Satellite Image Analysis

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The lab on satellite image analysis deals with a very typical application, the extraction of land use information.

Starting point is an image recorded by a satellite, which is then analysed in order to extract information on the type of ground cover (e.g., vegetation, water, urban area).

The following gives a very brief summary of concept necessary for this lab experiment. Some topics will be treated later in other lectures as well.

As the title implies, there are 3 topics to deal with:

Satellites: How fast/high? Where? When? Orbits, height, ...

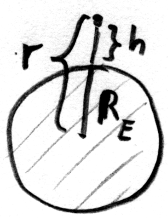
Images: Which wavelength? What instrument?
Digital? How to display? ...

Analysis: How to distinguish, e.g, forest from water? Automatically? ...

1 Satellites

1.1 Circular orbit

- satellite: mass m, orbit height h, orbit radius r, speed v, angular velocity $\omega = v/r$



- force of gravity:

$$F_g = mg \left(\frac{R_E}{r} \right)^2 \tag{1}$$

where $g = 9.81$ m/s^2 is the acceleration of gravity at the Earth surface

- centripetal force (for circular orbit):

$$F_c = m\omega^2 r = \frac{mv^2}{r} \tag{2}$$

- circular orbit: $F_g = F_c$

$$\Rightarrow mg\left(\frac{R_E}{r}\right)^2 = \frac{v^2}{r} \Rightarrow v = \sqrt{\frac{g{R_E}^2}{r}} \tag{3}$$

  Note: No dependence on satellite mass!

- orbital period:

$$T = \frac{2\pi}{\omega} = \frac{2\pi r}{v} = 2\pi r\sqrt{\frac{r}{gR_E^2}} \tag{4}$$

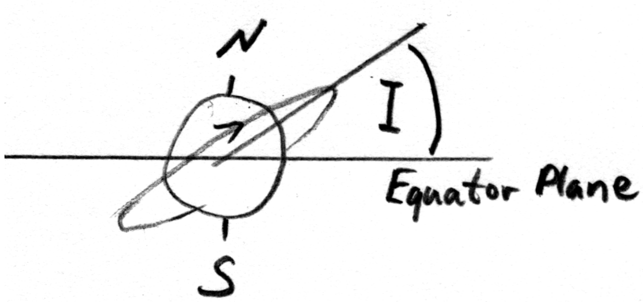
- Example: geostationary orbit (communication satellites): $T = $ 23h56min
  $\Rightarrow r = [T\sqrt{g}R_E/(2\pi)]^{2/3}$
  $\Rightarrow h = r - R_E = \ldots = 35808$ km.

- Example: many remote sensing satellites: $h \approx 800$ km
  $\Rightarrow v = 7.46$ km/s, $T \approx$101min.

- Note: T dictates h and vice versa

1.2 Sun-synchronous orbit

- Inclination I = angle between equator plane and orbital plane



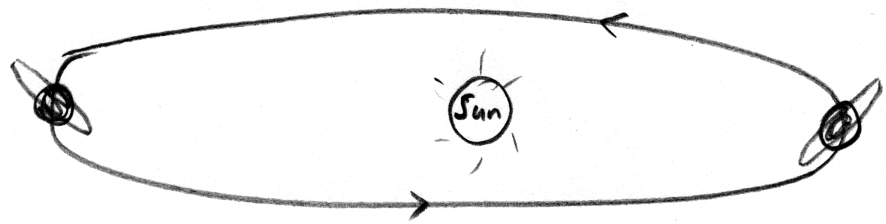
- equator-crossing South-North = "ascending node"

- Earth not spherical (gravitation potential = $\frac{1}{r}$+ higher order terms)

$\Rightarrow$ precession of orbit if orbit not in equator plane

- Precession frequency = function of I and r

- for $I = 98°$, precession period is 1 year!
  i.e., position of orbit relative to sun is constant



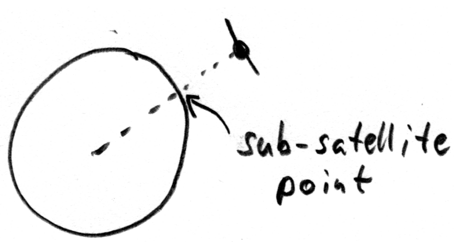
⇒ satellite passes over same latitude at the same local time

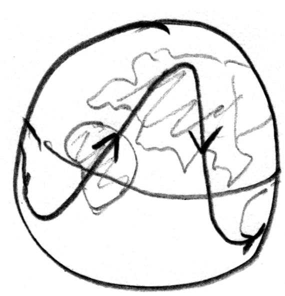
- this is called "sun-synchronous orbit"
- useful to avoid varying illumination conditions caused by different time of day
- used by most remote-sensing satellites
- Note: seasonal variation of illumination cannot be avoided:

  Approximate sun elevation angle at local noon for some locations and the 4 seasons

	21 Dec	21 Mar/22 Sep	21 Jun
Bremen, 53°N	14°	37.5°	61°
Delhi, 28°N	39°	63°	85°
Singapore, 1°N	65.5° (over S horizon)	90° (zenith)	67.5° (over N horizon)

- ground track of sun-synchronous, near polar orbiting satellite: wavy line





- repeat passes: After a number of orbits, sub-satellite point retraces its path → repeat cycle.

2 Images

2.1 Satellite sensors

- active sensors: sensor produces its own illumination of object (e.g., Radar, Lidar)

- passive sensors: sensor uses radiation emitted/reflected/scattered by object (e.g., Radiometers)

- wavelength ranges used in remote sensing of the Earth:

name	wavelength range	radiation source	surface property of interest
Visible	0.4-0.7 μm	solar	reflectance
Near Infrared (NIR)	0.7-1.1 μm	solar	reflectance
Short Wave Infrared (SWIR)	1.1-1.35 μm 1.4-1.8 μm 2-2.5 μm	solar	reflectance
Mid Infrared (MWIR)	3-4 μm 4.5-5 μm	solar,thermal solar,thermal	reflectance, temperature
Thermal Infrared (TIR)	8-9.5 μm 10-14 μm	thermal	temperature
microwave, radar	1 mm – 1 m	thermal (passive) artificial (active)	temperature (passive) roughness(active)

- From now on: only visible/NIR passive sensor (the type relevant for the satellite image analysis experiment)

- sensor measures radiance, i.e., intensity of radiation

⇒ constructs 2-dimensional image from many point measurements (=digital image)

- uses movement of satellite (see Figure 1), scans cross-track, or has an array of detectors/sensors

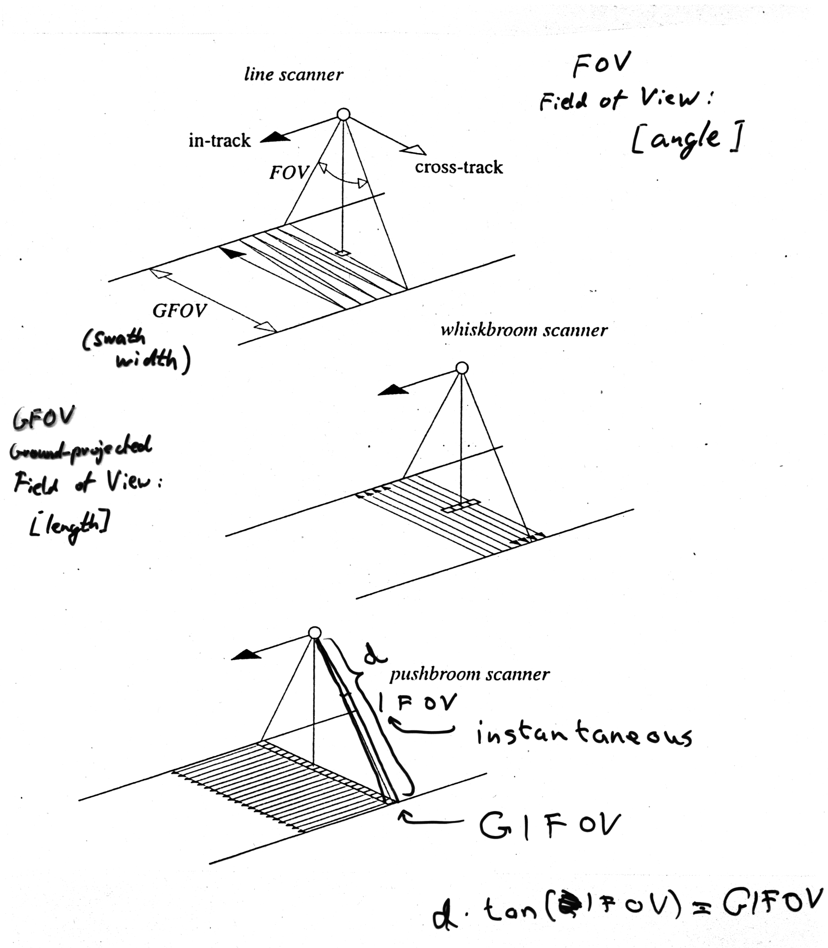


Figure 1: Scanning of the ground by a satellite

- IFOV = instantaneous field of view: angle, size depends on instrument (optics) and wavelength
- ground-projected IFOV (GIFOV) depends on IFOV and height; dimension: length
- GIFOV ≈ spatial resolution (minimum distance two small objects must have to be imaged separately)
- Spatial resolution of visible/NIR satellites: 1 m – 1000 m

- Multi-spectral sensors: several frequency ranges at once, e.g., blue, green, red, NIR (4 "spectral channels")
- hyperspectral sensors: dozens to hundreds of spectral channels

2.2 Digital images

Definition: Digital image

- 2-dimensional array (=matrix) of radiance measurements (=digital numbers) = pixels
- typical: (several hundreds to several thousands)^2 pixels
- e.g., 1300 × 1300 pixels, stored on computer as 1300 lines with 1300 digital numbers each
- typical: 8 bit (=1 byte) per pixel, i.e., 256 different pixel values: 0...255
- displayed as grey levels, by convention usually 0=black and 255=white, also called "half-tone image" (black, grey shades, white)

Histogram, Contrast enhancement

- grey-level histogram shows the frequency of occurrence of each grey level
- histogram shows if all possible grey levels are used, i.e. if there is good contrast
- grey levels can be transformed to enhance contrast
- Example: darkest pixel has value $D = 100$ and brightest $D = 151$ $\Rightarrow$linear transform $D_{new} = 5(D - 100)$ transforms 100 to 0 and 151 to 255, stretching the contrast.

Colour images

- needs image with 3 channels which are displayed in red (R), green (G) and blue (B) – RGB colour.
- why RGB? – Human eye has 3 types of colour receptors ("cones"), sensitive to red, green, and blue light (approximately)
- Result: True colour or false colour image:

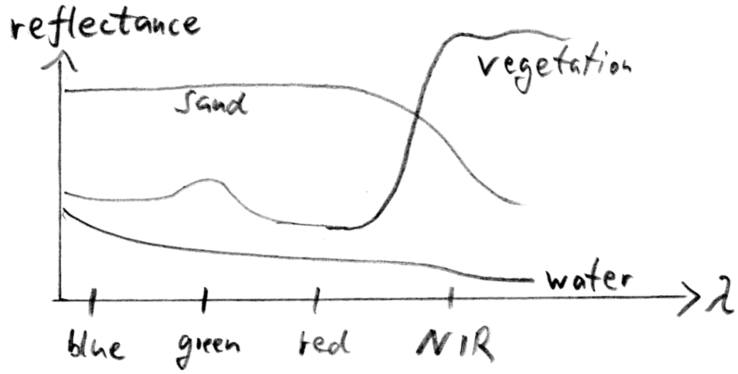
display colour	sensor spectral band		
	True Colour	Colour IR	False Colour
red (R)	red	NIR	any
green (G)	green	red	any
blue (B)	blue	green	any

- Note: A single-channel image can also be displayed as colour by using a range of colours ("palette", "colour table") instead of the grey levels – this is called pseudo-colour

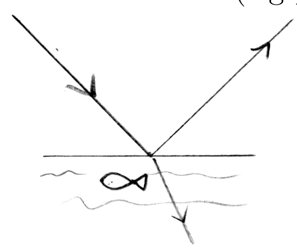
3 Image Analysis

3.1 Scattering/Reflection in Visible/NIR

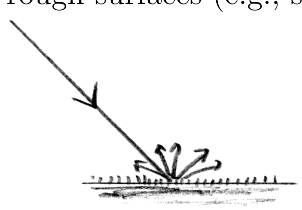
- Different materials
  reflect/scatter
  different wavelengths
  differently
- In other words: Different materials have different spectral signatures
- Most important fact here:
  strong reflection of NIR by vegetation:



- surface structure (on the wavelength scale) matters as well:
  - smooth surfaces (e.g., water surface[1]) cause specular reflection:



  - rough surfaces (e.g., soil, grass, roads) cause diffuse reflection:



  - distributed scatterers (e.g., leaves, twigs, branches in forest) cause multiple scattering, sometimes called volume scattering

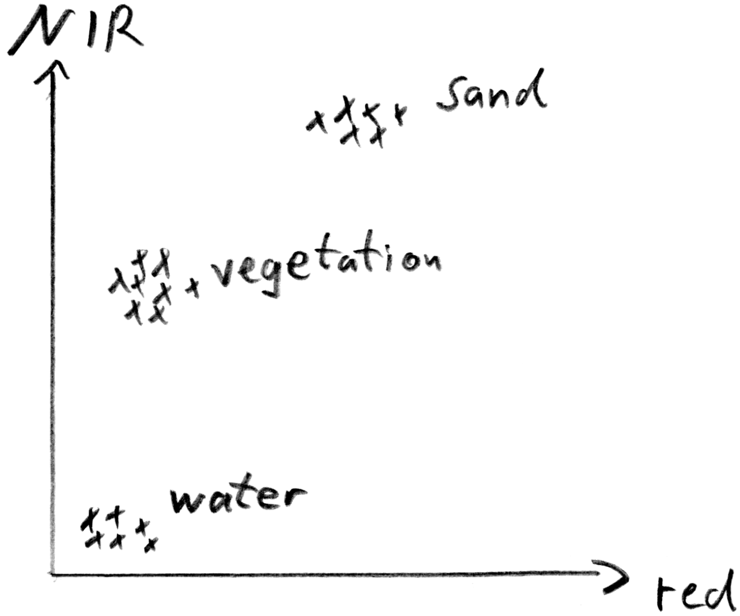
3.2 Surface type classification

- use the difference in spectral signatures for distinguishing surface types
- Vegetation density is a decisive feature of most surface types: e.g., fields and urban areas can be distinguished mainly by there different

[1]Note that a portion of light at the water surface is also refracted into the water and is scattered and/or absorbed there

vegetation density

- Using just the red channel and the NIR channel, a lot can be done: Plot pixels in a red-NIR scatter plot according to their pixel values in these channels:



⇒ pixels representing different surface types often group into distinct clouds ("clusters")

- Semi-automatic classification algorithm (rather simplistic, but working):

  1. select areas whose type is known ("training areas"), e.g., from a map; one training area for each surface type
  2. display red-NIR scatter plot, and get the ranges in red and NIR that the cluster corresponding to each surface type occupies
  3. classify pixels from unknown areas according to the ranges from previous step

  This is a so-called "parallelepiped[2] classifier"

[2]a kind of N-dim. box