Satellite image received courtesy of the Institute for Science and International Security, shows Iran's military site in Parchin. The UN atomic agency suspects Iran has conducted nuclear warhead design experiments at its military facility in Parchin. The UN atomic agency has sought fresh thinking in its impasse with Iran after two fruitless visits probing Tehran's suspected nuclear weapons drive. (AFP Photo/)
Active Sensors: LiDAR Principles Chapter 10
February 8, 2012
What is an active sensor?

Passive instruments
(i) Reflection
(ii) Emission

Active instruments
(iii) Emission-Reflection

Ex. LiDAR, Sounders, Radar

Chuvieco, 2002

Question to students what is an active sensor?
LiDAR Definition

- **LiDAR**: Light Detection and Ranging
- **Laser**: Light Amplification of Stimulated Emission of Radiation

- **Active sensor**: emits high energy pulses of short wavelength (R or NIR) light highly collimated: coherent and polarized
- **Measures the distance to the intercepted point on the ground based on the time delay between an emitted and received laser pulse**
**Laser characteristics**

**Collimated:** laser emission is a highly directional beam

**Coherent:** the photons are in phase

**Polarized:** electric vectors are aligned (usually linear)

Example with laser pointer
From airplane or satellite space shuttle:

LIDAR systems can emit pulses at rates >100,000 pulses per second, referred to as pulse repetition frequency. A pulse of laser light travels at $c$, the speed of light ($3 \times 10^8$ m s$^{-1}$). LIDAR technology is based on the accurate measurement of the laser pulse travel time from the transmitter to the target and back to the receiver. The traveling time of a pulse of light, $t$, is: $t = 2 \times \frac{R}{c}$

where $R$ is the range (distance) between the LIDAR sensor and the object. The range, $R$ is determined by rearranging the equation:
Mention beam divergence
Lambertian surface, but is not perfect
What would happen if it is not Lambertian?
We will not get any response back to the receiver
Lidar Scanning Method
Interpolated lidar data showing the detected returns and the estimated bare earth, derived from last returns.
Lidar Elevation Accuracy
Footprint size

- Small footprints - a few cm
- Large footprints – tens of m

Dubayah, 2003  http://earthobservatory.nasa.gov
Small Footprint LiDAR

New Ecologically Relevant Data Products:

- Vegetation height
- Distribution of structural elements in canopy
- Canopy-top topography
- Biomass
- Life form diversity

Canopy Surface Topography & Bathymetry
Recording capability

- Discrete pulses
  - First and/or last pulse
  - Up to five pulses
  - With intensity?
- Full waveform

If intensity is being recorded draw just a line for the discrete pulses
Single versus multiple discrete pulses

- Discrete pulses
  - First and/or last pulse
  - Up to five pulses

- Full Waveform
  - Continuous return pulses

Small footprint scanning LIDAR - Multiple Return

Dubayah, 2003
Many small discrete → Large full waveform

- High density small discrete
  - Locate individual trees
  - Locate ground easier
- Large full waveform
  - Less amount of data
- Conversion to frequency
- Gaussian laser intensity
- Example:
  - FLI-MAP
    - 10 cm footprint size
    - 33 cm across and along track spacing
  - LVIS
    - 25 m

Give an example on how to do it.
1. Draw in X and Y different small footprints with a specific pattern.
2. Draw a large footprint
3. Draw X and Z
4. Draw intervals every for example 10 cm
5. Draw waveform
Gaussian shape of the laser beam intensity
Why less amount of data

Blair, 1999
Simulation of large full waveform

- Selection of size of the large full waveform
- Selection of height interval
- Generation of frequency

Draw area
Scanning pattern

- Vertical profiling (no scanner)
- Zig-Zag
  - Oscillating mirror
- Parallel lines
  - Multifaceted mirror
  - Fiber scanner
- Elliptical
  - Nutating mirror (Palmer scan)

Fig. 6: Scanning mechanisms (from top left clockwise): oscillating mirror, Palmer scan, fiber scanner, rotating polygon.

Lohmann, 1999

Wehr, 1999
Explain that uses NIR for the surface of water and Green for the bottom. Higher reflectance of green means also higher transmittance. So the green transmits better to the bottom of the surface, whereas the NIR absorbs everything and cannot reach the bottom. Toposys at 1535 nm less harmful to the eye can emit higher power.

Aki me quedé
Generation of canopy height of individual laser pulses

- Point X, Y, Z
- Interpolate: selection of $Z_{\text{ground}}$ for X and Y, from DGM or classified ground points
- Canopy height = $Z - Z_{\text{ground}}$

Draw an X and Y graph
Center of pixel of DGM
Generation of canopy height of individual laser pulses

- Ground points
- Interpolate: selection of $Z_{\text{ground}}$ for $X$ and $Y$
- Canopy height = $Z - Z_{\text{ground}}$
- Elevation above ground
Forest Structure & Biomass from Small Footprint LIDAR

Riano et al., 2004

- Laser pulse-tree
- Laser pulse-shrub
- Laser pulse-ground
- Tree height
- Crown base height
- Understory height

Tree height = 35.50 m
Crown base height = 17.89 m
Understory height = 2.82 m
Tree cover = 58.43%
Under. cover without cor. = 15.81%
Under. cover after cor. = 26.41%
Folage biomass = 0.78 kg/m²
Crown volume = 10.01 m³/m²
Crown bulk density = 0.078 kg/m³
Density of points at each interval

Lefsky, 2002
Feature extraction from Lidar

- Large full waveform
Surface canopy height

- Large full waveform
  - Difficult to obtain from large footprints
  - Bare ground is mixed with surface canopy signals on steep slopes due to the spreading of the ground return
  - Ground from the vegetation signal: copy and flip vertically the lower half of the ground return to define the higher half of the ground return.
  - Surface canopy height: gap between the ground and shrubs
    - Decomposed in Gaussian components: trees, underlying vegetation and ground

Draw a waveform from the ground and a waveform from the vegetation.
Superimpose them. If you do this on homogeneous vegetation the distribution is going to be the same but it will not be if it is heterogeneous. Power greater than the level established by the ground return is assumed to be vegetation canopy.
The **LIDAR data for the generation of forest parameters** in the highest part of the gaussian component represents the underlying vegetation would be the surface canopy height.
Difficult to separate if more than 3 gaussians
LIDAR Canopy Height Retrievals

Wind River Experimental Forest
LiDAR Crown Depth
PSME: *Pseudotsuga menziesii* at Wind River

Large footprint (SLICER) out performs
Synthetic waveform from small foot print (Aeroscan)
Both match 1:1 line

Similar results for TSHE
LIDAR Crown Diameter

Derived from multi step process for delineating crowns automatically from LIDAR
Generation of Crown Bulk Density From These Equations

Lidar flight line
False colour
Aerial photo

10m resolution

CBD (kg/m³)

Riaño et al., RSE, 2004
Urban architecture

http://www.geolas.com/Pages/Building.html
Urban architecture

Manheim, Germany

www.toposys.com
Infrastructure

http://www.helica.it/eng/prod/elettro.asp#
Floods

http://www.geolas.com/
Coastal erosion

Changes between 1997 and 1998 in coastal area of North Carolina (North Wrightsville Beach)

http://www.csc.noaa.gov/products/ncz/haz/lidtopo.htm#lidar
Volcano

- Mt St Helen

Bathymetry

- SHOALS
- Blue-Green from the bottom and NIR from the top
- Blue-Green reflects more but transmits more

Fig. 2: Reflectance and transmittance spectra of (a) fresh and (b) dry poplar leaves

U.S. Army Corps of Engineers <shoals.sam.usace.army.mil>

Draw water spectrum
Bathymetry

Looe Key, Florida

<www.optech.on.ca>

Molokai, Hawaii

<coralreefs.wr.usgs.gov>

James Goodman
Change Detection in Extent of Salt Marsh

Rosso et al., 2006
Change Detection
LiDAR Height Difference: January 2002 and December 2003

Roberts Landing marsh

Rosso et al., 2006
LiDAR Marsh Height: Estimate % Time Inundated

Inundation map overlaid on USGS 2004 natural color digital orthoquad.
Micro-topography Controls Length of Inundation Period & Marsh Species Distribution

Stege Marsh

% of Time Inundated

- 0% - 5%
- 5% - 10%
- 10% - 15%
- 15% - 20%
- 20% - 25%
- 25% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- 80% - 100%

Lidar inundation
Upward looking LiDAR

[Diagram showing LiDAR system with laser light, data access, and control processes.]
Advantages of LiDAR Instruments

• Day/night data acquisition
• Captures detailed vertical and horizontal landscape structure
• Sensitive to height/structure differences in short stature & sparse vegetation
• Relatively inexpensive, lightweight/power instruments
• Use has become common with many vendors
• Most terrestrial lidars flown with bands in the NIR; land surface materials are relatively well understood

Disadvantages of LiDAR Instruments

• Generally need video or images to aid interpretation
• Difficult to identify individual trees in dense vegetation
• Power requirements make satellite operation challenging
What you should know about LiDAR Data

1. Active systems
2. Measurement Principles: nomenclature, wavelengths (bands),
   backscatter,
3. How do these technologies work? How are signals transmitted?
4. Examples of unique measurements for this technology.