Satellites and Sensors:
How they work

18 April 2003
Outline

• Satellite and their orbits
• Sensor types
  whiskbroom scanners
  pushbroom scanners
• Example of pixel size calculation
How Satellites Work

• Launch -- how do they get up there?
• To put a satellite into a stable orbit, need to overcome gravitational attraction and the resistance of the lower atmosphere
A rocket of initial mass, $M_i$, burning a mass of fuel $M_f$ will increase its velocity, $\Delta V$, by

$$\Delta V = U \ln\left(\frac{M_i}{M_i - M_f}\right)$$

where $U$ is the velocity of the exhaust gases with respect to the rocket.

$U = 2.4 \text{ kms}^{-1}$

Orbital velocity of a satellite is about $7\text{kms}^{-1}$

Rocket must be about 97% fuel
Payload can only be about 3% of rocket mass
Terra launch
Vandenberg AFB
18 December 1999
Description Satellite Orbits

• Determined by Kepler’s Laws
  – perturbed by gravitational irregularities, friction, solar pressure, etc.
  – ranging and repositioning is required for satellites to maintain their orbit

• The orbital period is the time it takes for the satellite to circle the earth

• Easy to compute if assume the earth is a sphere but earth is an oblate ellipsoid
  – creates an orbit that precesses (it rotates around the polar axis)
Special Orbits

Orbital parameters can be tuned to produce particular, useful orbits

• Geostationary
• Geosynchronous
• Sun synchronous
• Altimetric
Geostationary Orbits

• Orbit is stationary with respect to a location on the earth
• Circular orbit around the equator (orbital inclination = zero)
• The orbital period is equal to the earth’s rotation (for a sidereal day, rotation with respect to the Sun)
• Orbital altitude must be about 36,000 km above the equator
Uses of Geostationary Orbits

- Weather satellites (GOES, METEOSAT)
- Telephone and television relay satellites

Constant contact w/ground stations
Limited spatial coverage
  - each satellite can only cover about 25-30% of the earth’s surface
  - coverage extends only to the mid-latitudes, no more than about 55°
Geosynchronous Orbits

- Orbital period = earth’s rotation
- Orbital inclination ≠ zero
  - traces a figure eight
  - half the time, the orbit is above(below) where it needs to be
  - highly eccentric versions of this sort of orbit are possible but not widely used
Sun-synchronous Orbit

- Precession of the satellite orbit is the same as the angular speed of rotation of the sun
- Satellite will cross the equator at the same time each day
- Orbital inclination is retrograde (typically ~98°)
Uses of Sun-Synchronous Orbits

• Equatorial crossing time depends on nature of application (low sun angle vs. high sun angle needs)
• Earth monitoring -- global coverage
• Orbital altitude typically between 600 and 1000km -- good spatial resolution
Altimetric Orbits

• Ascending and descending orbits should cross at 90°
  – Designed so that orthogonal components of surface slope will have equal accuracy

• Orbital inclination depends on location of altimetric needs
Getting the Data to the Ground

- On-board recording and pre-processing
- Direct telemetry to ground stations
  - receive data transmissions from satellites
  - transmit commands to satellites (pointing, turning maneuvers, software updating)
- Indirect transmission through Tracking and Data Relay Satellites (TDRS)
Imaging Systems

- Cross-track scanner
- Whiskbroom scanner
- Pushbroom sensor
Cross-track Scanner

• “back and forth” motion of the foreoptics
• scans each ground resolution cell one-by-one
• Instantaneous Field of View (IFOV) of instrument determines pixel size
• Image is built up by movement of satellite along the orbital track and scanning across-track
Dwell Time

- the amount of time a scanner has to collect photons from a ground resolution cell:
  \[
  \frac{\text{scan time per line}}{\text{#cells per line}}
  \]

depends on:
- satellite speed
- width of scan line
- time per scan line
- time per pixel
Dwell time example

(down track pixel size / orbital velocity)

(cross-track line width / cross-track pixel size)

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

This is a very short time per pixel -- low SNR
Along-track scanner ("Pushbroom")

- Linear array of detectors (aligned cross-track)
  - reflected radiance passes through a lens and onto a line of detectors
- Image is built up by movement of the satellite along its orbital track (no scanning mirror)
- Area array can also be used for multi-spectral remote sensing
  - dispersion used to split light into narrow spectral bands and individual detectors
Dwell Time Example

(down track pixel size / orbital velocity)

(denominator = 1.0)

dwell time = 4.0 x 10^{-3} \text{ seconds/pixel}

but different response sensitivities in each detector can cause striping in the image
Whiskbroom Sensor

- Linear or area array of detectors
- Image is built up by movement of satellite along its orbital track and by cross-track scanning using a mirror
  - wide field of view (FOV)
  - pixel resolution varies with scan angle
Whiskbroom vs. Pushbroom

- Wide swath width
- Complex mechanical system
- Simple optical system
- Filters and sensors
- Shorter dwell time
- Pixel distortion

- Narrow swath width
- Simple mechanical system
- Complex optical system
- Dispersion grating and CCDs
- Longer dwell time
- No pixel distortion
Calculating the Field of View (FOV)

\[ \text{FOV} = 2 \ H \ \tan(\text{scan angle} + \frac{\pi}{2}) \]

\( H = \) satellite altitude

Example:

SeaWIFS satellite altitude = 705 km
Scan angle = 58.3°

\[ \text{FOV} = 1410 \times \tan(58.3°) = 2282 \text{ km} \]
Computing pixel size

\[
\tan(\text{angle}) = \text{opposite/adjacent}
\]

\[
\theta = \text{IFOV}
\]

\[
P_n = \text{pixel size at nadir}
\]

\[
\text{H} = \text{altitude of satellite}
\]

\[
\tan\left(\frac{\theta}{2}\right) = \frac{(P_n/2)}{\text{H}}
\]

\[
P_n = 2 \times \text{H} \times \tan\left(\frac{\theta}{2}\right)
\]
\[ x = H \tan\left(\frac{q + b}{2}\right) \]
\[ x_2 = H \tan\left(\frac{q - b}{2}\right) \]
\[ x_1 = x - x_2 \]
\[ P_c = H \tan\left(\frac{q + b}{2}\right) - H \tan\left(\frac{q - b}{2}\right) \]

\[ \frac{H}{\cos q} = \sec q \]