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Before dam breach: 2019-01-22

After dam breach: 2019-01-28

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Recent “Radar in the News”
Some Basics and Three Types of Radar Systems

Imaging Radars - Concepts:
- The Radar Equation
- Separating Several Range Resolution Cells within Antenna Footprint

Imaging Radars – How it’s Really Done:
- The Concept of Pulse Compression Systems
- The Resolution-Bandwidth Duality
- Range Compression – The Matched Filter Approach

Examples of Imaging Radar Data
Active Microwave Systems are called RADARS

- Radars actively transmit microwave signals (usually a radar pulse)
- Radar antenna provides directivity for transmitted signal
- A radar sensor records three different parameters: Amplitude, Phase and Polarization of the reflected microwave signals (here we focus on amplitude and phase)

Three Different Types of Radar Systems

- Based on measurement type, three different radar systems can be discriminated:
  
  **Non-Imaging Systems**
  - **RADAR ALTIMETERS**
    - Measuring distance (from travel time)
    - Transmitted pulses
  - **SCATTEROMETERS**
    - Measuring radar cross section
    - Transmitted pulses

  **Imaging Systems**
  - Range pixel size ~ pulse length
  - Azimuth pixel size = antenna footprint (or better when doing SAR)

Radar Principle

- Transmit
- Received echo
- Light velocity
- Range $R$
- $2R/c$
- Time $t$
A Short Word on Radar Altimeters

- Radar altimeter emits pulses towards the Earth’s surface (nadir direction)
- Signal travel time (transmission to reception) is proportional to satellite altitude.
- Measuring signal travel time not easy as echo signal has funny shape.

Idealized altimeter echo from flat surface (e.g., smooth ocean surface)

Calculating Surface Height from Altimeter Measurements

Sensor Geometry  
Ionosphere  
Dry Troposphere  
Wet Troposphere  
Dynamic Topography  
Geoid Undulations  

Center of Mass  

H_measured

Orbit Height = H

Instantaneous Sea Level

SWH  
Tides  
Barometric Effect

Mean Sea Level = SSH_measured

Geoid = H_geoid

Reference Ellipsoid

Mean Sea Level Height from Altimetry
Microwave Scatterometers

- Goal: measurement of wind speed and direction over oceans

Example: Scatterometer on ERS

QuikSCAT Windfield

Wind (m/s): time=20170211; 12Z

IMAGING RADAR CONCEPTS
BOARDWORK: HOW RADAR'S WORK - THE RADAR EQUATION
The Radar Equation – A Reminder

- Transmit power: \( P_t \) [W]
- Antenna gain: \( G = \frac{4 \pi A}{\lambda} \)
- Power density at scatterer: \( \frac{P_t G}{4 \pi R^2} \) [W/m²]
- Radar cross section: \( \sigma \) [m²]

- Power density at receiver: \( \frac{P_t G}{4 \pi R'^2} \) [W/m²]
- Antenna area: \( A \) [m²]
- Reflected power: \( \frac{P_t G \sigma}{(4 \pi R'^2)} \) [W]

- Received power: \( P_r = \frac{P_t G \sigma}{(4 \pi R'^2)} \) [W]

Pulse Waveform and Range Resolution

- Targets: #1 and #2 easily separable, \( \Delta t > T = \frac{\lambda}{v} \) [range resolution]

Range Resolution Example

- Insufficient Target Separation
- Sufficient Target Separation
Think – Pair – Share

What does the Spectrum of an Image Tell Us?

1. Explain what the “Spectrum (Fourier Representation)” of an Image represents
2. Assign the right spectrum to the right image:

   - Image #1
   - Image #2
   - Image #3

   - Spectrum #A
   - Spectrum #B
   - Spectrum #C

3. Based on these image relationships above, which image parameter dictates how “wide” the spectrum of the image is?
Some Problems with the Radar Imaging Concept

- Power $P_r$ of returned signal reduces rapidly the distance $R$ to the target
  \[ P_r \propto \frac{1}{R^4} \]
  with $P_t =$ transmit power

- For satellite applications:
  \[ P_r \approx \frac{1}{R^4} P_t \]

For Satellite applications:
Difficult to transmit a pulse that (1) has enough power to be able to detect backscattered response AND (2) is short enough to yield sufficient range resolution.

Most Radars Replace Pulse with Linear Frequency Modulated (Chirped) Signal

- Reason: Sending sufficient power in a single short pulse is near impossible
- Radars that send chirped signal are called “Pulse Compression Systems”

- Procedure:
  1. Transmit frequency coded signal of length $\tau_p$
  2. Receive frequency coded echo
  3. Compress frequency coded signal using a decoding operation called matched filtering

- What is the resolution of the compressed pulse?
  - Ability to compress the pulse depends on the bandwidth $W_p$ of transmitted chirp signal
  - The higher the bandwidth, the narrower the compressed pulse
    \[ \tau_p = \frac{1}{W_p} \]

Achieving Good Range Resolution

The Airborne Case

- $R$, $\Delta R$
- Antenna
- Point targets
- Transmitted signal
- Echoes of pulse
- $2R/c$, $2\Delta R/c$
Achieving Good Range Resolution
The Spaceborne Case

Send a longer "chirped" signal to increase $P_1$

Use a focusing process to recover the smeared targets

Properties of the Frequency Coded (Chirped) Signal

- Chirp signal: $u(t) = \exp(j\pi kt^2) = \cos(\pi kt^2) + j \cdot \sin(\pi kt^2)$

- Chirp rate $k$
- Time $\tau$
- Bandwidth $W_0$

Range Compression by Matched Filtering (I)

1. Data Acquisition:
   1. Transmit chirp instead of short pulse
   2. Every point target will return chirp echo

2. Range Compression: Correlate received signal with replica of transmitted chirp

3. Final range resolution after Range Compression: $\rho_0 \approx \frac{c}{2W_0}$
Range Compression by Matched Filtering (II)

signal

reference chirp

\[ \times \]

correlation

\[ = \]

Focused pulse

Range Compression: Resolution-Bandwidth Duality

- You see two different chirps of identical duration but different chirp rates \( k = 50 \) & \( k = 100 \) Hz/s
- Higher chirp rate \( \Rightarrow \) twice the bandwidth \( \Rightarrow \) two times better resolution after correlation

Range Compression: Matlab Example (I)
Range Compression: Matlab Example (II)

Three Overlapping Chirp Signals

Three Overlapping Chirps in Noise

Range Compression: Matlab Example (III)

Reconstructed peak signals after range compression

Chirp-Rate Error Effects – Matlab Example

\( k_0 \): Chirp rate of transmitted signal

\( k_1 \): Chirp rate used for focusing

Chirp rate errors → insufficient focusing of scattered energy
Where Do Side-Lobes Come From?
Effect of Windowing – Matlab Example (I)

Where Do Side-Lobes Come From?
Effect of Windowing – Matlab Example (II)

EXAMPLES OF IMAGING RADAR DATA
Side-Looking Airborne Radars (SLARs)
• Developed in 1950s driven by military
• Key element: Long antenna transmitting narrow fan-beams sideways from the aircraft
• Resolution defined by pulse length & length of antenna
• Resolution generally fair

Side-Looking Radars Use Pulse Compression to Increase Range Resolution

Imaging the Surface with SLARs
Scanning Ground-based Radar System as a SLAR Example
• Resolution defined by pulse length & length of antenna

Example of Scanning Ground-Based Radar Acquisition
• 180 degrees scan angle – location: Fairbanks, Alaska
What’s Next?

- After improving resolution in range we also want to enhance the azimuth resolution of imaging radars

- Hence, next lecture (Tuesday 20-Feb-17) we will chat about something called “Aperture Synthesis” (the basis of Synthetic Aperture Radar)

- In preparation please read in Woodhouse (2006):
  - Pages 271 – 280
  - Specifically think about the two different interpretations of the aperture synthesis process (we will discuss those in class)