Potential Synthetic Aperture Radar applications of small satellites

United Nations / South Africa Symposium on Basic Space Technology
“Small satellite missions for scientific and technological advancement”

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Overview

Aspects of SAR Operation

• Basic Radar theory and mechanics of Synthetic Aperture Radar (SAR).
• Why SAR from Space?
• Applications of Spaceborne SAR.
• SAR Wars
Brief introduction to Radar and SAR
Radar

• Repeated burst of EM waves: carrier wavelength of 1 cm to 23 cm (Ka Band down to L Band).
• Resolution determined by modulation bandwidth of pulse, typically Linear Frequency Modulated, bandwidth $B$.
• Range resolution is $\delta R = c / 2B$.
• Sensitivity depends on Energy radiated and aperture size.
• Received signals compete with thermal noise from receiver and the environment (some man-made).
• Moving targets result in a Doppler shift.
• Detection ability falls with the fourth power of range to target.
• Range is measured by time delay to target and back.
• Beamwidth of a real aperture antenna determined by $\lambda/D$. 
Generic Side Looking Imaging Radar

Note: along track resolution depends on antenna beamwidth
Range resolution in slant range depends on bandwidth, modified by incidence angle in ground range coordinates.
Imaging Problems
Synthetic Aperture Formation

• An antenna of dimension d results in a beamwidth of $\theta = \frac{\lambda}{d}$.

• A real azimuth antenna pattern results in an along track or azimuth resolution that is poor unless the azimuth dimension is extremely large (especially from space).

• The azimuth resolution degrades with range ($\delta x = R \theta$), thus:
  • Store the range echoes in the azimuth direction.
  • For each range resolution cell, form a synthetic, large aperture antenna.
  • Results in a synthetic, narrow beam view of the swath.

• Can be shown that the best azimuth resolution is $\delta x = \frac{l_a}{2}$, where $l_a$ is the azimuth dimension of the real antenna.

• Sensitivity depends on Energy and Aperture as before, but decreases with cube of range, since many samples are added to form the synthetic aperture.
Point and Distributed Targets

- A point target backscatter is measured by its “radar cross section”, $\sigma_0 [m^2]$.  
- A distributed target is measured by $\sigma^0 [m^2/m^2]$ i.e. the backscatter per illuminated area. Example, a field of maize, rocky, flat terrain.  
- The backscatter depends on incidence angle.  
- The backscatter for SAR is the vector sum of a large number of scatterers in the resolution cell.  
- Results in a magnitude that fluctuates from cell to cell, even for a uniform target area: called “speckle”.  
- Characteristic of all coherent imaging systems.
SAR key parameters

- The range and azimuth resolution of the sensor is specified. Generally the processing is arranged so that these are equal, i.e. "square pixels".
- The probability of detection ($P_d$) of a single object within a resolution cell, with given probability of false alarm ($P_{fa}$) should be stated.
  - This is important when detecting, for example, vehicles in a field, ships on the ocean.
- The value of “Sigma Zero” when a resolution cell’s response is equal to the system noise floor is known as the “Noise Equivalent Sigma Zero” ($NESZ$).
  - This is important when discriminating against different types of surface being imaged, for classification.
- More technical are the ambiguities caused during image formation: discussed in a more advance forum.
Why SAR from Space?
Imaging with Radar from Space

**EM wave advantages**

- Penetrates cloud and hardly affected by rain.
- Can detect moving targets i.e. discriminate against a background.
- Millimetric changes in phase between consecutive images can be used for change detection.

**Free Access to all of the Earth’s Surface**

- Day / night operation (own illumination).
- Not restricted by aircraft operational limitations (range, airspace control).
- No legislative control
Applications of SAR
Numerous SAR Applications

- Cryosphere
  - Ice / snow
  - Navigation
- Land
  - Vegetation
  - Geology / Tectonics
  - Land Use
  - Change detection
- Oceans
  - Currents
  - Wind and Waves
  - Maritime Domain Awareness
3-d modelling (digital elevation Model).

Tomography (Urban Modelling).

Differential Interferometry (for tectonic analysis).

Repeat pass interferometry.

Images © DLR and ESA
Brief History of Spaceborne SAR
SAR in Space

- NASA
  - SEASAT 1978
  - SIR A/B/C
- German Government and Industry
  - DLR Tandem X
  - PPP TerraSAR X
  - Military SAR Lupe
- European Countries
  - ESA ERS1/2
  - ESA Envisat
  - ISA COSMO Skymed
  - Russia, India, Japan
  - Now, “SAR Wars”, the march of the miniature systems.
<table>
<thead>
<tr>
<th>Satellite</th>
<th>Agency/Country</th>
<th>Year</th>
<th>Band</th>
<th>Az Res</th>
<th>Range Res</th>
<th>Pol</th>
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<td>1</td>
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<td>China</td>
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<td>S</td>
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<td>20</td>
<td>VV</td>
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<td>2300</td>
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<td>L</td>
<td>1</td>
<td>3</td>
<td>quad</td>
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<td>Hisdesat/Spain</td>
<td>2015</td>
<td>X</td>
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<td>1</td>
<td>quad</td>
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Information contained is Confidential and Proprietary.
The “SAR Wars”
The “SAR Wars”

SAR Performance

• Resolution
• Coverage per orbit, per day, per month, often quoted in terms of swath width.
• Target detection Signal to Noise (SNR)
• Area sensitivity: Noise Equivalent Sigma Zero (NESZ)
• Ambiguity rejection
• Illumination angle across the swath
• Specialist high resolution modes (spotlight mode)
The “SAR Wars”

**Capella Space**
- No published specifications
- Launch in 2017 (83 days to go…)
- More than USD 12m in venture capital.
- "Hourly images of anywhere on earth".
- Detect millimetre surface deformations.
- 36 satellites
- Below 50 kg satellite
- 1 m resolution

**Urthecast**
- The OptiSAR (trademark) Constellation comprises 8 tandem pairs of SAR and Optical Satellites divided into two orbit planes.
- The 4 tandem pairs will be equi-spaced around an orbit plane, where each tandem pair consists of a leading SAR satellite, which uses UrtheCast’s SAR-XL technology for its payload.
- A trailing Optical satellite that is following approximately 2 minutes behind the SAR satellite.
- Phased array technology.
- Narrow strips (7 km) but out to 140 km in scansar.
- Resolution around 1 m X 1 m.
- NESZ around -20 dBm in X, closer to -26 dBm in L Band.

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The “SAR Wars”

Surrey Space Systems Limited (SSTL)
- Close to Launch
- NovaSAR will consist of four state of the art SAR satellites able to operate day and night in all weather conditions.
- The first of these satellites is being funded by the UK government and is currently in development.
- Government investment announced in November 2011
- Mass less than 500kg
- Expected launch in 2018

Iceye
- Aerial imaging with Jet aircraft 2017 - Selected countries 4 week response 3m resolution
- Phase 1 3 satellite constellation 2018 - Global access 24 hour response 10m resolution
- 1st Generation 6+ satellite constellation 2019 - Global access 6 hour response 3m resolution
- Mass of less than 100kg
- Raised around USD18M in funding
- Launch mid 2018
## MicroSAR Constellation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
<td>Constellation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of planes</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Number of SAR satellites per plane</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>8</td>
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<tr>
<td>Total number of satellites</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>16</td>
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<td>SAR coverage 24 hrs</td>
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<tr>
<td>Number of SAR passes over CT</td>
<td>12</td>
<td>24</td>
<td>49</td>
<td>97</td>
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<tr>
<td>% Area covered by SAR satellites</td>
<td>73.7</td>
<td>96.7</td>
<td>99.9</td>
<td>100</td>
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<tr>
<td>Overlapping Scans across ROI (revisits)</td>
<td>1.2</td>
<td>2.4</td>
<td>4.8</td>
<td>9.6</td>
</tr>
</tbody>
</table>
Conclusions

• SAR is a mature field and currently occupies 60% of Earth Observation applications research:
  • the diversity has been shown in this presentation.
• The number and diversity of applications is huge.
• To some extent, the population of earth is well served with research instruments but:
  • niche applications in surveillance required a large number of spaceborne instruments to achieve 24/7 coverage,
  • with frequent updates.
• Spaceborne SAR technology is very well understood: note that high sensitivity systems require large apertures / energy.
Designing a Radar Imaging Satellite: Pitfalls and Trade-offs