (passes Red and Green).
  - Magenta filter subtracts Green (passes Red and Blue).
  - Cyan + Yellow + Magenta filters→ Black

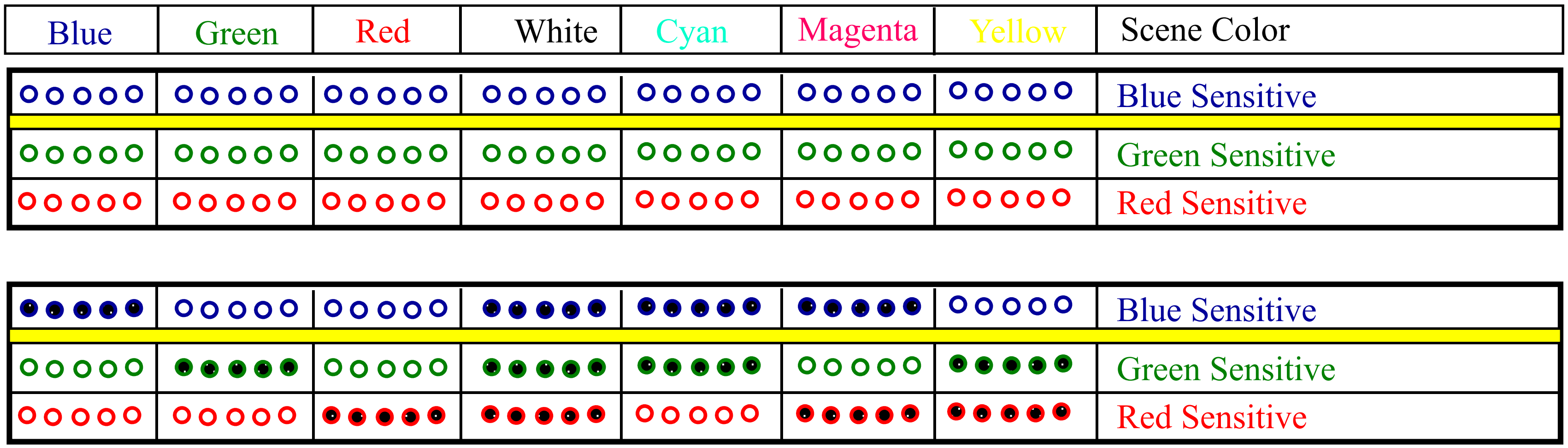
Color Film


Blue Sensitive
Yellow Filter
Green & Blue Sensitive
Red & Blue Sensitive
Anti-halation layer
Base

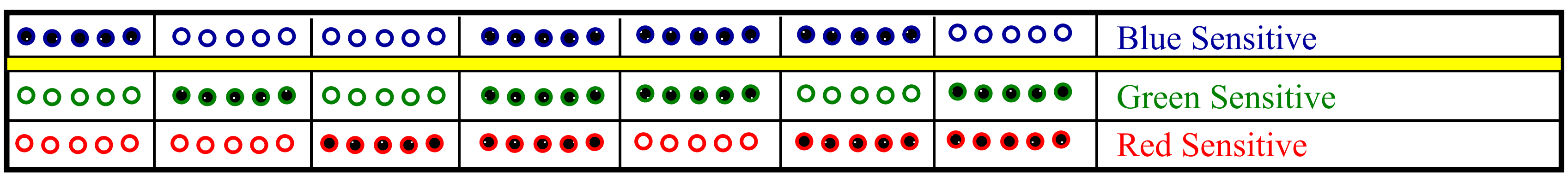
Development of Color Negative Film

- Exposure of film to light → Latent image
- Latent Image:
  - The bond between the silver and the bromide is broken.
- Development of latent image:
  - The silver (in the affected crystals) is separated from the bromide. We get rid of the bromide. Only metallic silver and unexposed crystals remain.
- Fixing and Dying:
  - We get rid of the unaffected crystals and the yellow filter. The silver crystals are dyed with complementary color.

Processing of Color Negative Film

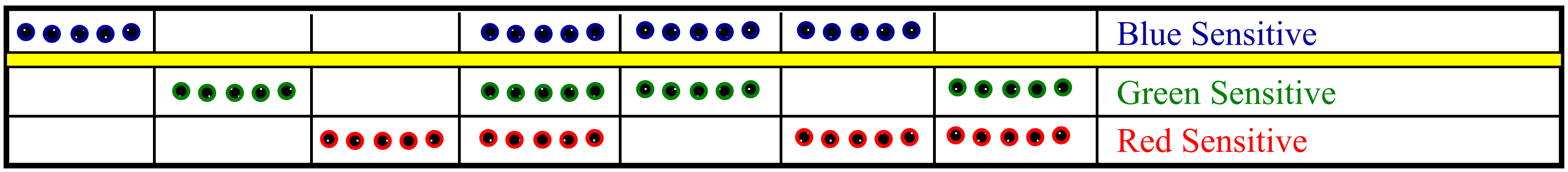


Latent Image



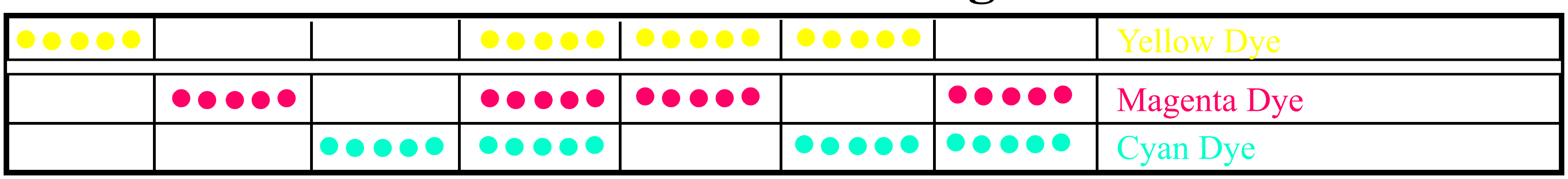
Developed Latent Image

Processing of Color Negative Film



After Fixing

Uniform White Light



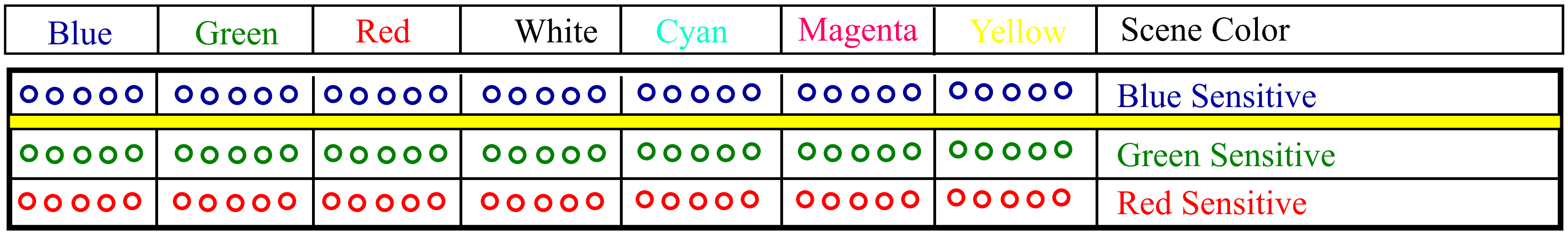
After Dying

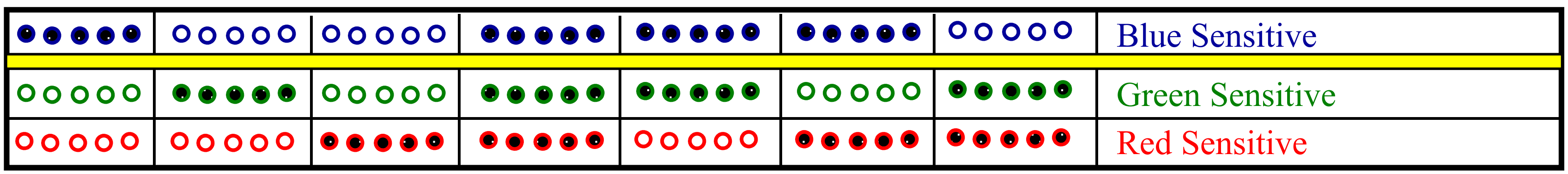
Yellow	Magenta	Cyan	Black	Red	Green	Blue	Negative Color
Blue	Green	Red	White	Cyan	Magenta	Yellow	Scene Color

Development of Color Inverse Film

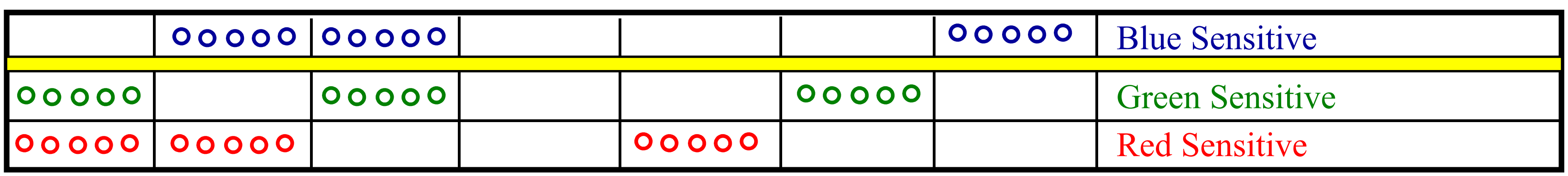
- Exposure of film to light → Latent image
- Latent Image:
  - The bond between the silver and the bromide is broken.
- Pre-development of latent image:
  - We get rid of the exposed grains.
- Expose the film to uniform white light
- Film Development, Fixing, and Dying:
  - We get rid of the bromide and the yellow filter. The silver crystals are dyed with complementary color.

Development of Color Inverse Film





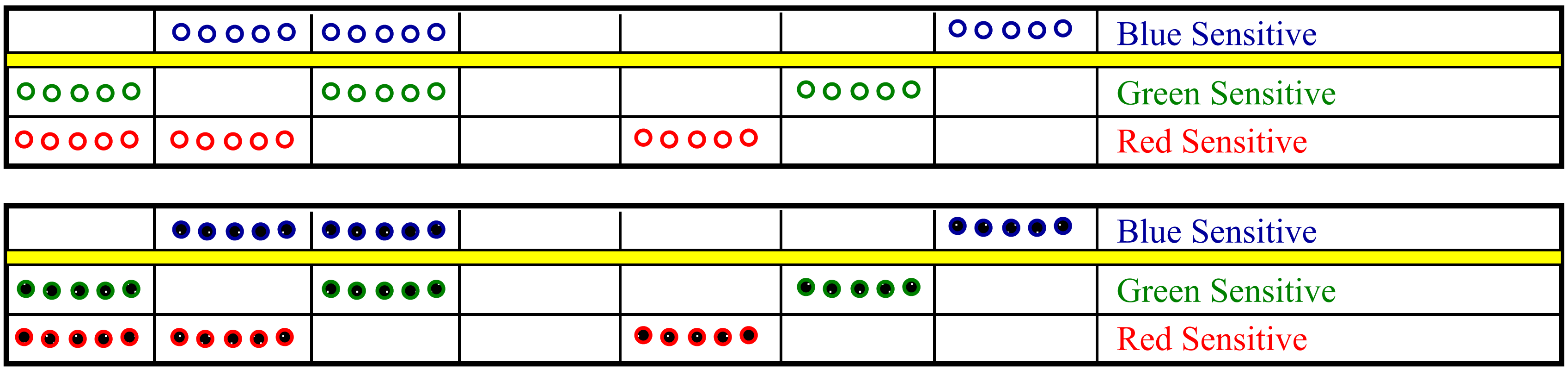
Latent Image



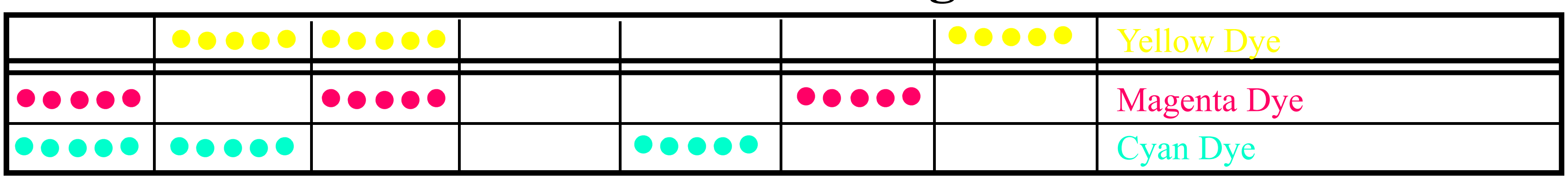
Pre-development Latent Image

Development of Color Inverse Film

Uniform White Light



Uniform White Light

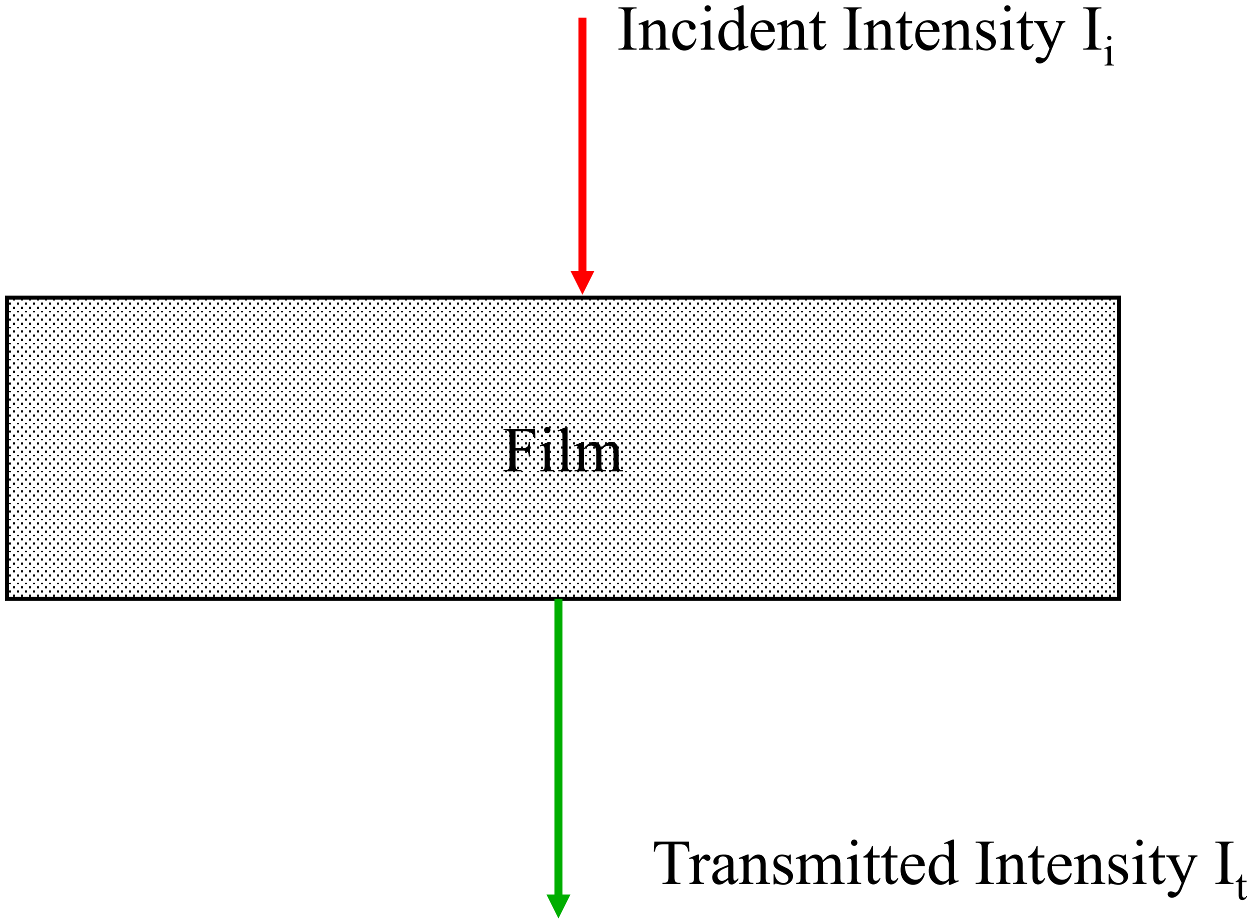


After Dying & Fixing

Blue	Green	Red	White	Cyan	Magenta	Yellow	Film Color
Blue	Green	Red	White	Cyan	Magenta	Yellow	Scene Color

Sensitometric Properties of the Emulsion

Sensitometric Properties of the Emulsion



Sensitometric Properties of the Emulsion

- Sensitometry (t):
  - A measure of the emulsion's response to light
- Opacity (O):
  - The ratio between the incident intensity (I_i) and the transmitted intensity (I_t)
  - $O = I_i / I_t$
- Transmittance (T):
  - $T = 1 / O$
- Density (D):
  - $D = \log_{10} (O) = \log_{10} (I_i / I_t)$

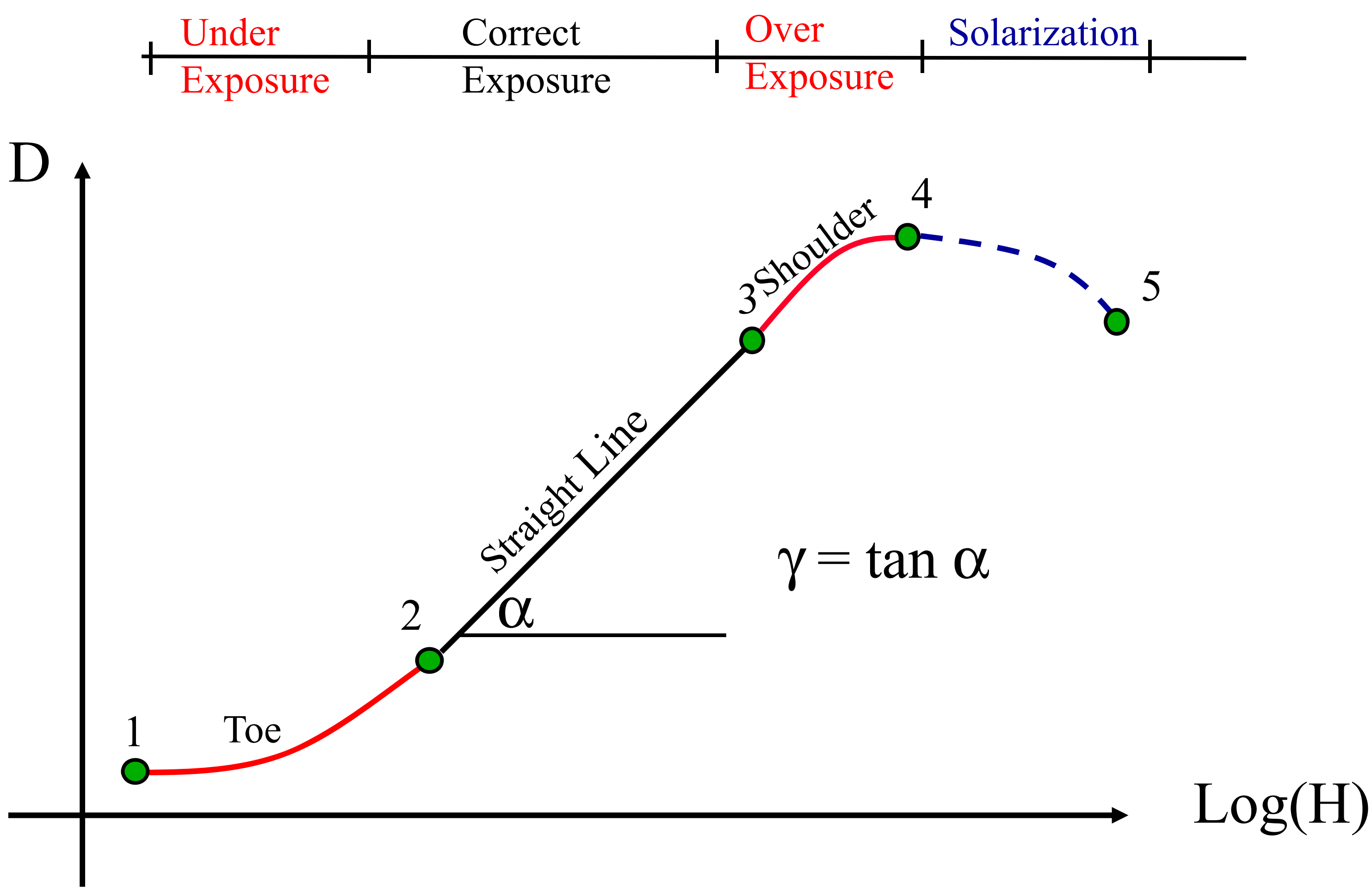
Density

- Density = 2
  - $I_i / I_t = 100 \rightarrow I_t = 0.01\ I_i$
  - 99% of the incident intensity was absorbed by the emulsion.
- Density = 1
  - $I_i / I_t = 10 \rightarrow I_t = 0.1\ I_i$
  - 90% of the incident intensity was absorbed by the emulsion.
- Density = 0
  - $I_i / I_t = 1 \rightarrow I_t = I_i$
  - 0% of the incident intensity was absorbed by the emulsion. → Transparent material

Sensitometric Properties of the Emulsion

- Exposure (H):
  - The product of the illuminance "E" falling on the emulsion (in LUX) times the exposure time
  - H is expressed in (LUX • Sec).
- Characteristic "density" curve for an emulsion:
  - The graphical plot of (log H) against the corresponding density (D)

Characteristic "Density" Curve



The Density Curve: Remarks

- Area of under exposure (Toe):
  - The density builds up with a higher rate than that of the exposure.
- Area of correct exposure (Straight Line):
  - Scene brightness is in proper proportion with the film brightness.
- Area of over exposure (Shoulder):
  - The rate with which the density increases is smaller than the rate of increase in the exposure.
- Solarization:
  - Any increase in the exposure would reduce the density.

Gradation of the Emulsion

- Gradation $\gamma = \tan(\alpha)$
- Gradation > 1 (Hard Photographic Material):
  - Small differences in the exposure → Larger differences in the density → Increase the contrast
- Gradation < 1 (Soft Photographic Material):
  - Large differences in the exposure → Smaller differences in the density → Decrease the contrast
- Gradation = 1 (Normal Photographic Material):
  - Differences in the exposure → Similar differences in the density
- Correct exposure of hard films is more difficult than soft ones.

Analog Versus Digital Cameras

Analog Photogrammetric Cameras

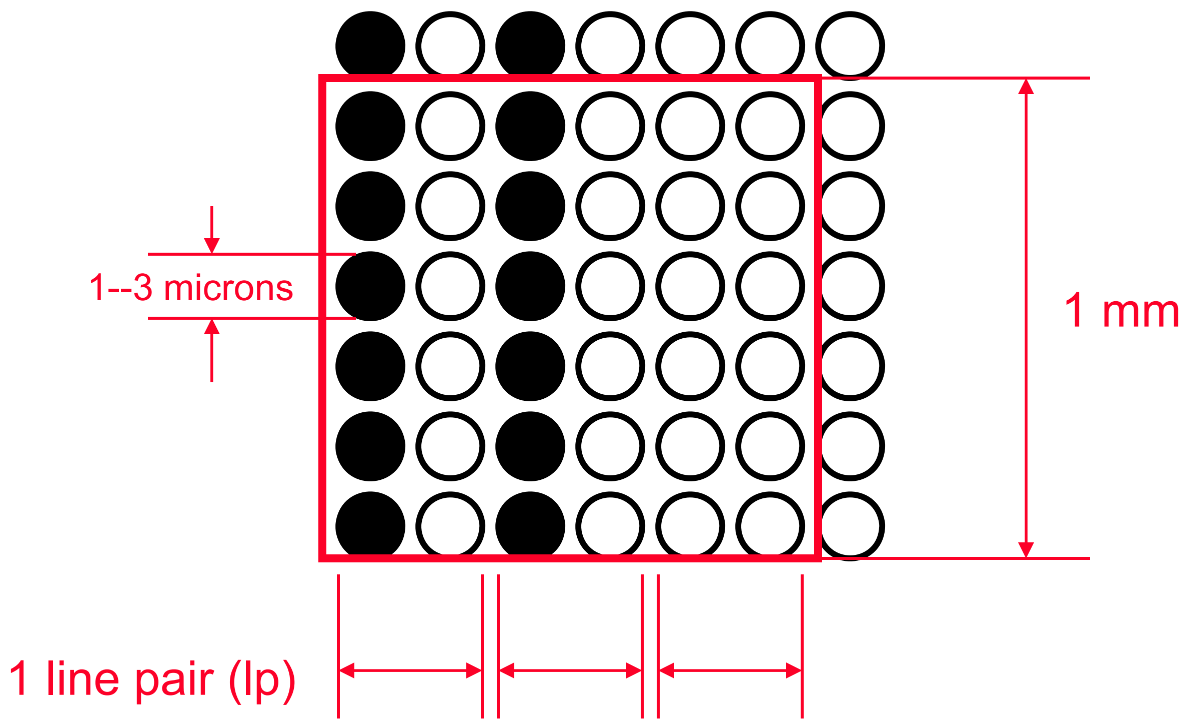
- Mapping film cameras with 9" x 9" format and a focal length of 6" have enjoyed a dominant position in the airborne mapping and remote sensing business (e.g., RC30).
- A modern analog camera will deliver a film with resolving power of approximately 40–100 line pairs/mm.
- The dynamic range of a typical analog camera is roughly180 shades of gray.

Analog Aerial Camera: RC30

http://www.leica-geosystems.com

Resolving Power: Line Pairs/mm

Average grain size: 1 – 3 μm

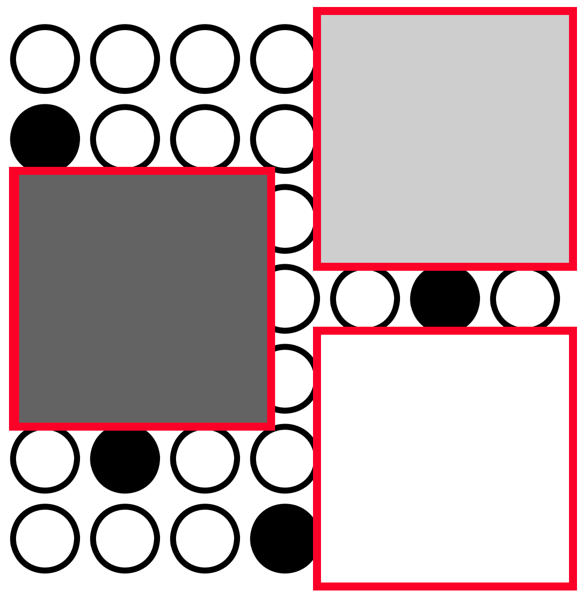


Resolving Power: Line Pairs/mm

- Factors affecting the resolving power of an analog camera include:
  - Lens aberrations, depth of field, depth of focus, diffraction, film material, and motion blur.
- Fine grained emulsions > 100 lp/mm
- Including atmosphere + optics ~100 lp/mm
- Hazy conditions ~ 40 lp/mm

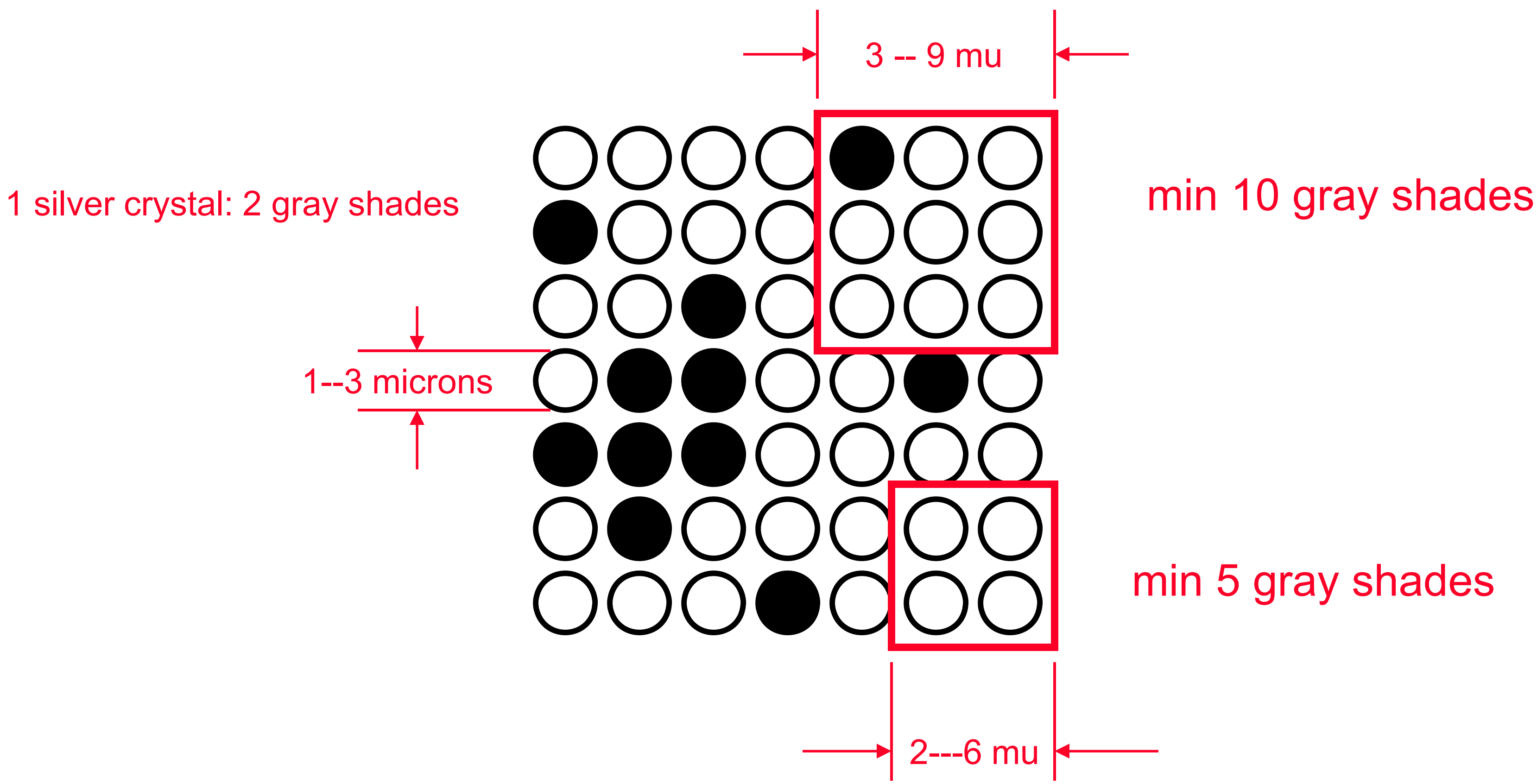
Radiometric Resolution (Dynamic Range)

- **Radiometric resolution** is the ability of the sensor to quantify different amounts of energy at a specific waveband.
- The sensor's ability to detect low to high amounts of detected energy is called the **dynamic range** of the sensor.



Perceiving Gray Shades

Radiometric Resolution (Dynamic Range)

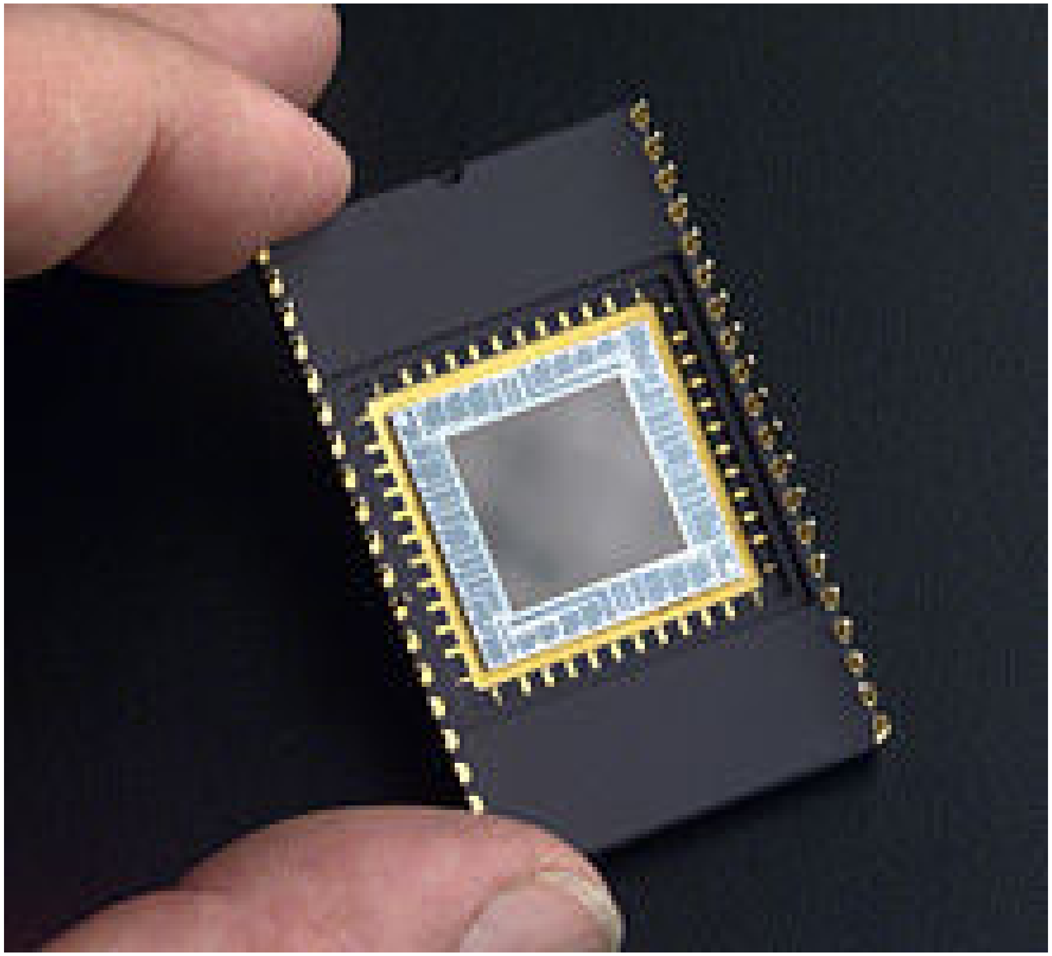


Perceiving Gray Shades

Digital Cameras & Mapping

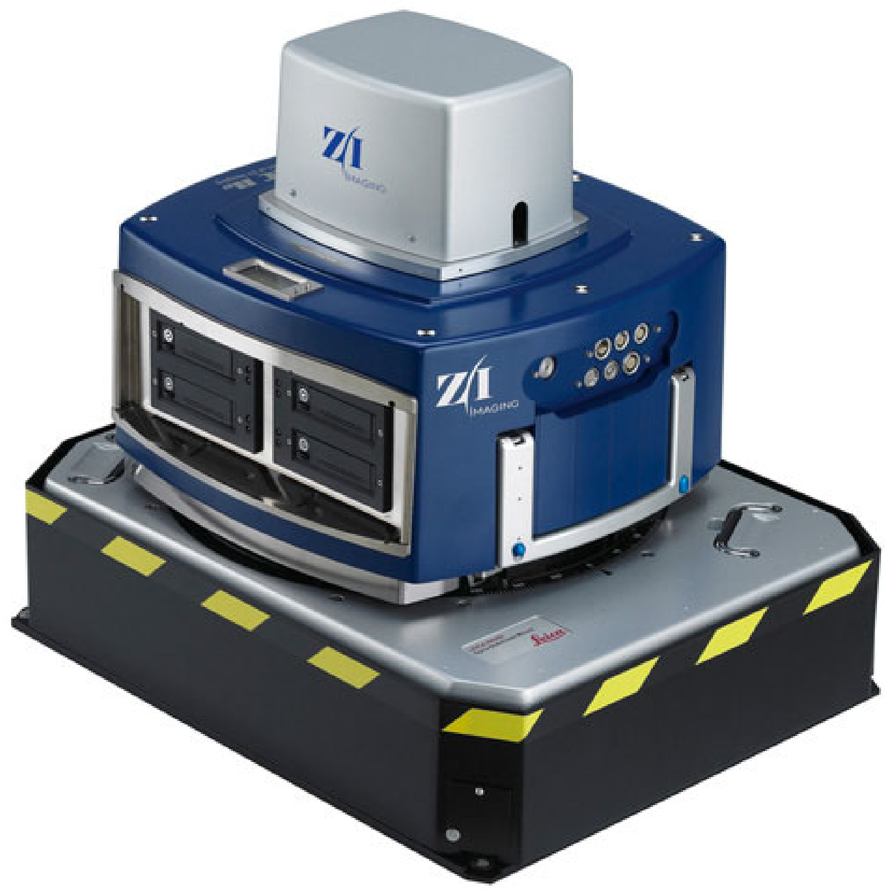
- Digital camera technology is already established within the airborne imaging marketplace (DMC™, ADS 100).
- The basic difference between analog and digital cameras is that:
  - Film and film processing are replaced by solid state electronics such as charge coupled devices (CCD) or complementary metal–oxide–semiconductor (CMOS), which are arrays with thousands of tiny detectors called picture elements (pixels).
- Digital camera uses computer technology to quickly process the image data and store it on a large storage system.

Digital Frame Cameras



http://en.wikipedia.org/wiki/Charge-coupled_device

Digital Aerial Camera: Z/I DMC IIe 250



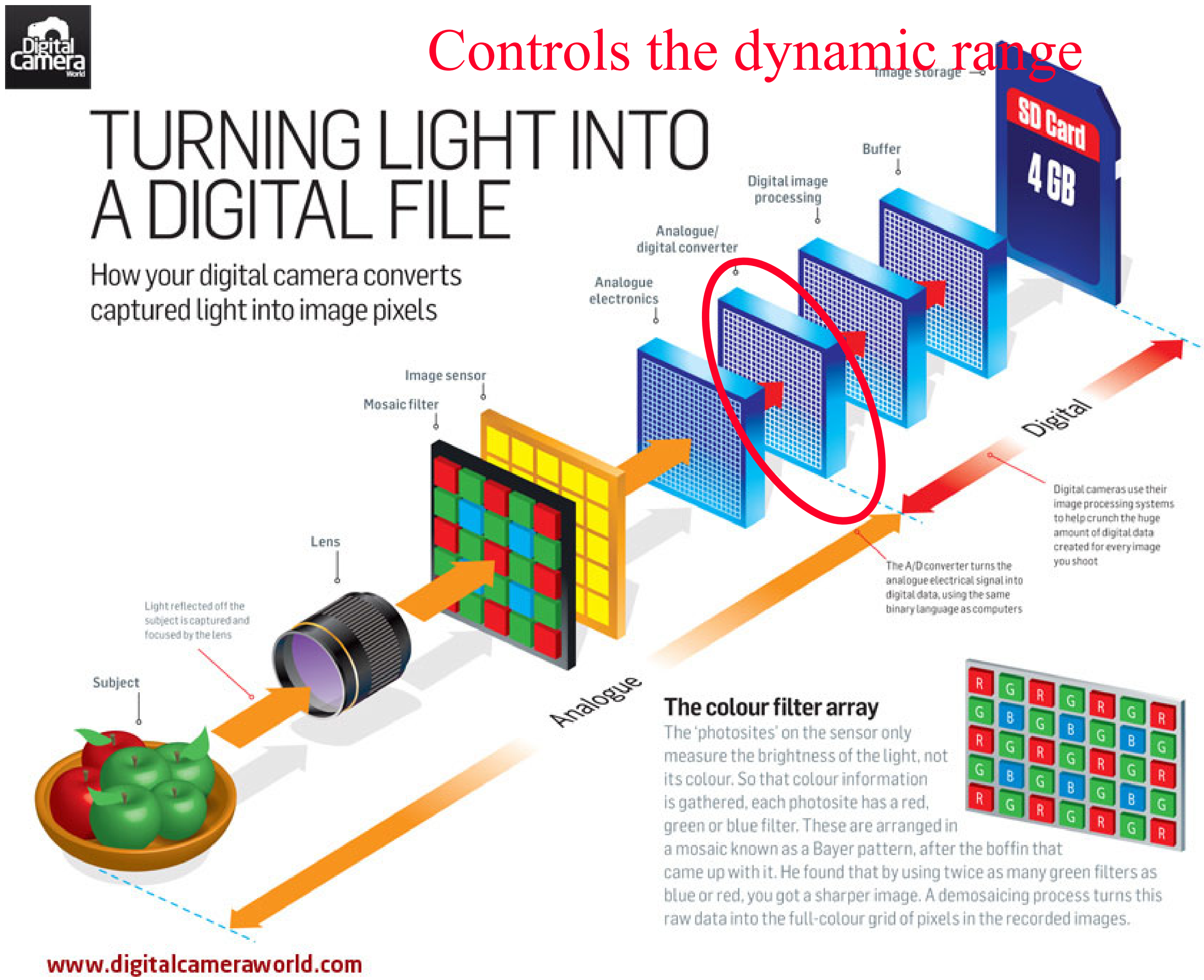
Source: Z/I Imaging

Z/I DMC IIe 250 (16,768x14,016 image format)

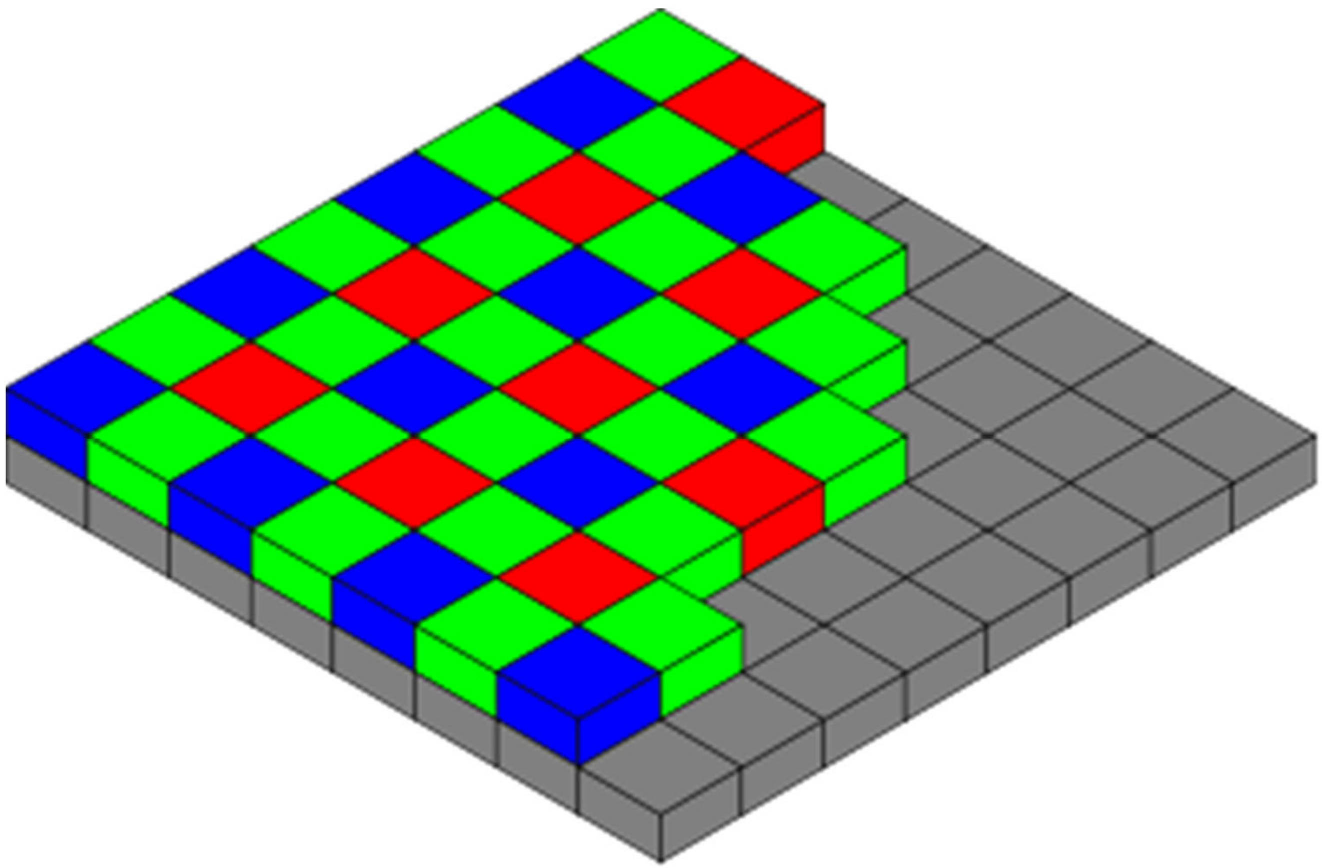
- Single PAN CCD and four multispectral cameras

Digital Cameras: Block Diagram

Controls the dynamic range



Digital Color Camera: Bayer Filter

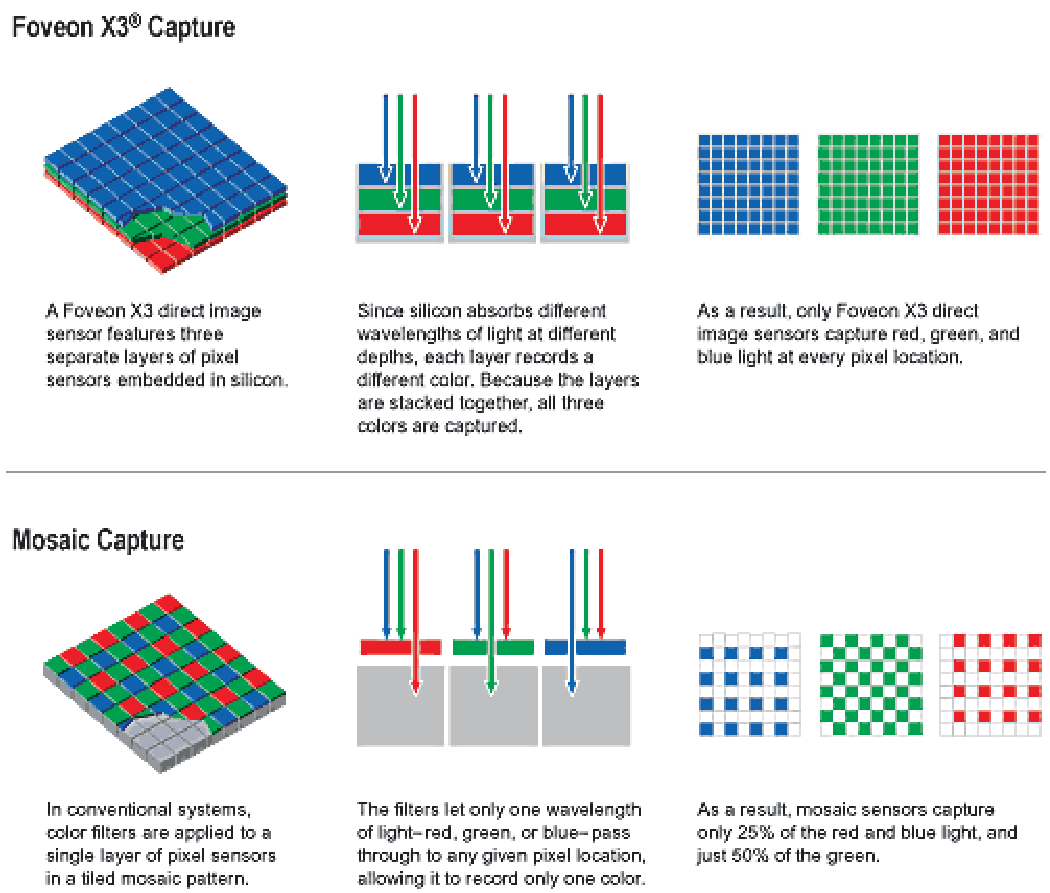


http://en.wikipedia.org/wiki/Bayer_filter

Digital Color Camera: Foveon Technology

Foveon

Bayer



http://www.foveon.com

Dynamic Range in Digital Cameras

- The sensing elements (pixels) in a digital camera absorb the energy of the incoming photons and yield an electrical charge.
- The electrical charge is converted to a voltage, which is amplified to a level that can be processed further by the Analog to Digital Converter (ADC).
- The ADC classifies ("samples") the analog voltages from the pixels into a number of discrete levels of brightness and assigns each level a binary label.
  - A "one bit" ADC would classify the pixel values as either black or white.
  - A "two bit" ADC would categorize them into four groups.
  - Most consumer digital cameras use 8 bit ADC, allowing up to 256 gray shades for a single pixel.

Resolving Power and Pixel Size

- Factors affecting the resolving power of a digital camera include:
  - Lens aberrations, depth of field, depth of focus, diffraction, pixel size, and motion blur.
- Pixel size = 1/2 of smallest detail to be resolved
- Smallest detail: lp/mm
- Pixel size = 1/(2*lp/mm)
  - 100 lp/mm pixel size = 1000 µm/200 = 5 µm
  - 40 lp/mm pixel size = 1000 µm/80 = 12.5 µm

Analog Versus Digital Cameras

Components	Analog Cameras	Digital Camera
Optics	Lenses and Mirrors	Lenses and Mirrors
Detectors	Film	Solid State Detectors (CCD , CMOS)
Processors	Chemistry	Computers
Output Media	Film	Computer Readable Discs and/or Tapes and Monitors

Analog Versus Digital Cameras

- The dynamic range of a digital camera can yield up to 4096 shades of gray (12 bits ADC).
  - Remember that the dynamic range of a typical analog camera is about 180 shades of gray.
- An analog camera with 9" x 9" format will deliver a resolving power of approximately 40 lp/mm.
  - Comparable digital camera should have 20,800 x 20,800 pixels, with each pixel being 11μ*m* in size.
    - Image size 432 mega-pixels per frame.
  - Today's largest digital cameras have up to 250 mega-pixels (Z/I DMC IIe 250).

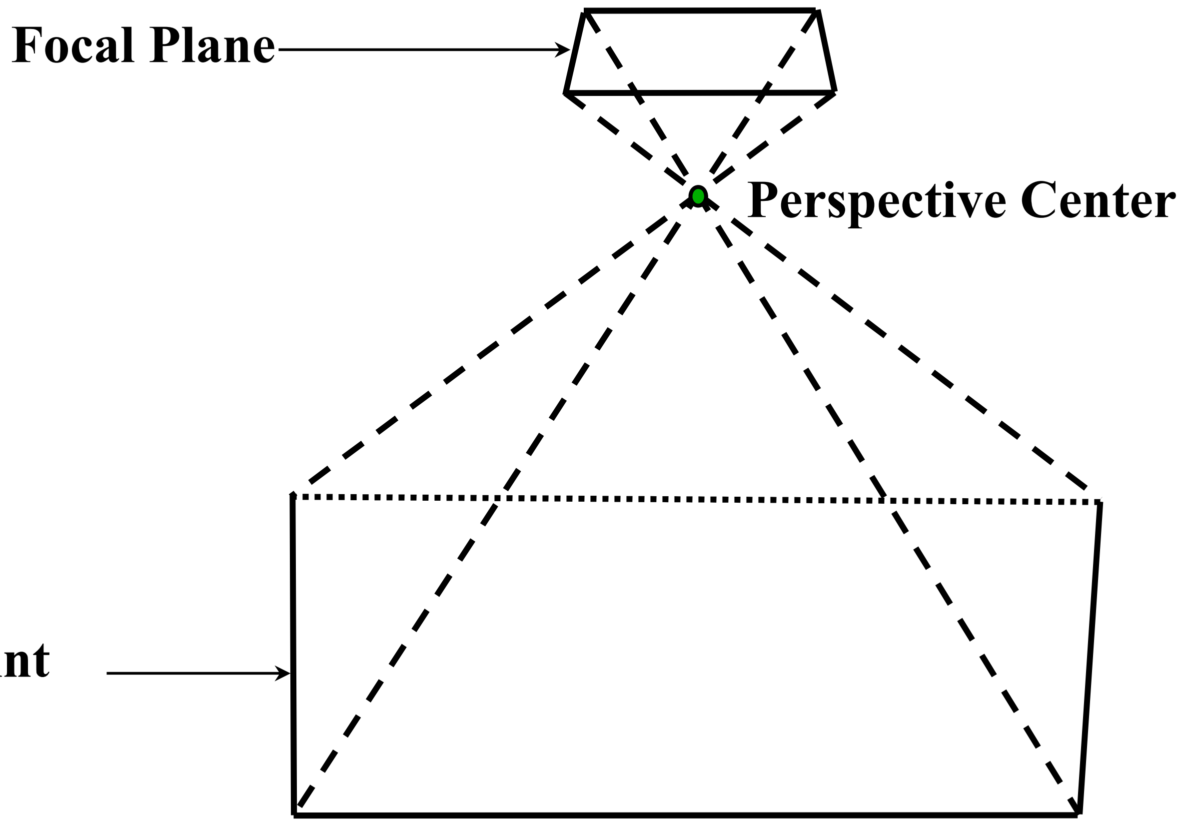
Resolution and Storage Requirement

Pixel Size [micron]	Number of Pixels	Storage Requirement (uncompressed) [MB]
960	240×240	0.058
480	480×480	0.230
240	960×960	0.922
120	1920×1920	3.686
60	3840×3840	14.746
30	7680×7680	58.982
15	15360×15360	235.931
7.5	30720×30720	943.721

- Problem: Largest available 2-D array – 250 mega-pixels
- Solution: Multi-head frame cameras and Linear Array Scanners (Line Cameras)

Frame Camera & Data Acquisition

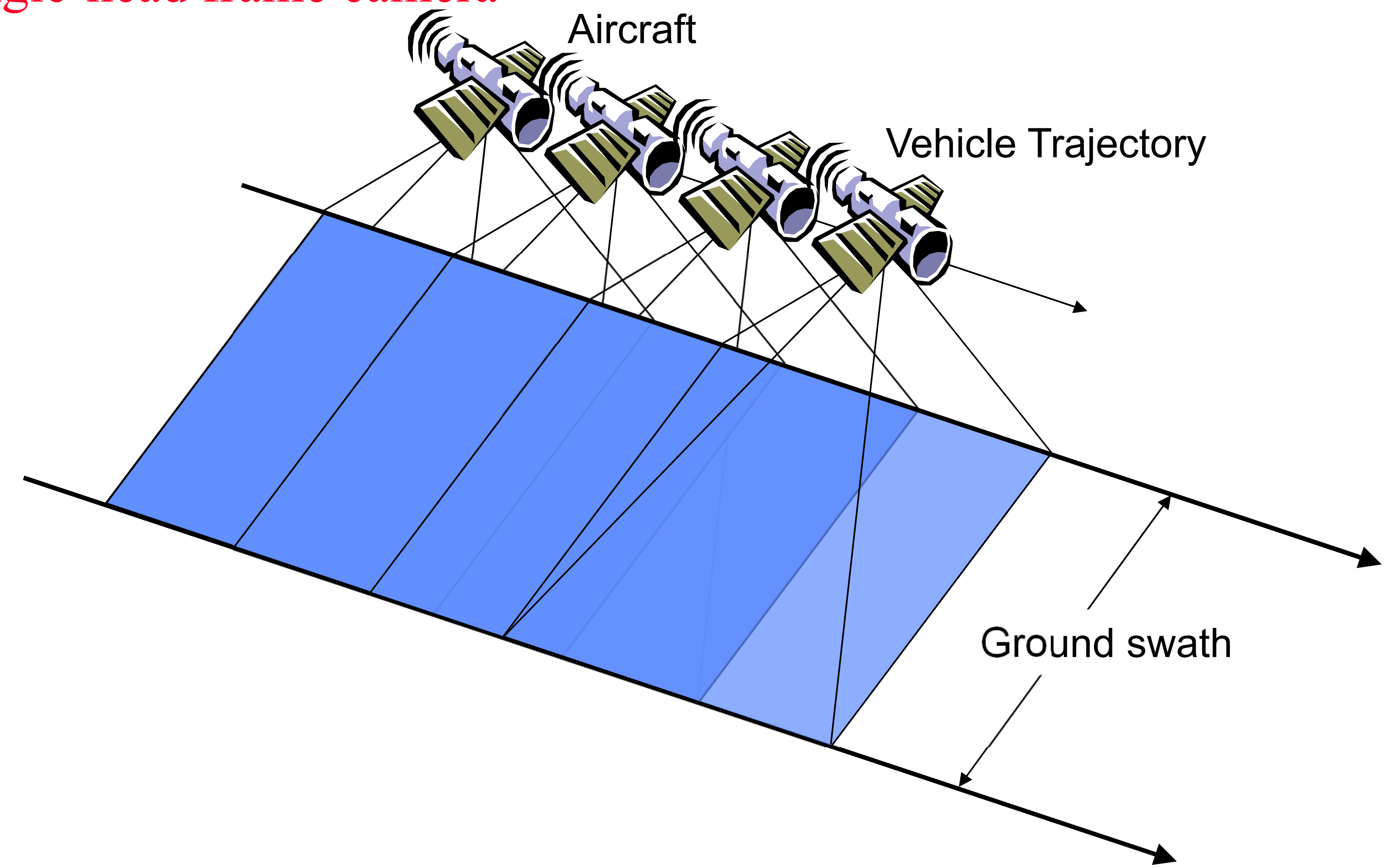
Single-head frame camera



- The image footprint is captured through a single exposure.

Frame Camera & Data Acquisition

Single-head frame camera

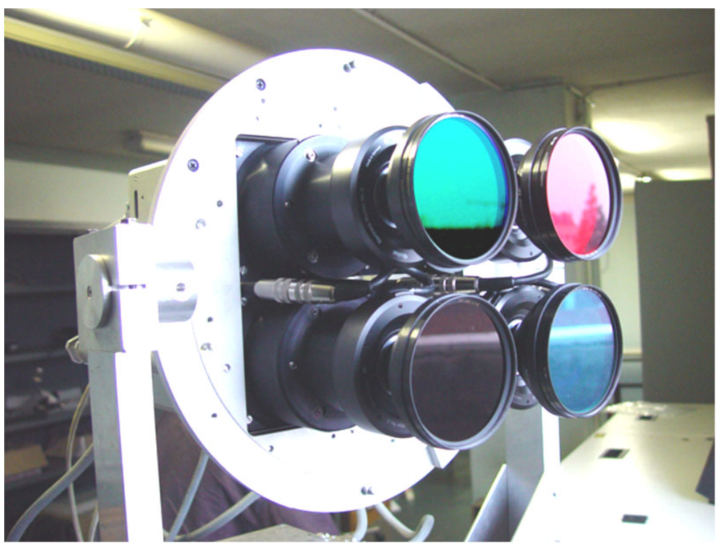


Multi-Head Digital Frame Cameras

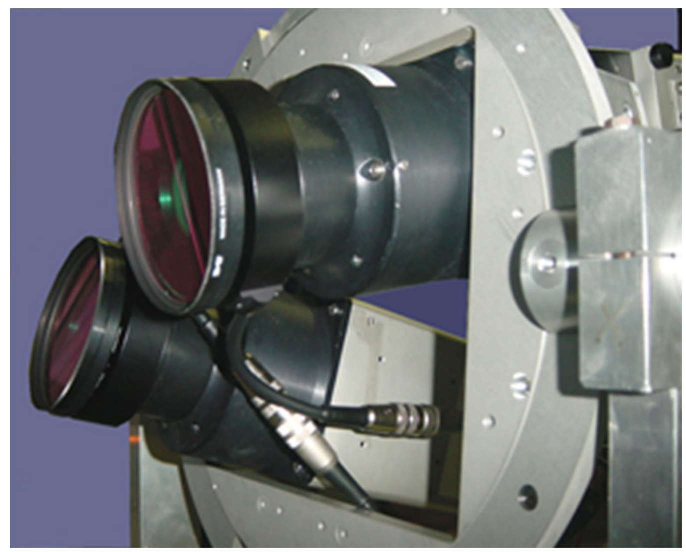
- The camera is composed of several frame cameras (e.g., n-cameras), which are rigidly fixed within one unit.
- The n-cameras are controlled to capture n-images at the same time or at specified increments.
- The resulting n-images are integrated to generate a single virtual image.
- The virtual image can be dealt with as if it is an image captured by a single-head camera.
  - The same software can be used to deal with imagery captured by single-head and multi-head frame cameras.

Multi-Head Digital Frame Cameras

- LOEMI Lab, IGN (Institut Géographique National), France
- Multiple-camera system
  - 2 Panchromatic cameras, principal distance =100mm
  - 4 Cameras for 4 spectral bands, principal distance = 60mm



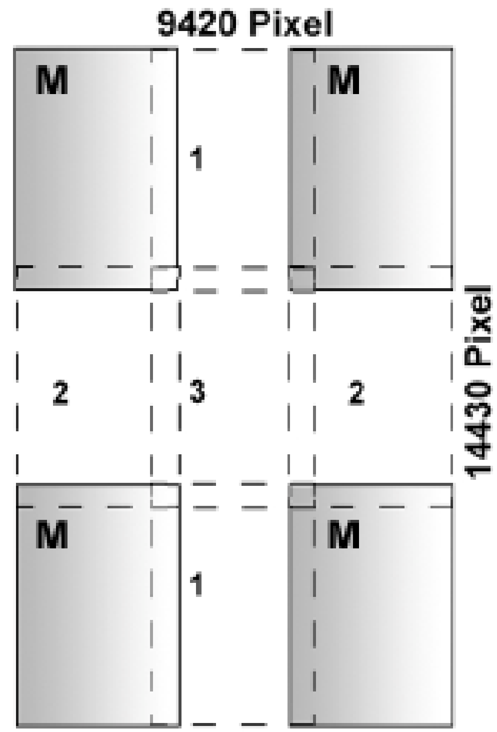
Multi-Spectral Cameras



Panchromatic Cameras

http://www.etiennearnal.fr/cnes.php

Multi-Head Digital Frame Cameras



Source: Microsoft UltraCam

UltraCam X (14430x9420 image format)

- Multi-head frame camera

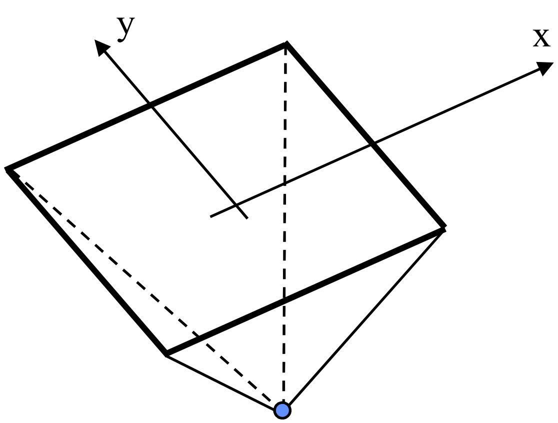
Multi-Head Digital Frame Cameras

Source: Microsoft UltraCam

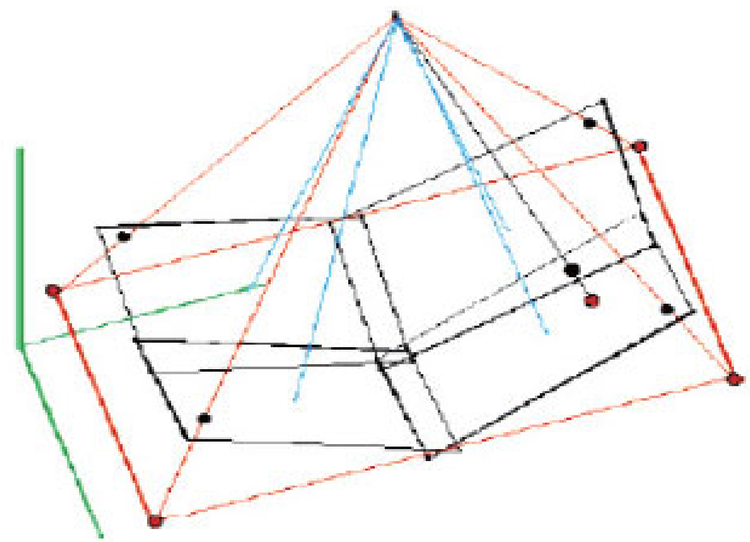
UltraCam Eagle (20,010x13,080 image format)

- Multi-head frame camera

Frame Versus Multi-Head Frame Cameras



Frame Camera

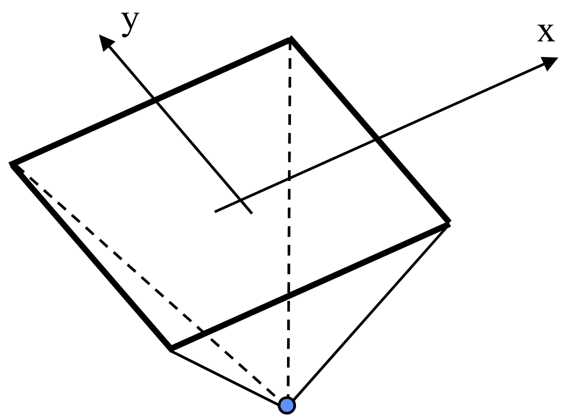


Multi-Head Frame Camera

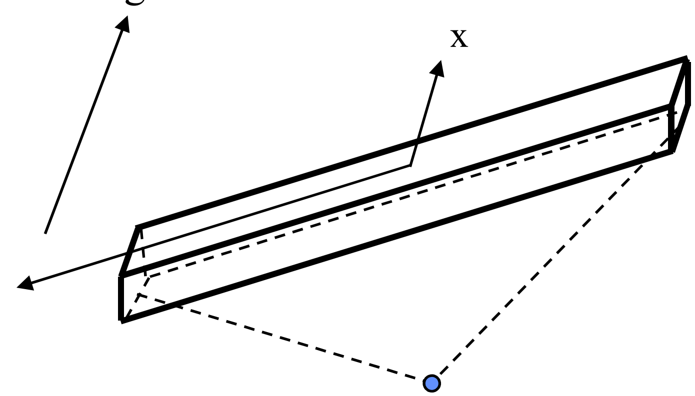
Line Cameras

- Digital frame cameras capture 2- D images through a single exposure of a two-dimensional CCD/CMOS array.
- Line cameras capture scenes with large ground coverage and high geometric and radiometric resolutions through multiple exposures of few scan lines along the focal plane.
- Successive coverage of different areas on the ground is achieved through the motion of the imaging platform.
  - Open shutter mechanism
- New software should be developed for the geometric manipulation of scenes captured by line cameras.

Frame Versus Line Cameras

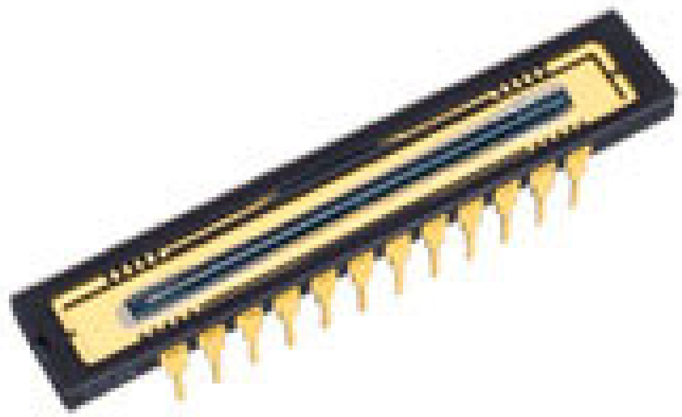


Frame Camera

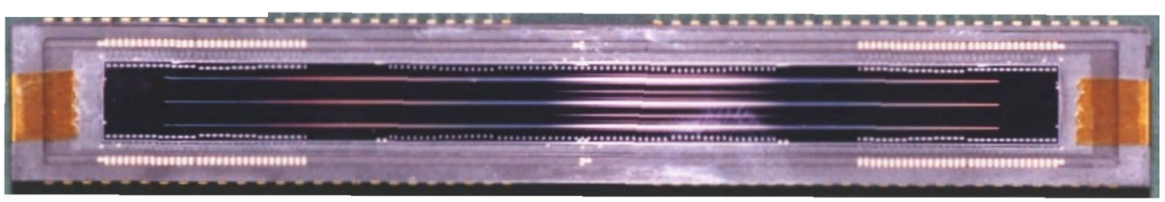


Single Line Camera

Line Cameras

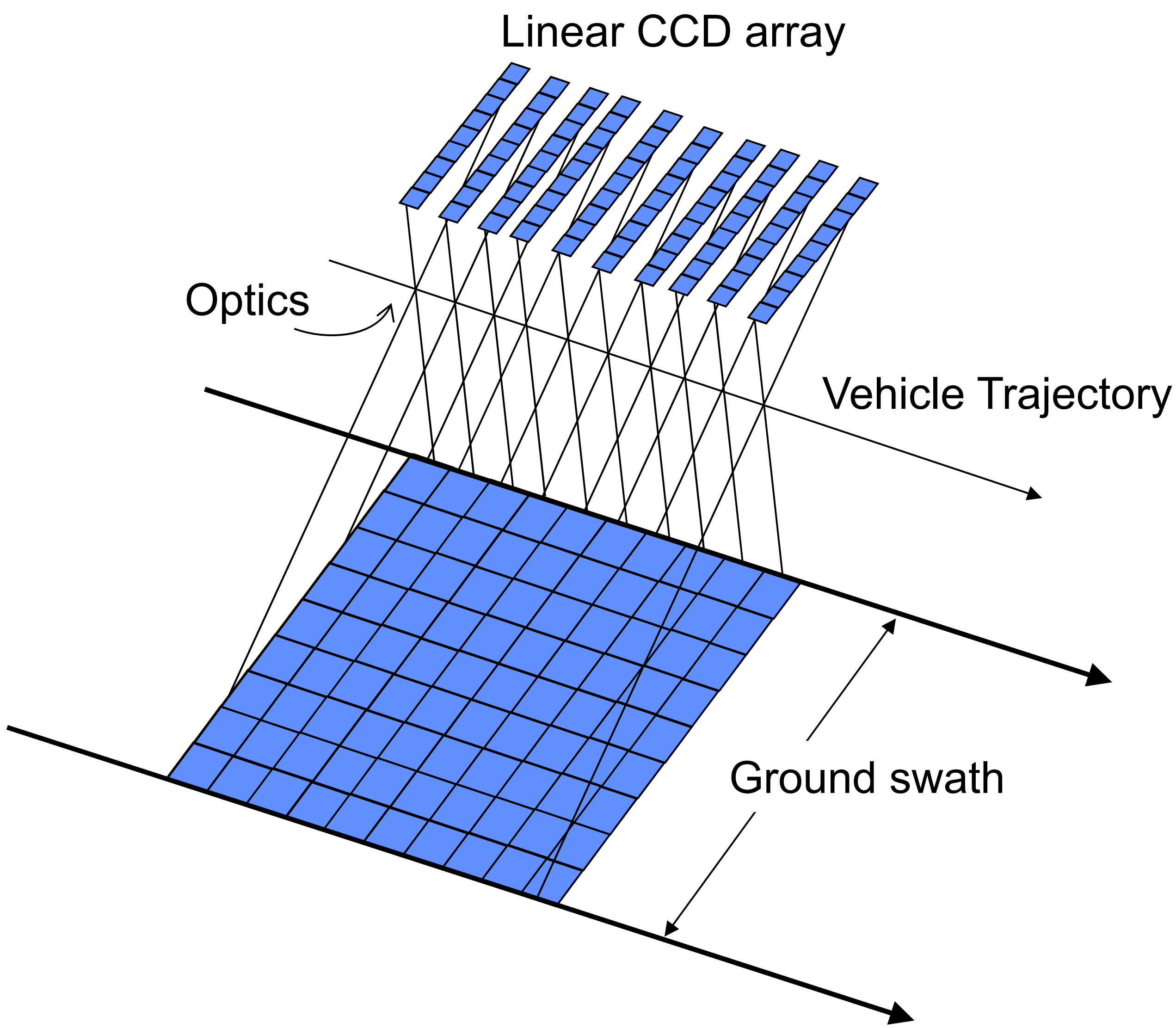


http://www.teledynedalsa.com/images/sensors/Il-cc_198w.jpg



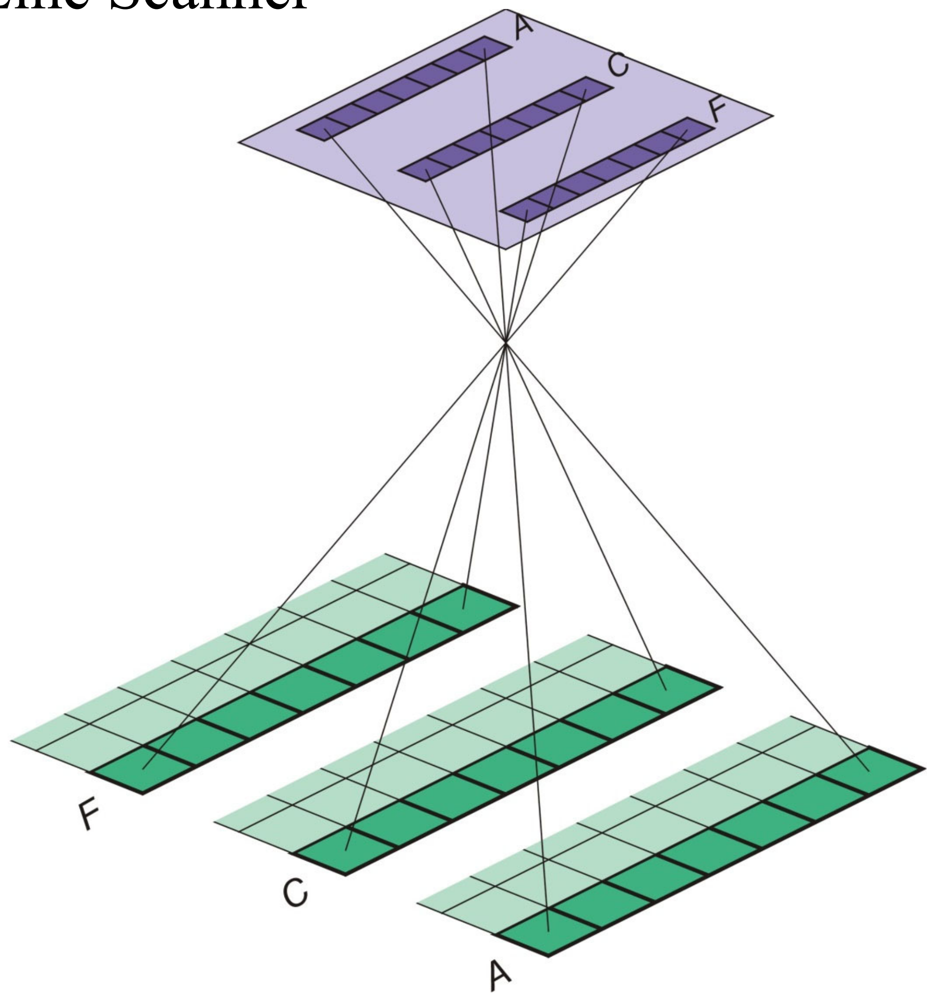
Single CCD line in the image plane

Line Camera & Data Acquisition



Digital Aerial Camera: ADS 40

Three Line Scanner



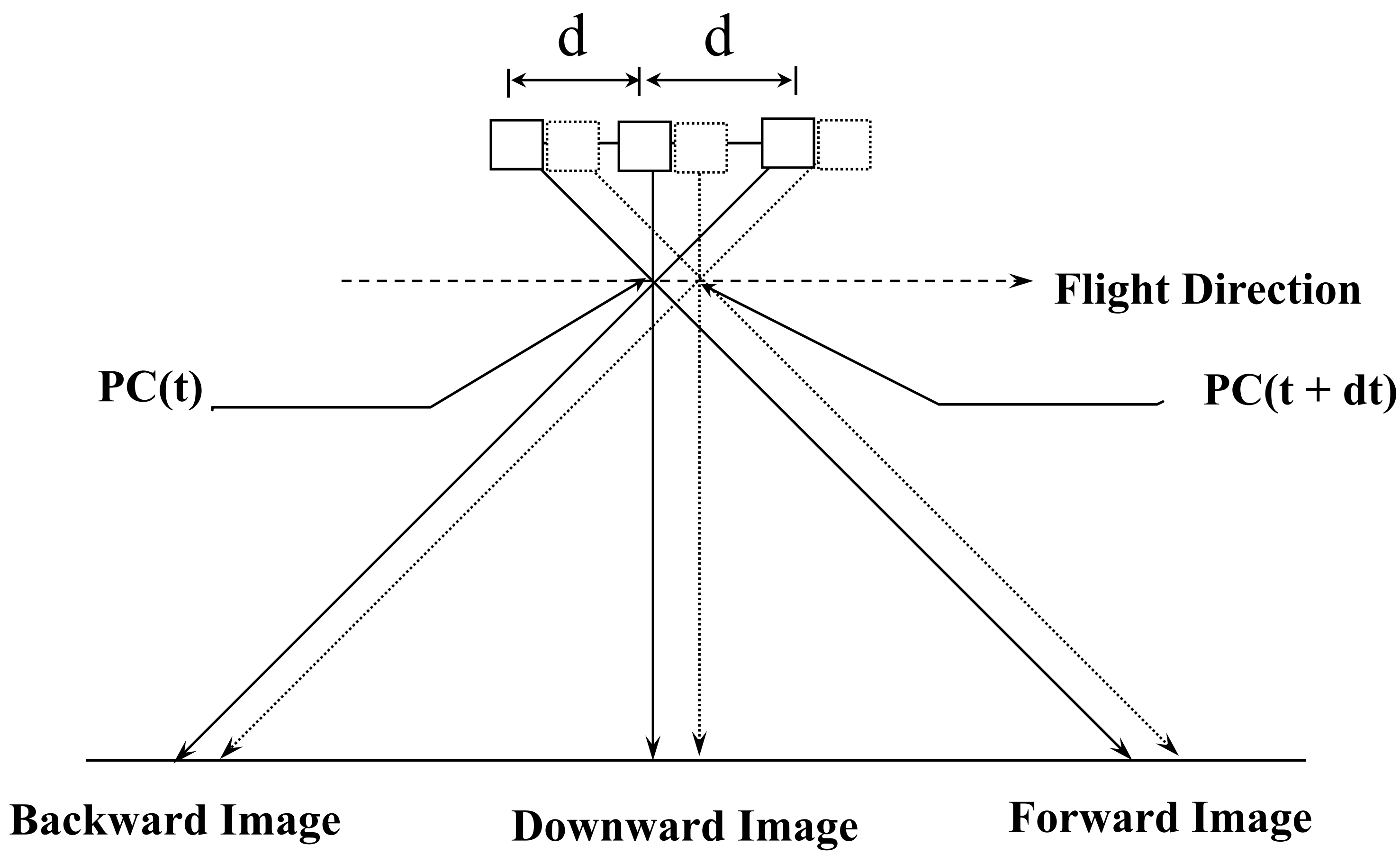
http://ptd.leica-geosystems.com

Digital Aerial Camera: ADS 100

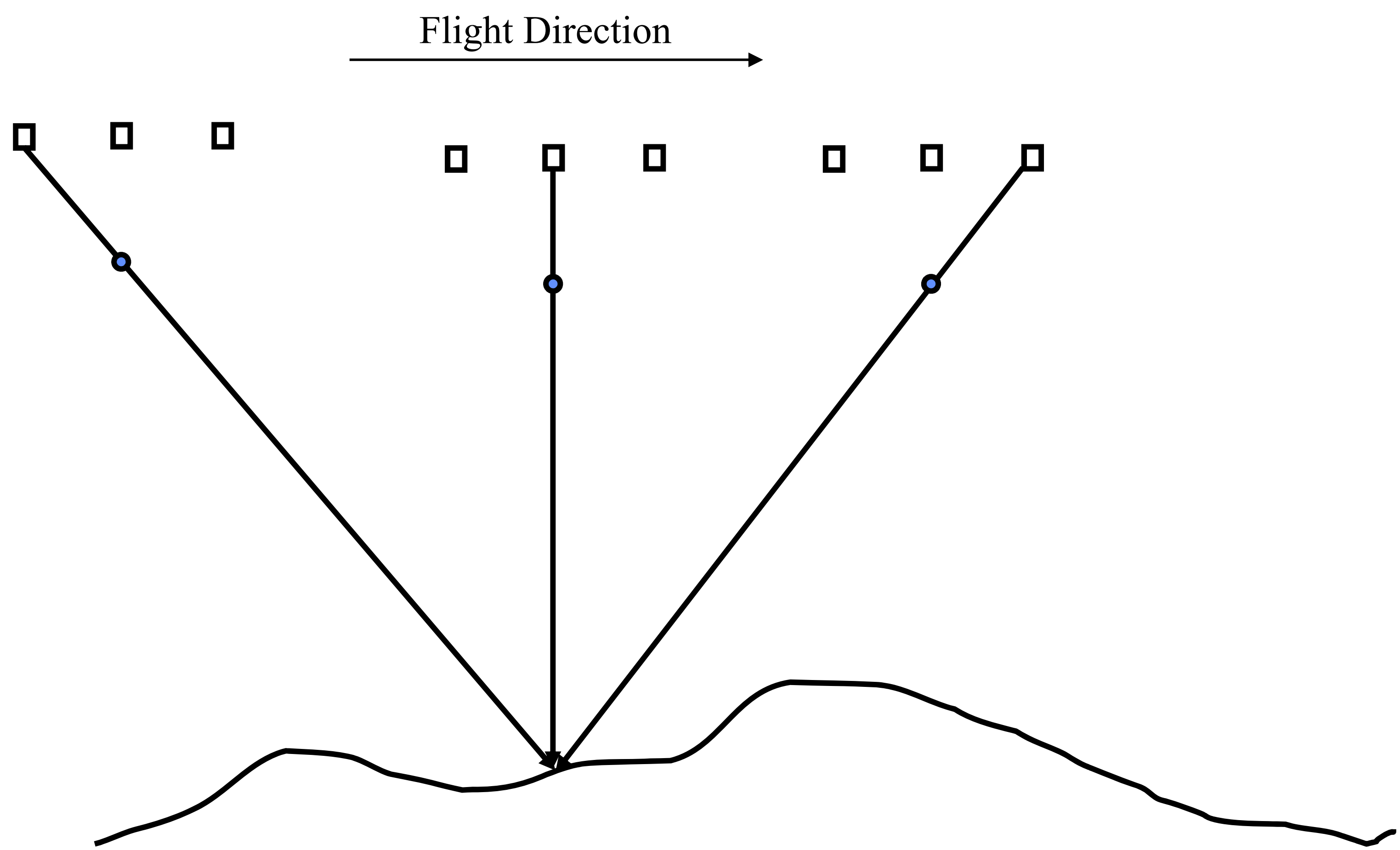
Source: LeicaGeosystems

Three-Line Camera: ADS 100 (Leica Geosystems)

Digital Aerial Camera – ADS 100 (**Triple Coverage**)



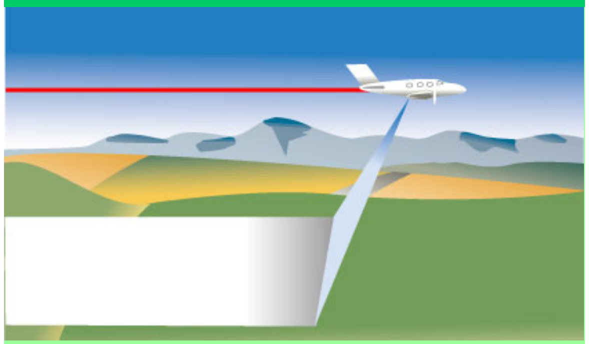
Digital Aerial Camera – ADS 100 (**Triple Coverage**)



- Triple coverage is achieved by having three scanners in the focal plane.

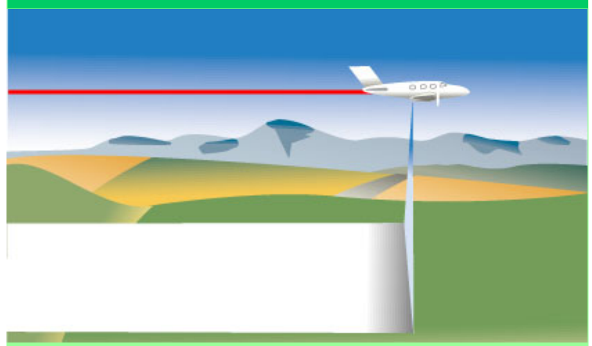
Digital Aerial Camera – ADS 100 (**Triple Coverage**)

Backward scene



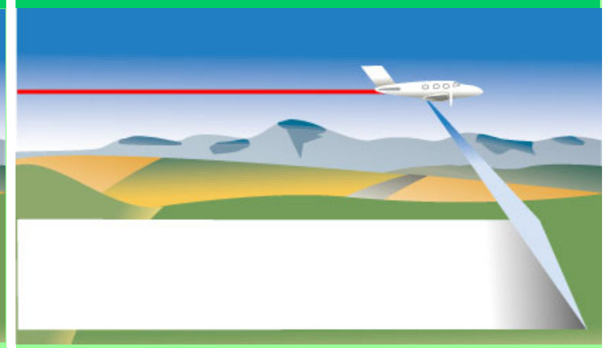
composed of backward view lines

Nadir scene

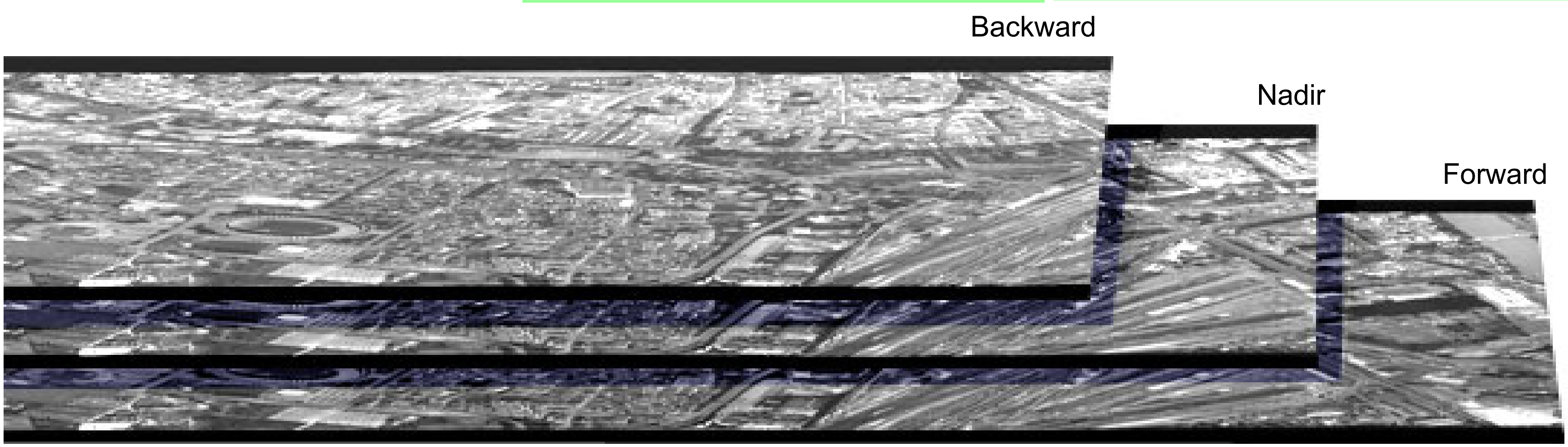


composed of nadir view lines

Forward scene

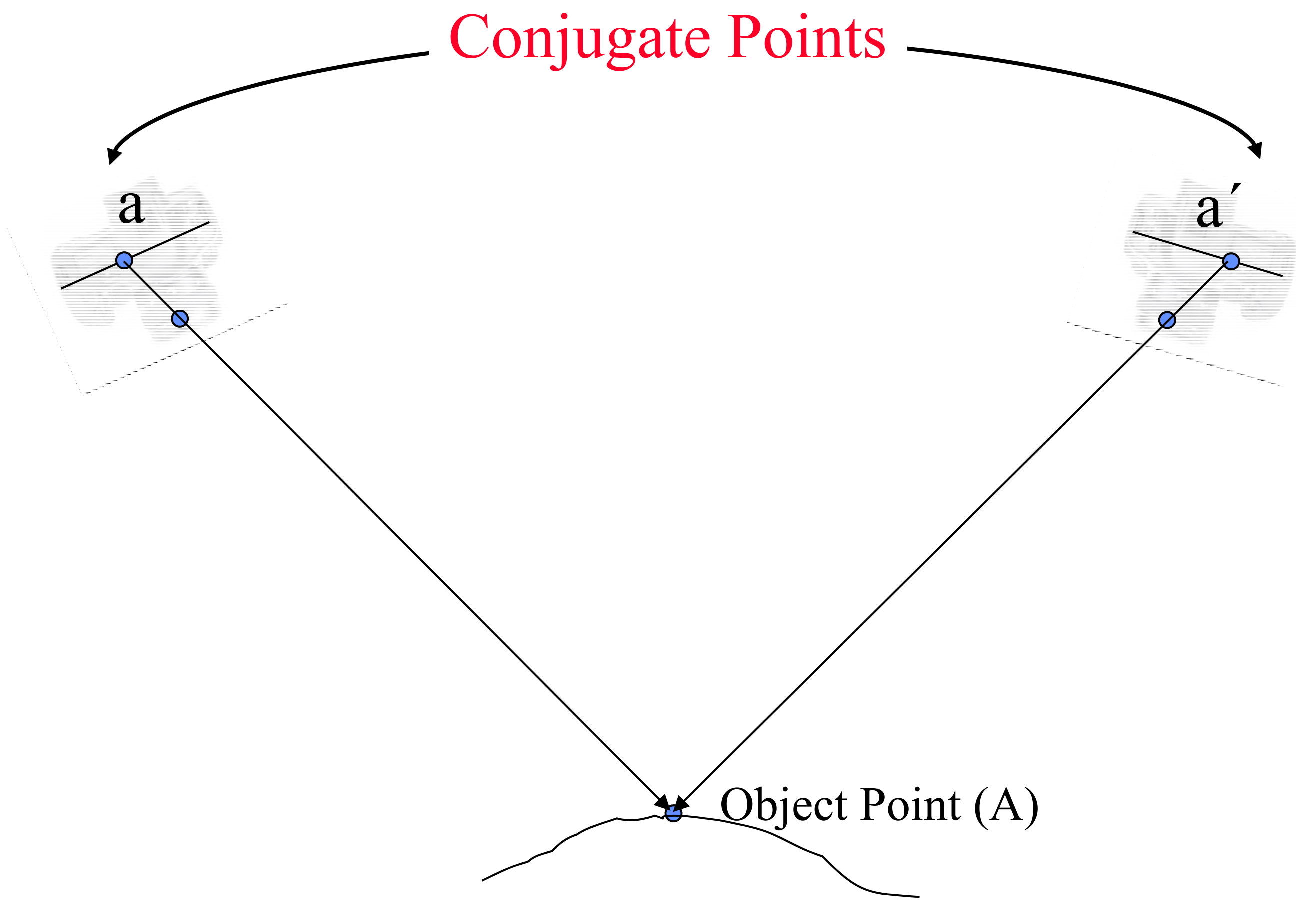


composed of forward view lines



http://ptd.leica-geosystems.com

Photogrammetric Reconstruction

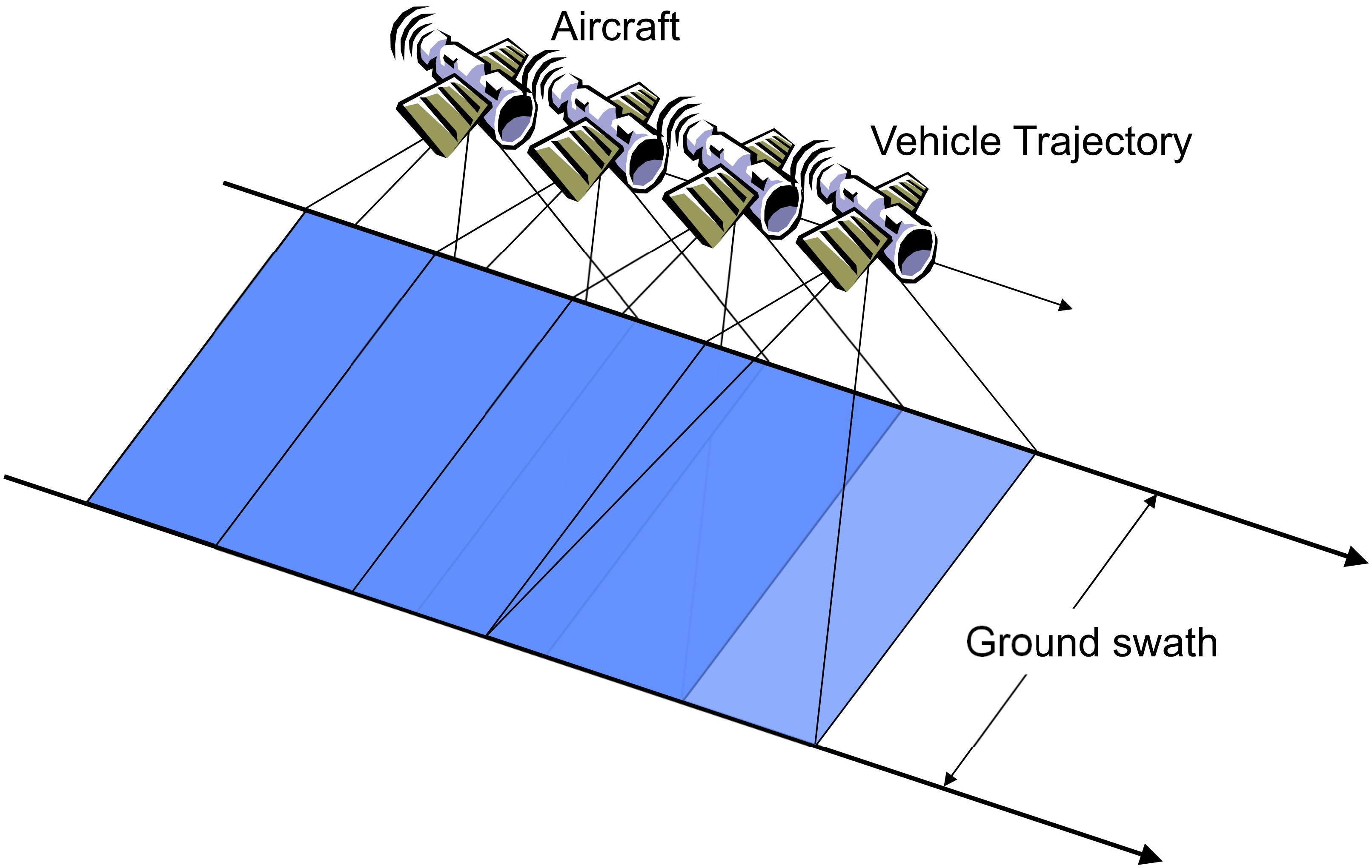


- Stereo coverage is essential for photogrammetric reconstruction.

Photogrammetric Reconstruction

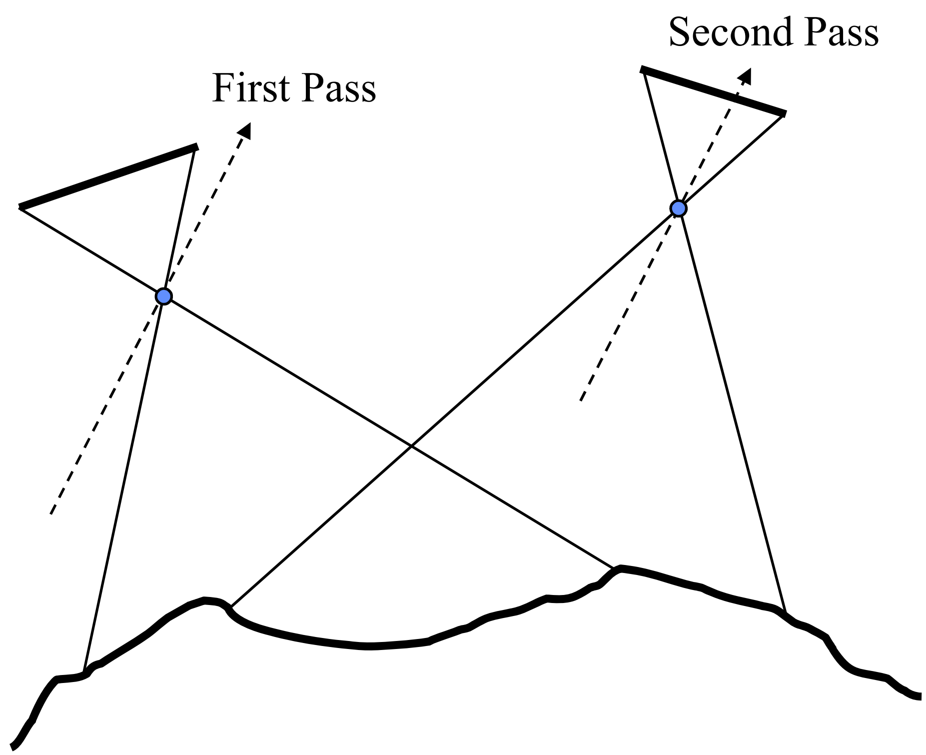
- Photogrammetric reconstruction ≡ deriving 3-D information from 2-D imagery.
- Photogrammetric reconstruction is possible if and only if stereo coverage is available.
- For frame cameras:
  – Stereo coverage from <u>successive images</u> along the same flight line is possible.
    - Common overlap percentage = 60%.
- For line cameras:
  – Stereo coverage from <u>successive images</u> along the same flight line is not possible.
  – Alternative methodologies are needed for stereo coverage.

Frame Camera: Stereo Coverage



Frame Camera: Stereo Coverage

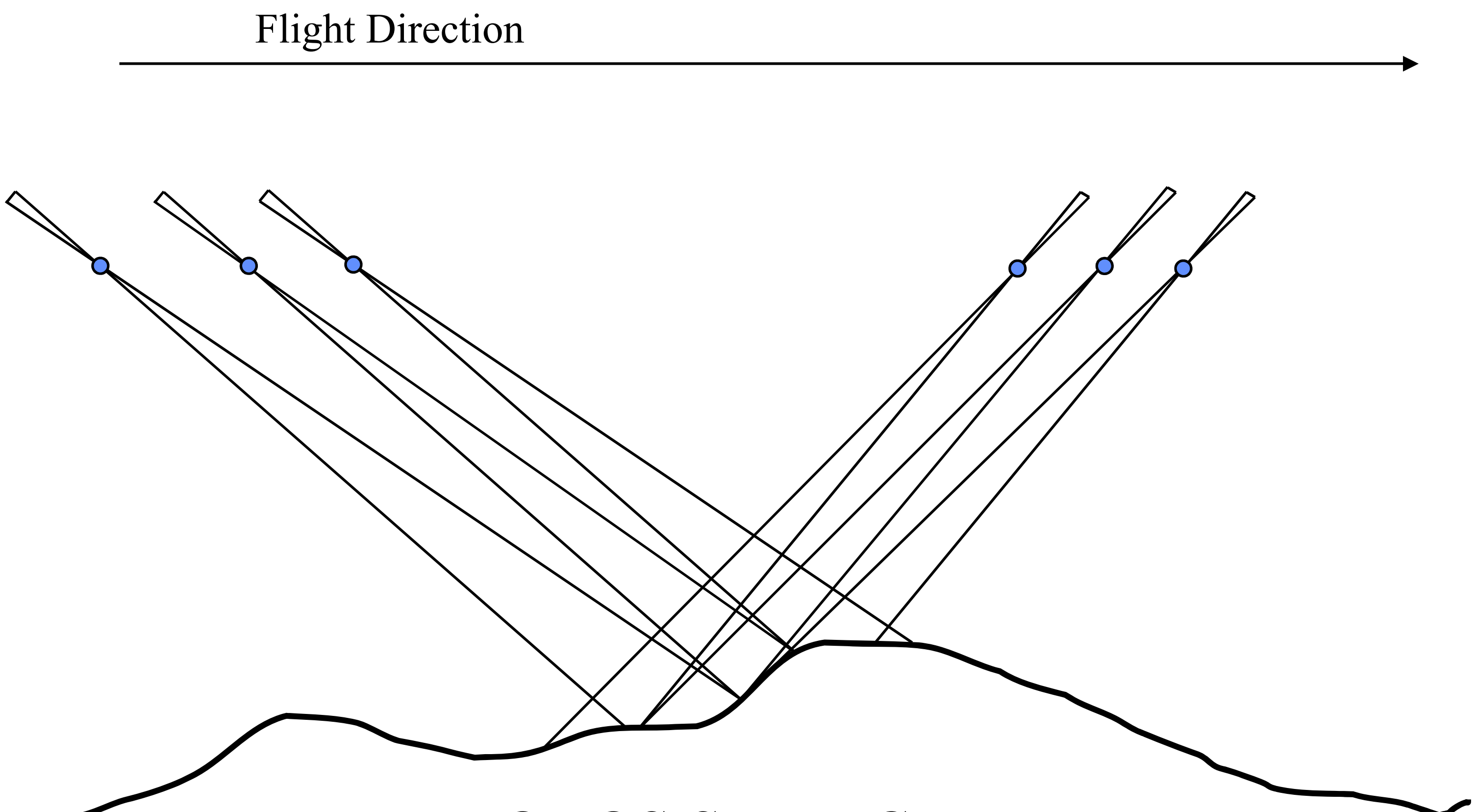
Line Camera: Stereo Coverage - I



SPOT Stereo Coverage

- Stereo coverage is achieved by tilting the sensor across the flight direction.

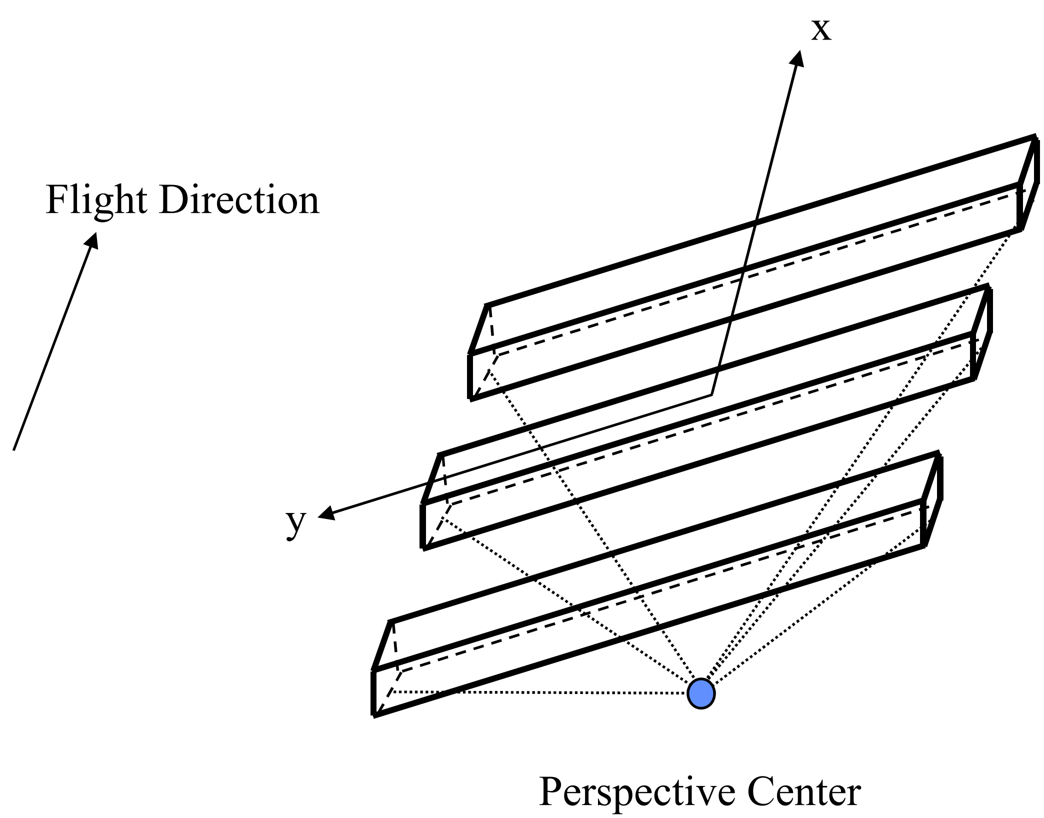
Line Camera: Stereo Coverage - II



IKONOS Stereo-Coverage

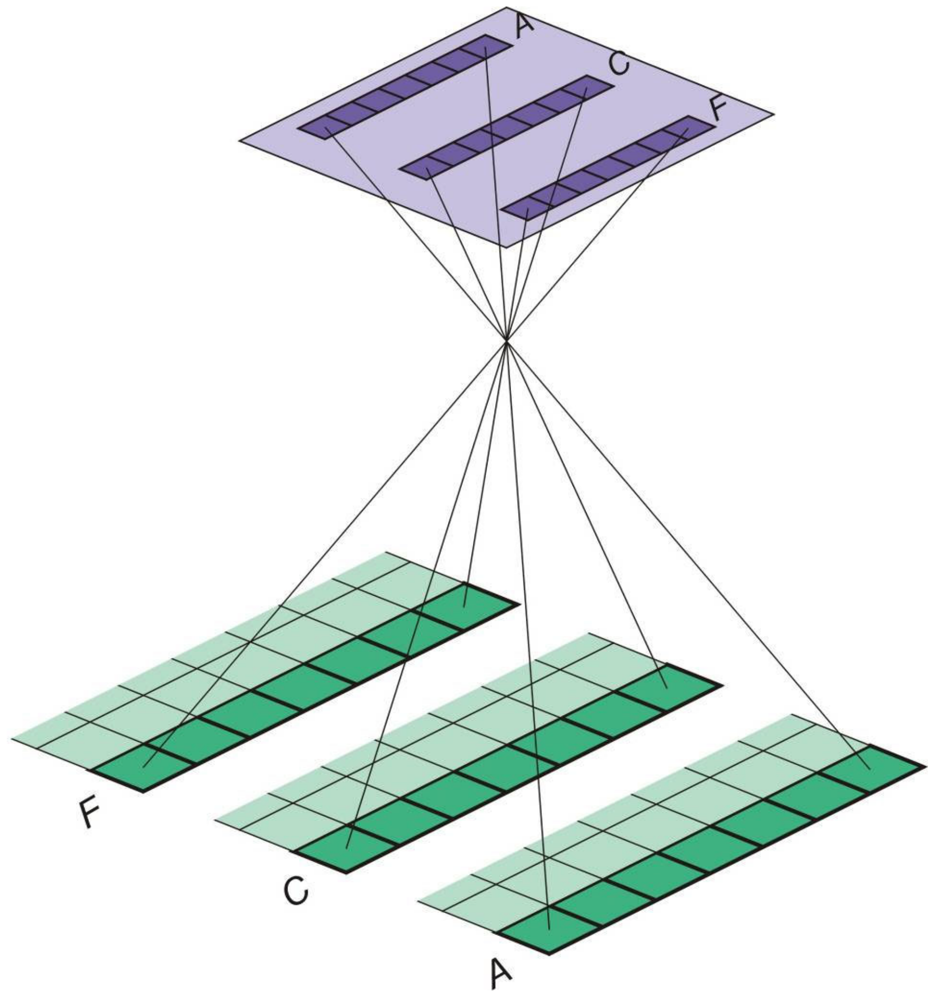
- Stereo coverage is achieved by tilting the sensor along the flight direction.

Line Camera: Stereo Coverage - III



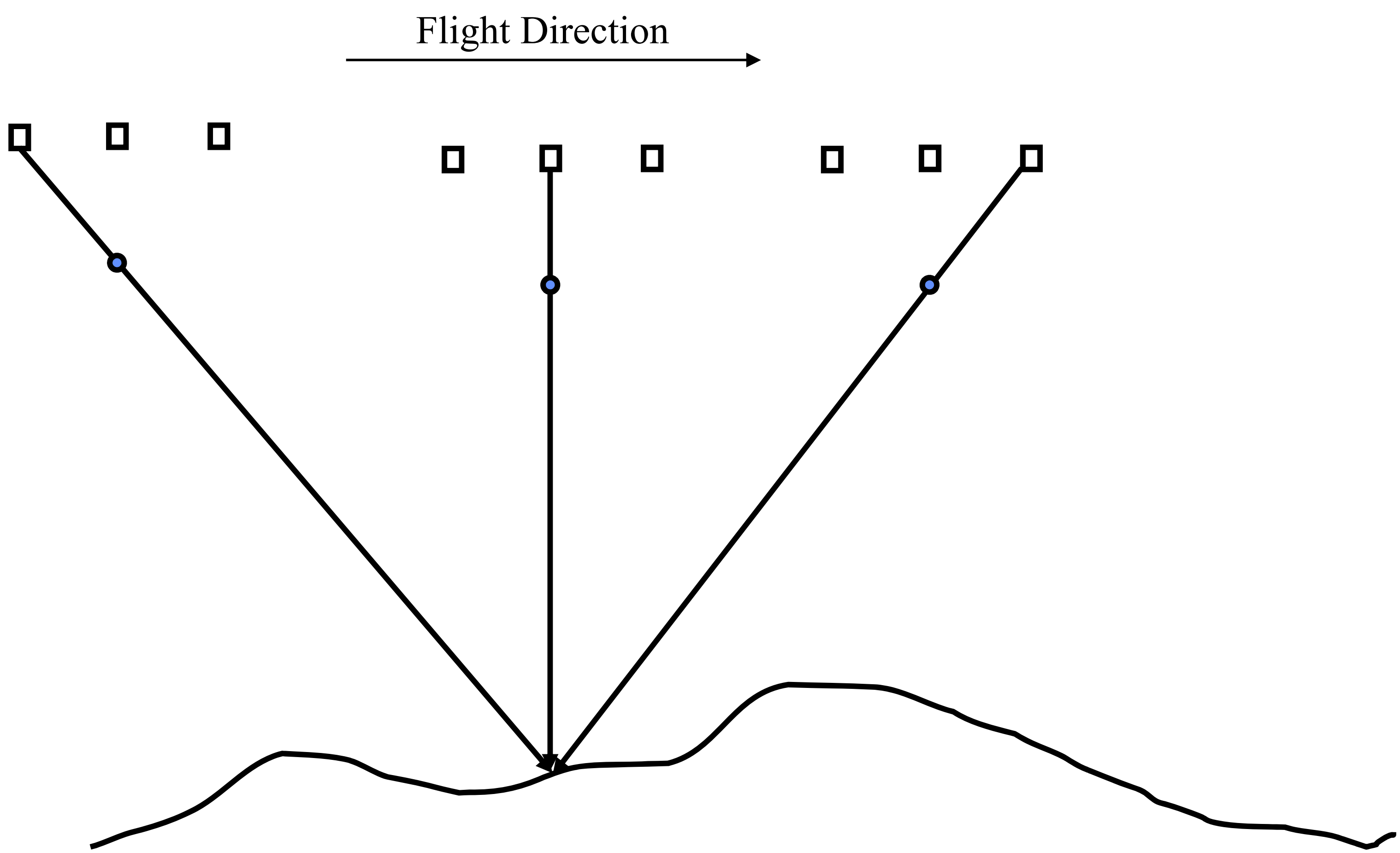
Three-Line Scanner

Line Camera: Stereo Coverage - III



Three-Line Scanner

Line Camera: Stereo Coverage - III



- Triple coverage is achieved by having three scanners in the focal plane.

Line Camera: Stereo Coverage

- Stereo coverage can be obtained through:
  - Tilting the sensor across the flight direction (SPOT)
    - The stereo is captured in two different orbits/flight lines.
    - Problem: Significant time gap between the stereo images (possible variations in the object space and imaging conditions)
    - Problem: Non-continuous stereo-coverage
    - Problem: Variation in the scale along the scan line
  - Tilting the sensor along the flight direction (IKONOS)
    - The stereo is captured in the same orbit/flight line.
    - Short time gap between the stereo images (few seconds)
    - Problem: reduced geometric resolution [scale = $f * \cos(\alpha) / H$]
    - Problem: Non-continuous stereo coverage

Line Camera: Stereo Coverage

- Stereo coverage can be obtained through:
  - Implementing more than one scan line in the focal plane (MOMS & ADS 40)
    - The stereo scenes are captured along the same flight line.
    - For three-line scanners, triple coverage is possible.
    - Short time gap between the stereo images (few seconds)
    - Continuous stereo/triple coverage
    - Same geometric resolution (scale = f/H)
    - Problem: Reduced radiometric quality for the forward and backward looking scanners (quality degrades as we move away from the camera optical axis)
      - Can be compensated for by a calibration procedure