Ships and Ice Monitoring with Improved Revisit Time Using GNSS-R Constellations

Alessio Di Simone¹, Hyuk Park², Daniele Riccio¹, Adriano Camps²

¹ Dipartimento di Ingegneria Elettrica e delle Tecnologie dell’Informazione, Università degli Studi di Napoli «Federico II», Naples, Italy.
    {alessio.disimone, daniele.riccio}@unina.it

² Departament de Teoria del Senyal i Comunicacions, Universitat Politècnica de Catalunya-BarcelonaTech, Barcelona, Spain.
    {park.hyuk, camps}@tsc.upc.edu
Outline

• Why ship/ice detection?

• Why GNSS-R?
  • GNSS-R vs. SAR, Optical, AIS
  • Revisit Time

• Sea Target Detection from spaceborne GNSS-R DDM
  • Algorithm Rationale
  • Preliminary results on UK TDS-1 data

• Comments and Conclusions
Outline

• Why ship/ice detection?

• Why GNSS-R?
  • GNSS-R vs. SAR, Optical, AIS
  • Revisit Time

• Sea Target Detection from spaceborne GNSS-R DDM
  • Algorithm Rationale
  • Preliminary results on UK TDS-1 data

• Comments and Conclusions
Globalization has its effects...

- Global seaborne shipments have increased 3.4% in 2013-2015.
- 9.84 billion tons over the world sea and oceans in 2015.
- Global imports increased of 3.5 times more than in the ‘70s in developing countries.
- World commercial fleet consists of 89,464 vessels with a total tonnage of 1.75 billion dwt.
- World fleet grew by 3.5% in 2015 - the lowest annual growth rate in over a decade.

Developments in international seaborne trade

Human decisions have their effects...

Understanding the thickness and extent of sea ice on a global scale is critical for studying climate change.

In 2016 Arctic sea ice wintertime extent hits another record low.

Sea ice plays a key role in the exploration of oil and gas fields and the worldwide sea trade.

The determination of sea ice extents serves as a validation tool in cryosphere modeling studies.

Icebergs dramatically affect maritime security and traffic.

Ice melting may open new commercial routes (i.e. Arctic)

Source: National Snow and Ice Data Center (NSIDC)
Outline

• Why ship/ice detection?

• Why GNSS-R?
  • GNSS-R vs. SAR, Optical, AIS
  • Revisit Time

• Sea Target Detection from spaceborne GNSS-R DDM
  • Algorithm Rationale
  • Preliminary results on UK TDS-1 data

• Comments and Conclusions
Global Navigation Satellite System-Reflectometry

- Recently remote sensing approach based on the measurements of the Earth’ surface reflected GNSS signals.
- Geophysical parameters (e.g. wind speed) can be inferred from GNSS observables, e.g., Delay-Doppler Maps.
Why sea target detection from GNSS-R?

<table>
<thead>
<tr>
<th></th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| Automatic Identification System (AIS) | • Accurate information (ship name, position, speed, course, IMO, MMSI).  
  • Very high update rate (from 3 minutes for anchored or moored vessels, to 2 seconds for fast moving or maneuvering vessels).  
  • Global coverage (Satellite AIS). | • Vulnerable (e.g. spoofing)  
  • Required on board of ships with gross tonnage of 300 or more, and all passenger ships regardless of size.  
  • Non-cooperative ships cannot be tracked |
| Synthetic Aperture Radar (SAR) | • Independence on cloud & illumination conditions.  
  • Very high spatial resolution (up to 1 m) | • Cost and size ↑  
  • Sensitive to sea state + speckle $\Rightarrow P_{fa} \uparrow$  
  • Limited revisit time |
| Optical | • Very high spatial resolution (up to 0.5m)  
  • Suited to hyperspectral imaging  
  • Easy to interpret (no expert user needed) | • Sensitive to cloud & illumination conditions + sea clutter $\Rightarrow P_{fa} \uparrow$  
  • Limited revisit time  
  • The large amount of data prevent the use in real time. |
| GNSS-R | • Independence on cloud & illumination conditions.  
  • Bistatic system  
  • Ability of counter the attack of anti-radiation missiles  
  • Compact, low-power, light-weight and cheap  
  • Very low revisit time | • Low spatial resolution (order of km)  
  • Not yet extensively study and assessed. |
## GNSS-R and nanosat constellations

<table>
<thead>
<tr>
<th></th>
<th>Sentinel-3A</th>
<th>Sentinel-1B</th>
<th>AISSat-1</th>
<th>^3Cat-2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spacecraft class</strong></td>
<td>Large satellite</td>
<td>Large satellite</td>
<td>CubeSat</td>
<td>6-Unit CubeSat</td>
</tr>
<tr>
<td><strong>Payload instrument</strong></td>
<td>Spectrometer, radiometer, SAR altimeter</td>
<td>C-band SAR</td>
<td>VHF antenna, onboard computer</td>
<td>Dual-band altimeter, multi-frequency, multi-constellation, dual-polarization GNSS-Reflectometer</td>
</tr>
<tr>
<td><strong>Total mass</strong></td>
<td>1,250 kg</td>
<td>2,300 kg</td>
<td>6 kg</td>
<td>7.1 kg</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>390 x 220 x 220 cm³</td>
<td>390 x 260 x 250 cm³</td>
<td>20 x 20 x 20 cm³</td>
<td>10 x 24.3 x 34 cm³</td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td>2,300 W</td>
<td>4,400 W</td>
<td>9 W</td>
<td>5.46 W</td>
</tr>
<tr>
<td><strong>Launch date</strong></td>
<td>February 16(^{th}), 2016</td>
<td>April 25(^{th}), 2016</td>
<td>July 12(^{th}), 2010</td>
<td>August 15(^{th}), 2016</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td>305,000,000 €</td>
<td>270,000,000 €</td>
<td>3,500,000 €</td>
<td>750,000 €</td>
</tr>
</tbody>
</table>

Ships and Ice Monitoring with Improved Revisit Time Using GNSS-R Constellations
Universitat Politècnica de Catalunya-BarcelonaTech, Spain – University of Naples Federico II, Italy
GNSS-R and nanosat constellations

- Low weight
- Low size
- Low power consumption
- Simple architecture

Low cost -> GNSS-R constellations comes into play

Remote sensing with improved revisit time!
Outline

• Why ship/ice detection?

• Why GNSS-R?
  • GNSS-R vs. SAR, Optical, AIS
  • Revisit Time

• Sea Target Detection from spaceborne GNSS-R DDM
  • Algorithm Rationale
  • Preliminary results on UK TDS-1 data

• Comments and Conclusions
Revisit Time of GNSS-R constellations

- Two realistic scenarios defined.
- Mission simulations performed using AGI-STK® Suite.
- Specular point position and glistening zone computed with spatial resolution of 1° x 1°.
- Mean, median and standard deviation of revisit time estimated as a function of number of tracking channels for different constellation subsets size.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude [km]</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Inclination [degree]</td>
<td>98°</td>
<td>98°</td>
</tr>
<tr>
<td>Orbit type</td>
<td>Circular</td>
<td>Circular</td>
</tr>
<tr>
<td>Number of satellites</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Number of parallel channels</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>GNSS systems tracked</td>
<td>GPS</td>
<td>GPS, Galileo, Glonass, BeiDou</td>
</tr>
</tbody>
</table>
Revisit Time of GNSS-R constellations

Scenario 1

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude [km]</td>
<td>500</td>
</tr>
<tr>
<td>Inclination [degree]</td>
<td>98°</td>
</tr>
<tr>
<td>Orbit type</td>
<td>Circular</td>
</tr>
<tr>
<td>Number of satellites</td>
<td>32</td>
</tr>
<tr>
<td>Number of parallel channels</td>
<td>16</td>
</tr>
<tr>
<td>GNSS systems tracked</td>
<td>GPS</td>
</tr>
</tbody>
</table>

Graph showing average revisit time (h) vs. number of receiving channels for different numbers of satellites (1, 8, 16, 24, 32) and orbit types. The revisit time for 32 satellites is highlighted with a blue line, showing a significant improvement over the other configurations.
Scenario 2

- **Altitude [km]**: 500
- **Inclination [degree]**: 98°
- **Orbit type**: Circular
- **Number of satellites**: 32
- **Number of parallel channels**: 16
- **GNSS systems tracked**: GPS, Galileo, Glonass, BeiDou

Average Revisit Time (h) vs. Number of Receiving Channels

- 1 Sat
- 8 Sat
- 16 Sat
- 24 Sat
- 32 Sat

Revisit Time of GNSS-R constellations: 2 h 13 m
Revisit Time of GNSS-R constellations

Scenario 2

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude [km]</td>
<td>500</td>
</tr>
<tr>
<td>Inclination [degree]</td>
<td>98°</td>
</tr>
<tr>
<td>Orbit type</td>
<td>Circular</td>
</tr>
<tr>
<td>Number of satellites</td>
<td>32</td>
</tr>
<tr>
<td>Number of parallel channels</td>
<td>16</td>
</tr>
<tr>
<td>GNSS systems tracked</td>
<td>GPS, Galileo, Glonass, BeiDou</td>
</tr>
</tbody>
</table>

4 h 30 m ÷ 6 h 30 m
Revisit Time of GNSS-R constellations

Revisit time improvement up to 60%

Number of Receiving Channels

Average Revisit Time (h)

1 Sat 16 Sat 32 Sat

GPS, Galileo, Glonass, BeiDou

Ships and Ice Monitoring with Improved Revisit Time Using GNSS-R Constellations
Universitat Politecnica de Catalunya-BarcelonaTech, Spain – University of Naples Federico II, Italy
Outline

• Why ship/ice detection?

• Why GNSS-R?
  • GNSS-R vs. SAR, Optical, AIS
  • Revisit Time

• Sea Target Detection from spaceborne GNSS-R DDM
  • Algorithm Rationale
  • Preliminary results on UK TDS-1 data

• Comments and Conclusions
Sea Target Detection from GNSS-R imagery

Simulation study performed by using the actual spaceborne GNSS-R mission simulator developed by UPC-BarcelonaTech: GEROS-SIM (http://www.tsc.upc.edu/rslab/gerossim).

Targets?
Sea Target Detection from GNSS-R imagery

One target

No Target

Four targets
Sea Target Detection from GNSS-R imagery

Sea Target Detector

- Pre-processing
- Pre-screening
- Selection
- Geolocation

Ships and Ice Monitoring with Improved Revisit Time Using GNSS-R Constellations
Universitat Politecnica de Catalunya-BarcelonaTech, Spain – University of Naples Federico II, Italy
Outline

• Why ship/ice detection?

• Why GNSS-R?
  • GNSS-R vs. SAR, Optical, AIS
  • Revisit Time

• Sea Target Detection from spaceborne GNSS-R DDM
  • Algorithm Rationale
  • Preliminary results on UK TDS-1 data

• Comments and Conclusions
Preliminary results on UK TDS-1 data
Preliminary results on UK TDS-1 data
Outline

• Why ship/ice detection?

• Why GNSS-R?
  • GNSS-R vs. SAR, Optical, AIS
  • Revisit Time

• Sea Target Detection from spaceborne GNSS-R DDM
  • Algorithm Rationale
  • Preliminary results on UK TDS-1 data

• Comments and Conclusions
Comments and Conclusions

• Ship/ice detection plays a key role in maritime surveillance and security.
• Remote sensing represents a competitive alternative to AIS especially for open ocean or non-cooperative sea traffic.
• SAR and optical, although greatly exploited in the maritime traffic monitoring, exhibit important limitations, especially concerning the revisit time.
• GNSS-R technology paves the way for real-time sea target monitoring with cooperating constellations.
• The revisit time of GNSS-R constellations can be reduced by increasing the constellation size, the number of parallel tracking channels, the GNSS stations tracked.
• A sea target detection algorithm has been developed, and demonstrated with actual GNSS-R data for the first time.
• Further validation will be performed with the 3Cat-2 mission and the upcoming CYGNSS missions.
• Detection performance improvements expected with GNSS-R multilook processing. More work is going on.
THANK YOU.