Remote Sensing 1: GEOG 4/585

Lecture 3.1.

Sensors

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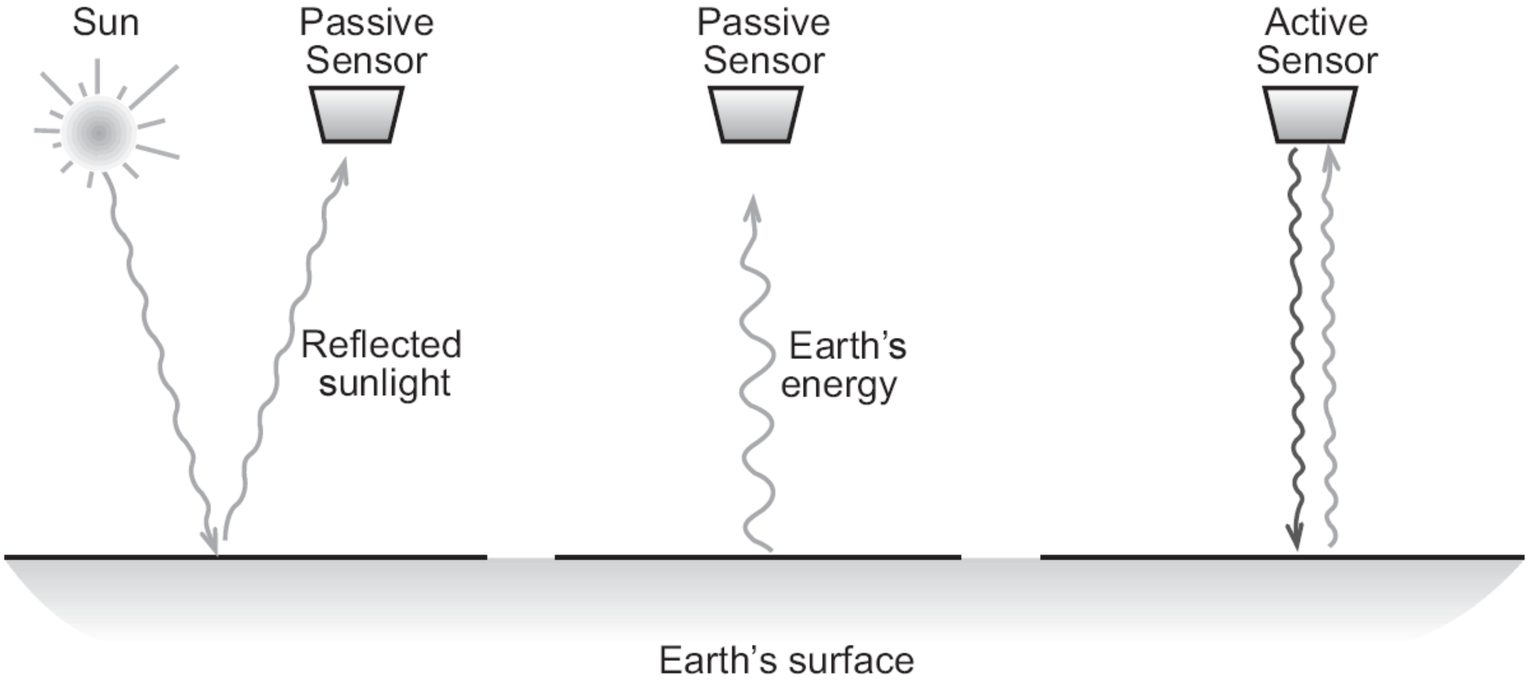
Required reading:
Principles of Remote Sensing pp 86-97
Principles of Remote Sensing pp 106-160

Overview

- Three main types of multispectral image sensing
- Image geometry, dwell time, signal-to-noise ratios
- Ground sampling distance, footprint, spatial resolution

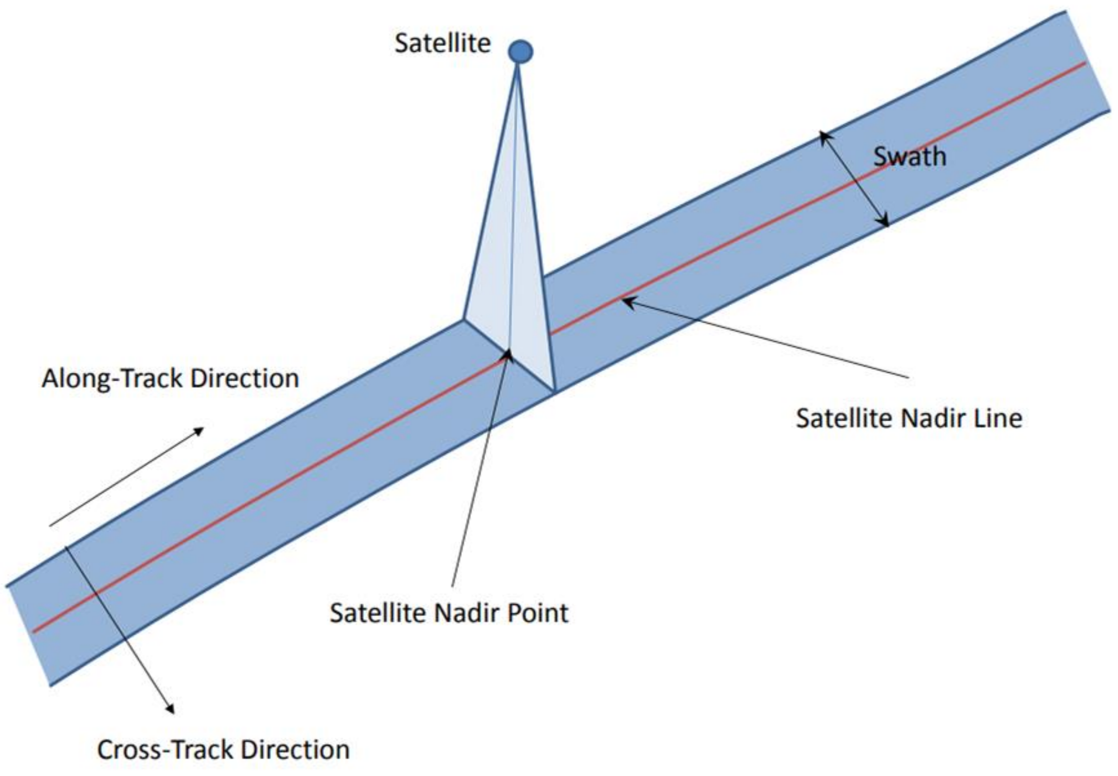
Classification of sensing systems



Three mains types of imaging systems

- Framing cameras
  - e.g. iPhone camera, digital camera, Planet Doves
- Whiskbroom scanner
  - e.g. older instruments like MODIS or Landsat 1-7
- Pushbroom or line scanner
  - e.g. newer instruments like Landsat 8, Landsat 9

Concept 1: imaging geometry

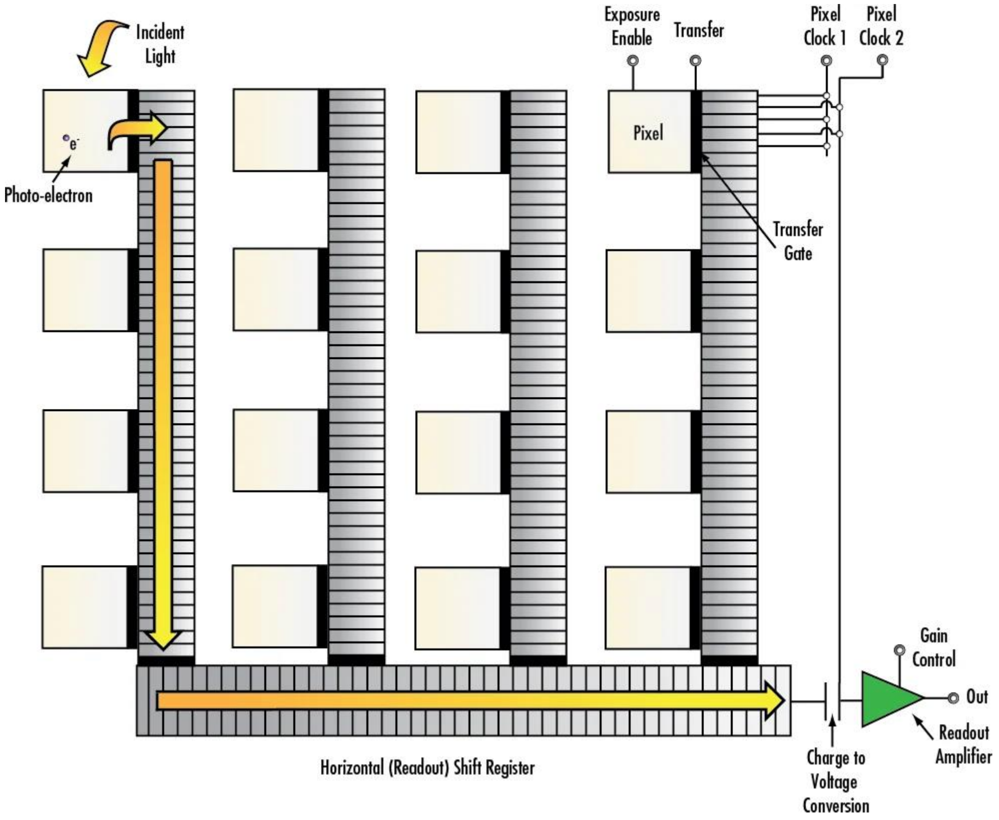


Framing cameras: charge-coupled devices

- At the heart of any camera is a sensor

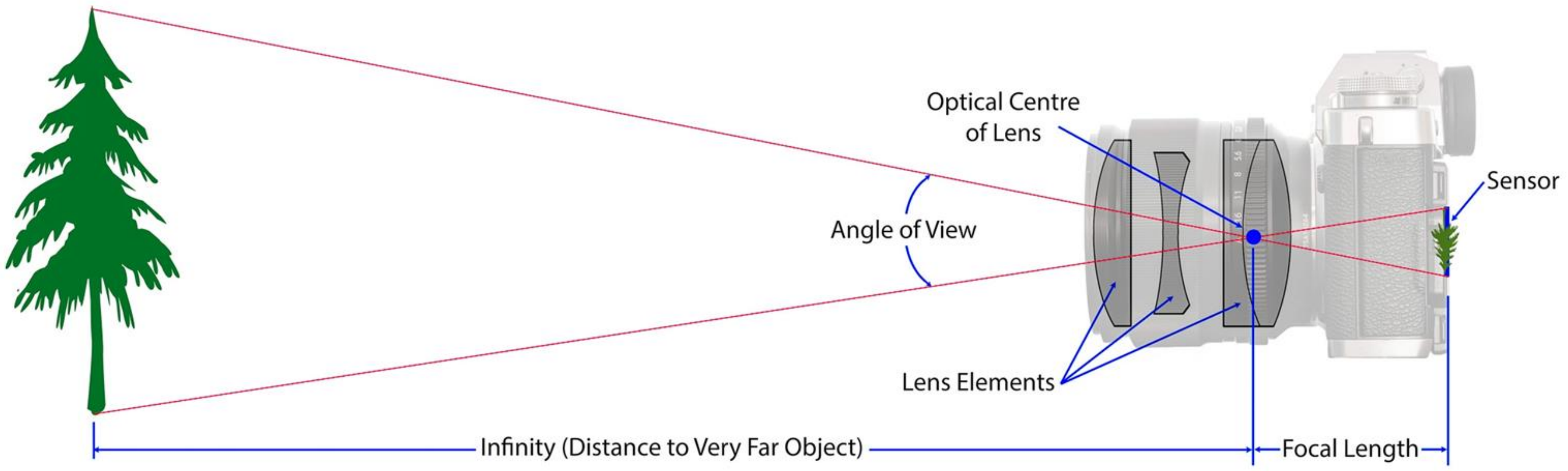
- Modern sensors are solid-state electronic devices containing up to millions of discrete photodetector sites called pixels

- The CCD sensor is a silicon chip that contains an array of photosensitive sites



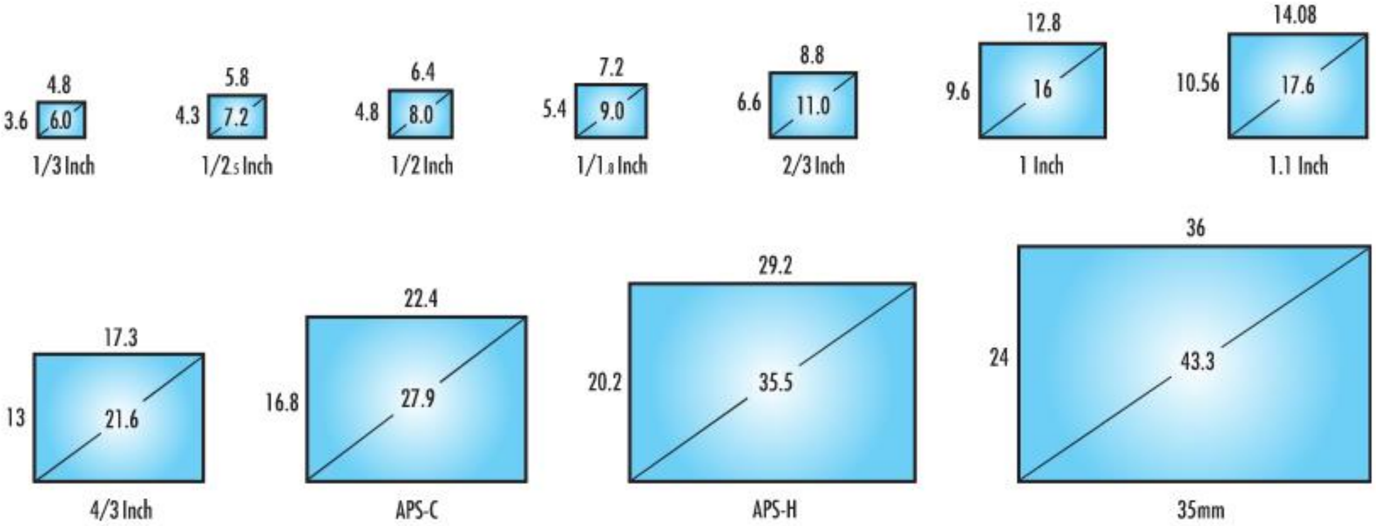
Framing cameras: focal length

- Lenses are used to focus light onto the sensor
- Focal length is the distance between the lens and the sensor



Framing cameras: sensor and pixel size

- The size of a camera sensor's active area is important in determining the system's field-of-view (FOV).
- Given a fixed primary magnification (determined by the imaging lens), larger sensors yield greater FOVs.

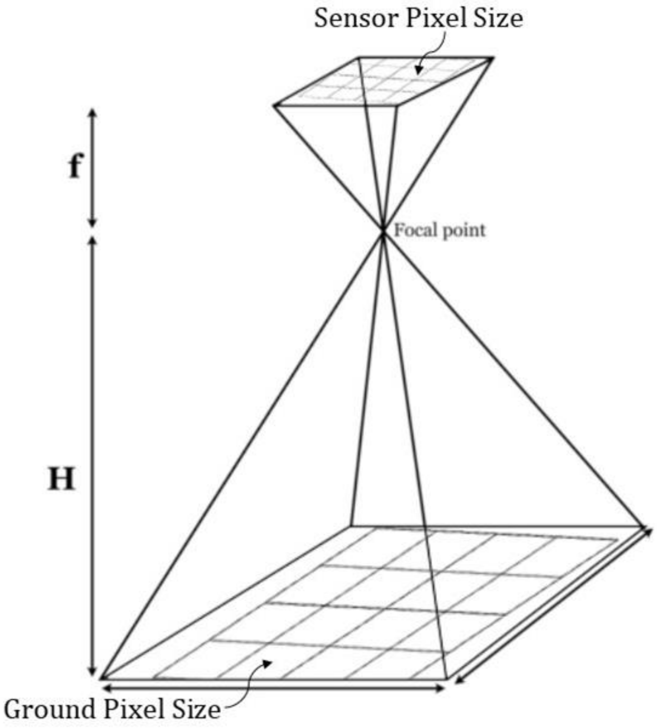


Framing camera: Ground footprint and sampling distance (GSD)

- Ground footprint and sampling distance of a framing camera are proportional to sensor size, sensor pixel size, focal length, and height above ground

- GSD = (height * sensor width) / (focal length * image width)

- Footprint = (GSD * image width) / height



Framing camera: Ground footprint and sampling distance (GSD)

- GSD = (height * sensor width) / (focal length * image width)
- Footprint = (GSD * image width) / height

A standard digital camera on a plane:

GSD = (100 m * 13 mm) / (15 mm * 4608 pixels) = 1.8 cm / pixel
Footprint = (1.8 cm * 4608 pixels) / 100 m = 83 m

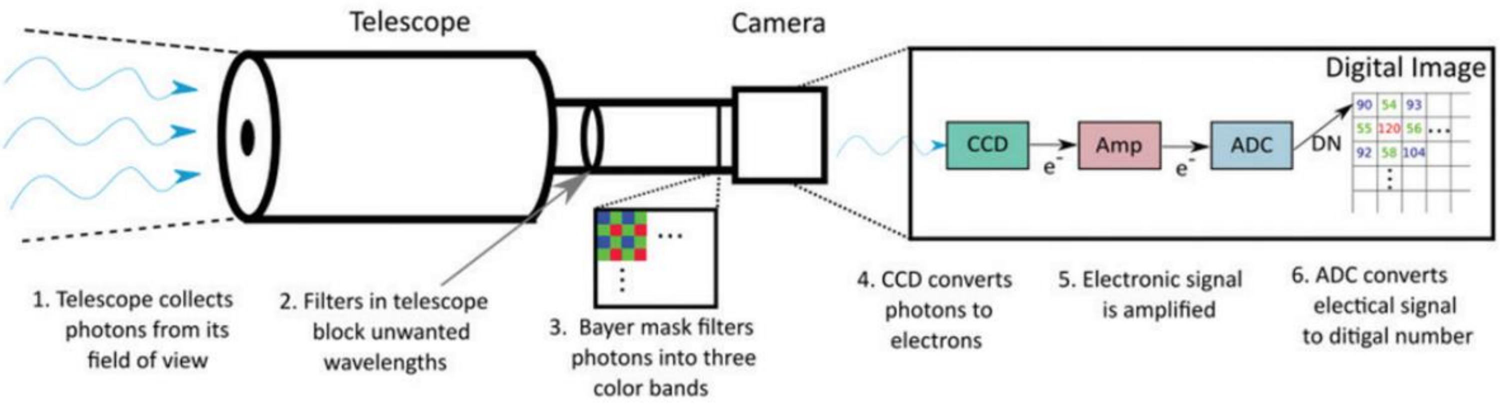
A standard digital camera on a satellite:

GSD = (705 km * 13 mm) / (15 mm * 4608 pixels) = 132 m / pixel
Footprint = (132 m * 4608 pixels) / 705 km = 611 km

Framing cameras

- For high resolution imagery, framing cameras on satellite platforms need:
  - Large focal lengths or
  - Large sensors with many thousands of photodetectors

- IKONOS famously had 10 m focal length and 80 cm/pixel resolution imagery in 1999
  - GSD = (height * sensor width) / (focal length * image width)
  - GSD = (680 km * 160 mm) / (10 m * 13500 pixels) = 80 cm / pixel



But framing cameras are not common in space...

- Due to difficulties in fabricating detector arrays of sufficient size and quality
- Also only narrow range of wavelengths because of reliance on silicon-based semiconductors which are only sensitive to visible and near-IR spectra.
- IKONOS was only sensitive to 400-900 nm wavelengths i.e. visible near-infrared wavelengths
- More recent Planet Dove satellites are only sensitive in 490-865 nm range

Whiskbroom scanner (across-track)

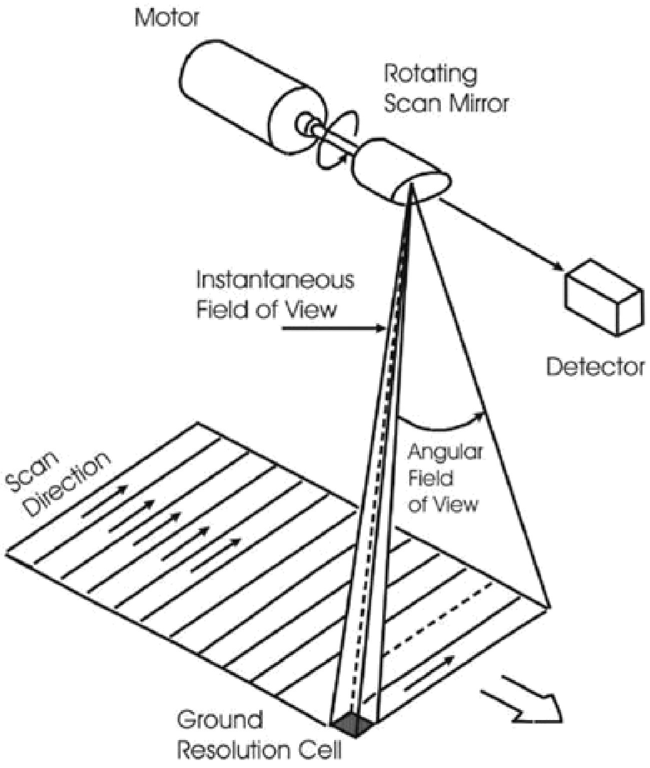
Rotating mirrors scan the landscape from side to side reflecting light into a single photodetector, one or a few pixels at a time.

Advantages: simple optical system, few detectors to calibrate, easy to record many wavelengths by splitting single beam of light, wide swath width

Disadvantages: complex to build, moving parts make it more likely to fail, short dwell time = high SNR

Examples: Landsat (1-7); MODIS; AVIRIS

https://svs.gsfc.nasa.gov/12754



Concept 2: signal-to-noise ratio

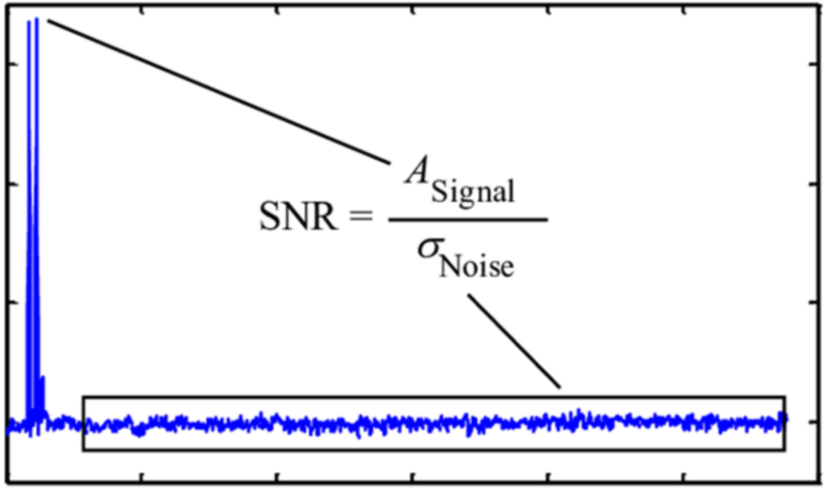
- The ratio between signal reaching the detectors and signal produced by the electronics of the sensor (noise):

- SNR = S(ignal)/N(oise)

- S is directly proportional to the light/EMR intensity, N is a “constant” in the sensor

- As SNR decreases, small differences in light/EMR intensity are more difficult to detect

- You would like to have a large SNR ratio (strong signal, low noise)



Concept 3: dwell time

- Length of time spent collecting photons, depends on:
  - Satellite speed
  - Width of scan line
  - Time per scan line
  - Time per pixel

- Analogous to shutter speed of camera and “exposure”

- More time allows more photons to be detected

- As dwell time increases, signal increases, increasing signal-to-noise ratio (SNR)

Dwell time for whiskbroom sensor example

(down track pixel size / orbital velocity)
(cross-track line width / cross-track pixel size)

dwell time = (30 m / 7500 m/s) / (185000 m / 30 m)
= 6.5×10^{-7} seconds/pixel

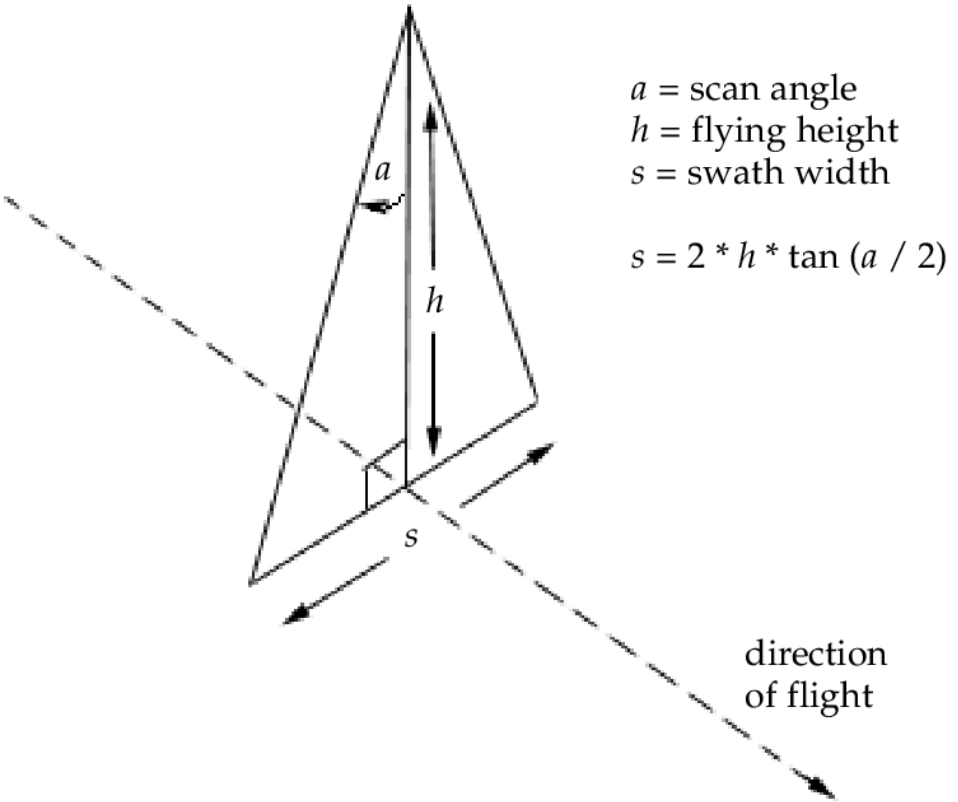
This is a very short time per pixel -- low SNR

Swath width for whiskbroom sensor

FOV = 2 * H * tan(scan angle)
H = satellite altitude

<u>Example</u>:
MODIS satellite altitude = 710 km
Scan angle = 55°
FOV = 1420 x tan(0.96) = ~2100 km

POINT: Swath width of whiskbroom sensors can be large



Pushbroom scanner (along-track)

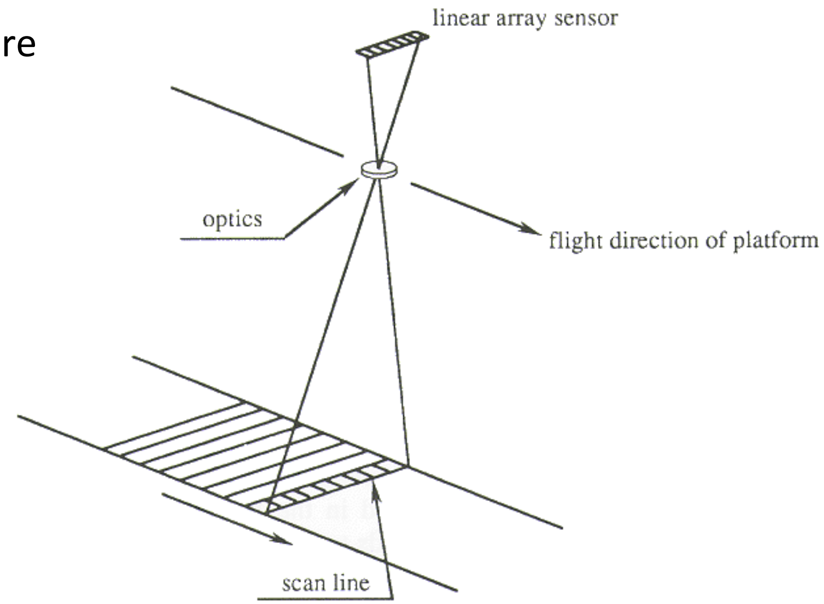
Photodetectors aligned in linear arrays, capturing the entire scan line at once

Examples: Landsat 8 and 9; Sentinel-2; ASTER; SPOT; Hyperspectral sensors

<u>Landsat 8</u>
GSD = (height * sensor width) /
(focal length * image width)

GSD = (705 km * 300 mm) / (886 mm * 8000 pixels)
= 30 m

https://svs.gsfc.nasa.gov/12754



Installing Landsat 8's 14-module detector array

Dwell time for pushbroom sensor example

(down track pixel size / orbital velocity)
(cross-track line width / cross-track pixel size)

dwell time = (30 m / 7500 m/s) / 1
= 4 x 10^{-3} seconds/pixel

Longer dwell time per pixel -- high SNR

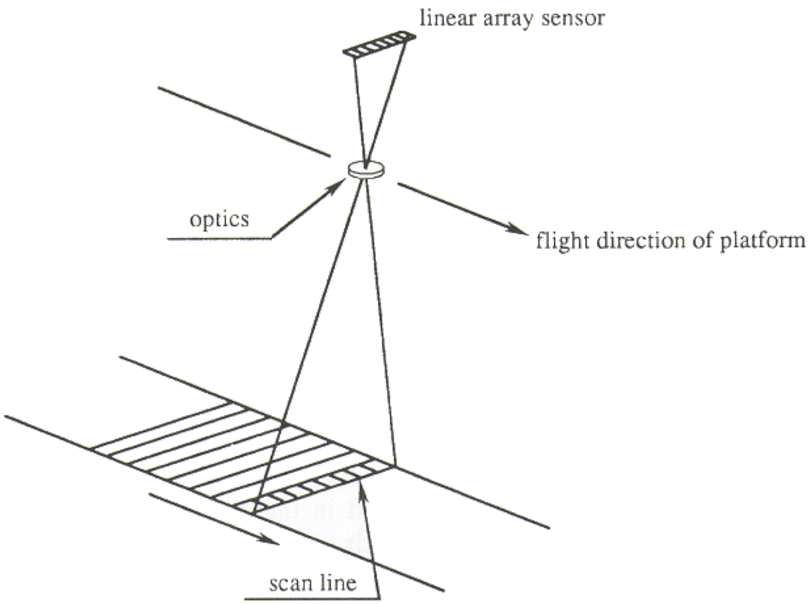
(compared with 6.5 x 10^{-7} seconds/pixel for whiskbroom sensor)

Pushbroom scanner (along-track)

Photodetectors aligned in linear arrays, capturing the entire scan line at once

Advantages: simple mechanical systems, better radiometric resolution, longer dwell time

Disadvantages: complex optical system, photodetectors have to be well-calibrated to each other, narrow swath width



Summary

Framing camera (2D array)

- Each pixel of image is acquired with a different detector
- Longest dwell time
- Highest spatial and radiometric resolution

Whiskbroom Sensor (1D array)

- Each pixel in each spectral image is acquired with the same detector
- Artifacts are relatively simple and easier to correct
- Short dwell time
- Relatively low spatial resolution

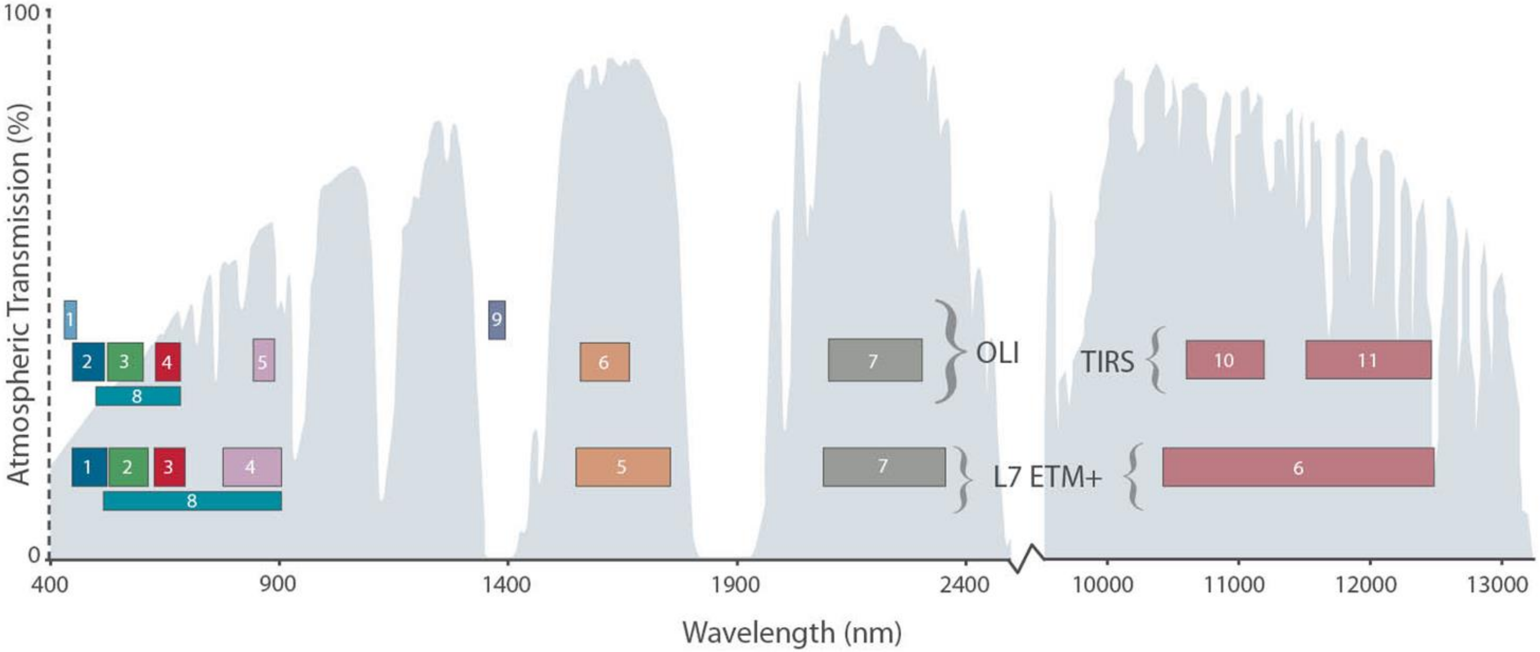
Pushbroom Sensor (2D linear array)

- Each column of each spectral image is acquired with a different detector
- Long dwell time
- Higher spatial and radiometric resolution

Examples

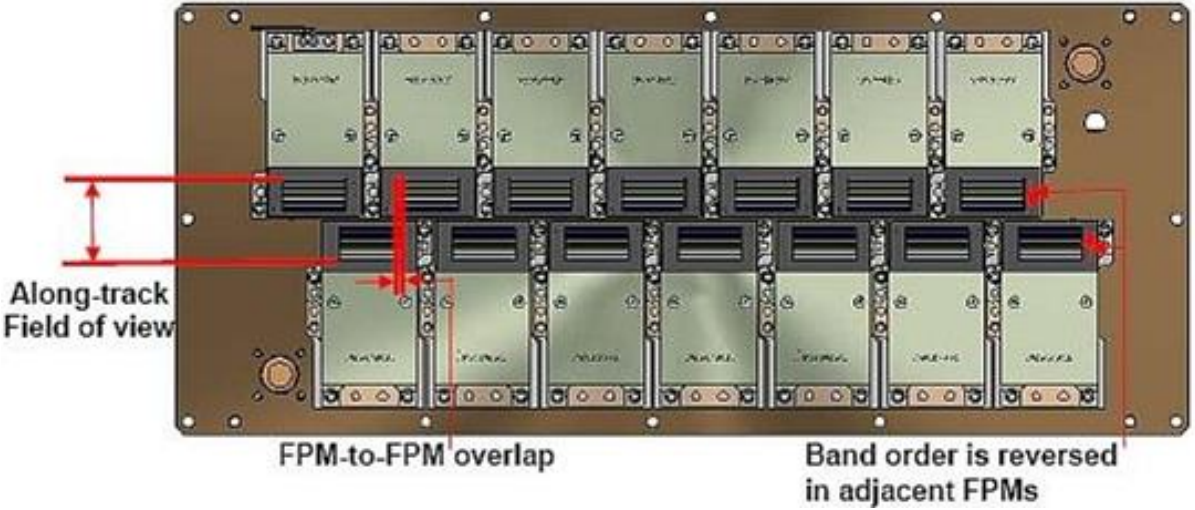
Satellite	**Sensor**	Type	**Orbit altitude**	**Swath width**	**Pixel resolution**
Terra	MODIS	Whiskbroom	713 km	2,330 km	500 m
Landsat 5	MSS	Whiskbroom	705 km	185 km	30 m
Landsat 7	ETM+	Whiskbroom	705 km	185 km	30 m
Landsat 8/9	OLI	Pushbroom	705 km	185 km	30 m
Sentinel-2	MSI	Pushbroom	786 km	290 km	10 m
Planet Dove	PS0/1/2	Framing camera	400 km	20 km	4 m

What about bands?



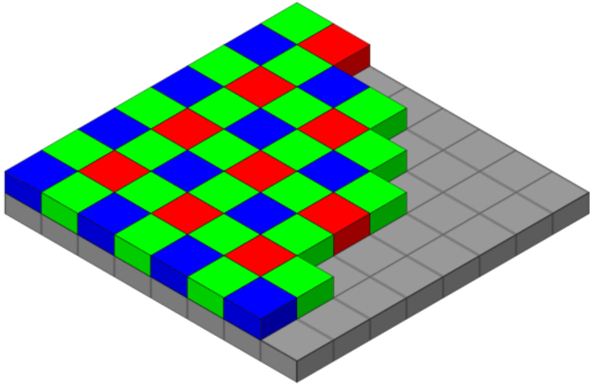
Pushbroom sensor

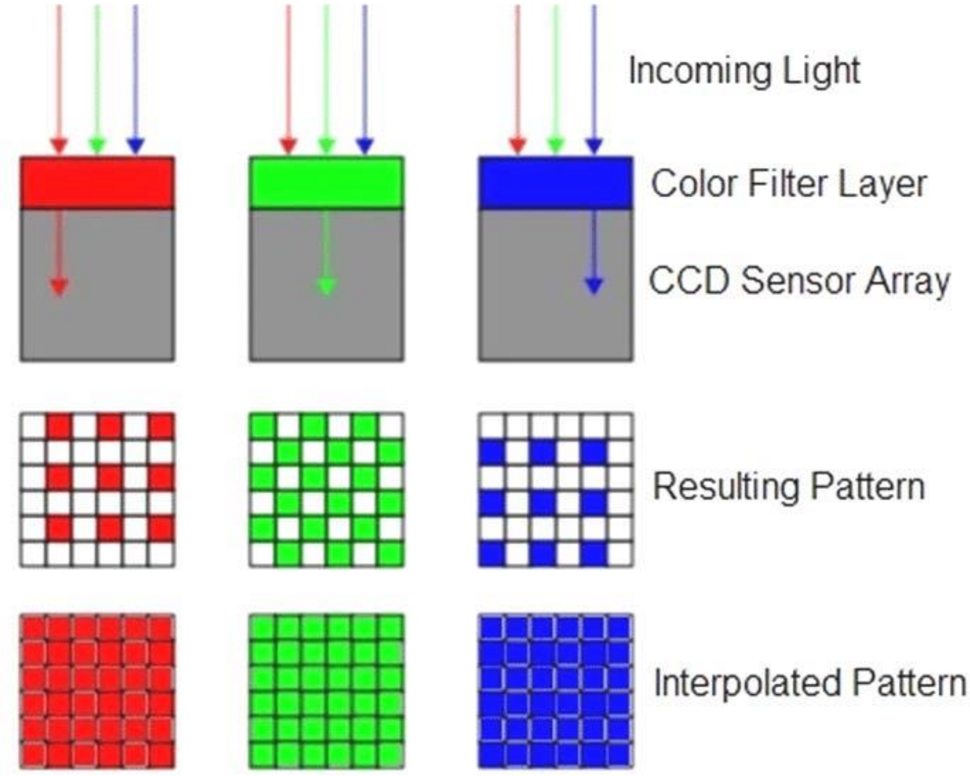
- 14 Focal Plane Modules (FPM), each containing nine spectral bands
- ~500 multispectral detectors within each FPM so 7000 active detectors per multispectral band



Framing cameras: Bayer Filter

- The detector has a Bayer pattern filter separating the wavelengths of light into blue, green and red channels
- We have to interpolate to derive RGB values for each pixel





Summary

- Three main types of multispectral image sensing
  - Framing cameras
  - Whiskbroom sensors
  - Pushbroom sensors or line-scanners

- Image geometry, signal-to-noise ratios, dwell time

- Ground sampling distances, ground footprints, spatial resolution

- Sensing in different bands