Progress in Automatic Ship Detection and Classification

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Plan of the presentation

- Context of ship detection versus marine applications
- Better estimation of characteristics of detected ships
- Using polarimetric information
Vessel detection versus marine applications

• The vessel detection is only a technical part of marine applications based on spaceborne SAR

• The vessel detection reports (VDR) usually have to be integrated into a full application chain, based on two kinds of SAR acquisitions modes (*):
  – High resolution / small coverage:
    • “One shot” observation of a limited area of interest with high reactivity
    • Focus on “expected” event: intelligence...
  – Medium resolution / wide coverage
    • Systematic monitoring of very large areas
    • Searching for unpredictable events: oil spill detection...

• The selection of optimal SAR acquisitions modes for vessel detection may not be possible due to requirements of the expected marine applications:
  – High reactivity => low incidence angle products in addition to high incidence angle
  – focusing on systematic monitoring of very large areas with a high revisit frequency => medium resolution products

• (*) The compromise between resolution / coverage will be updated with the Sentinel-1 mission
Example: Pollution Detection Operational Service

Detection of marine pollution and identification of polluters
Wide swath / Medium resolution products (ASA/WSM, RS1-2/ScanSAR Narrow/Wide...)
SAR Vessel Detection is a by-product
  Automatic processing is needed for NRT processing
  Optimal characterisation of the detected echoes is needed for an appropriate polluter identification
  Low false alarm rate is expected

EO Product acquisition
- EO Product (SAR image)

Quality pre-processing
- Geographic registration

Early detection & measurement
- vessel
- wind
- swell

Supervised Detection
- Oil

Polluter identification
- Drift model
- Correlation SAR/VTS/AIS/VTMS

Identification report

AIS/VTS/VMS

Metoocean models

EO Product acquisition

Quality report

Situation report

Detection report

Identification report

Reception report

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Example: Metocean measurement

- Wide swath / Medium resolution products (ASA/WSM, RS1-2/ScanSAR Narrow/Wide...)
- SAR Vessel Detection is an internal by-product
- Fully automated processing needed due to operational requirements and the volume of data
- No characterisation of the detected echoes is needed
- Medium/High false alarm rate is acceptable
- Automatic geographic registration is a expected
Example: Abnormal marine activity on limited area of interest

- For instance: detection of « go fast »
- Narrow Swath / High Resolution products
- Systematic vessel detection is an internal by-product
- Only the characterisation of a limited number of vessels of interest is needed
- Very low false alarm rate is needed
- Supervised/manual detection and characterisation of the vessels of interest is needed

- Note: we will not develop a vessel detection algorithm in human operators head
BETTER CHARACTERISATION OF THE DETECTED ECHOES
Characterisation of vessel in high resolution products is not a challenge

Example: RS2 / Multi Look Fine, 10m resolution

03: NORGAS TRADER
Pavillon: Singapour
Type: Transport de gaz liquéfié
Dimensions: 119 m x 18 m
Dimensions SAR: auto 145 m, manuelle 135 m
Code MMSI: 563662000

04: GRAND SAPPHIRE
Pavillon: Panama
Type: Transport de véhicule
Dimensions: 199 m x 32 m
Dimensions SAR: auto 402 m, manuelle 206 m
Code MMSI: 372516000

05: HARMEN OLDENDORFF
Pavillon: Liberia
Type: Minéralier
Dimensions: 225 m x 32 m
Dimensions SAR: auto 348 m, manuelle 221 m
Code MMSI: 636090932
Characterising the vessel in medium resolution products is the real challenge

• **Standard techniques of length estimation:**
  – Measurement of the shape of the detected echoes
  – Not best suited for medium resolution products
    • The biggest vessels have an extension of few pixels
    • For most of the vessels, the length is below the resolution of the product
Characterising the vessel in medium resolution products is the real challenge

- **New technique** of length estimation
  - Fused length estimation based on both geometric and radiometric measurements
- **Geometric measurement**
  - Measurement of the shape of the echo (as usual)
- **Radiometric measurement**
  - Inversion of a model of vessel RCS with respect to its length
  - Literature of the domain [Skolnik, Vachon97]
  - Obtained using AIS “ground truth”
Characterisation of AIS data as « ground truth »

Stacked positions

Characterisation of the receiver performances
SAR / AIS correlation

- **Color code:**
  - Green: reliable SAR targets matched with AIS position
  - Orange: unreliable SAR targets matched with AIS position
  - Red: Reliable SAR targets unmatched with AIS position
  - Black: Unreliable SAR targets unmatched with AIS position
  - Blue: AIS position unmatched

- **2 main issues**
  - Many red points: range of AIS reception or false alarms or vessels not equipped?
  - Many blue points: non detection by SAR image

- **Need for a comprehensive understanding of:**
  - AIS data reception for each station: range, angular aspect, sea state/atmosphere dependency...
  - Non detection linked to the SAR image itself
Characterisation: RCS model of vessels

- Modelling of vessel backscattering

Coupling between SAR & AIS
Empirical modelling of vessel RCS with respect to its size and incidence angle

\[ \sigma = g(L, \theta) \]

\[ L = h(\sigma, \theta) \]

Applies to the max RCS of the vessel:
- Ensures that there is no dependency on the echo segmentation
- Implies that the RCS model has to be tuned to each product type
1 estimation of length = 1 sensor

Here we have two imprecise sensors
- One sensor based on geometric measurement
- One sensor based on radiometric measurement

Each measurement is characterised by a distribution of possibilities
- Support corresponding to possible values
- Kernel corresponding to truthful values
- Max = 1 for truthful values
- Min = 0 for unrealistic values

The distribution is defined based on:
- The measurement itself and its variability
- Limits of ship lengths

Fusion operator
- T-norm of Zadeh = minimum
Data Fusion & distribution of possibilities

Concording sensors

Contradictions between sensors

Limg : 130 m
Lsigma : 70 m
L fus : 90 m

Solved by considering confidence of each measurement
Results of fuzzy logic size estimation: ASA/WSM/VV

- Geometric approach with step effect: related to the geometric estimation + pixel spacing.
- Overestimation of the length

- Improvement of length estimation (better fit of the data, no step effect)
- Effective fusion for medium resolution products
- 6447 vessels for the test, 1930 for the learning of the RCS law and fusion.
Results of fuzzy logic size estimation: ASA/WSM/HH

Geometric measurement

Fused geometric & radiometric

762 vessels for the test
290 vessels for learning
POLARIMETRIC DETECTION
Polarimetric signature of a vessel imaged in RS2 Fine Quad Pol mode
Pauli decomposition

Pauli RGB

Pauli RGB with lee filtering
Co-pol and cross-pol power

Synthesis of co-pol power from Muller Matrix

Synthesis of x-pol power from Muller Matrix
H/A/alpha polarimetric decomposition

alpha1

entropy
Optimization of Polarimetric Contrast Enhancement

- SAR based ship detection usually assumes a high contrast between a bright target and the sea clutter -> CFAR principle
  - Not valid for small target «lost» in sea clutter (low contrast)
- Full polarimetric data enables the generation of the target/clutter signature in any polarisation basis $P_b = h^t[K]_b g$
  - $K$ polarimetric Kennaugh matrix and $g$-$h$ the receiving and transmitting antenna polarisation state
- OPCE-like method optimizes the contrast (Kostinski et al 77-78) – recent fast implementation by Yang et al. 2004

$$\begin{align*}
\text{maximize} & \quad \left( \frac{h^t[K]a g}{h^t[K]b g} \right) \\
\text{subject to} & \quad g_1^2 + g_2^2 + g_3^2 = 1 \\
& \quad h_1^2 + h_2^2 + h_3^2 = 1.
\end{align*}$$

- Ideas to be developed/tested in the coming months
  - Build a comprehensive polarimetric database from RS2 quad-pol images
    - Various detected ships, incidence angle, sea state ...
  - Extract a limited (if possible) set of $g$-$h$ polarisation state optimizing the ship-to-clutter ratio
  - Apply this set of vector and apply a CFAR-based method on the simulated power
Conclusion

• Automatic vessel detection is usually only a part of marine applications
  – Help to operators in order to perform identification of polluters, or IUU activities...

• Multiple possibilities to measure vessel characteristics
  – Each of them with different reliabilities
  – Interest to combine/fuse them in order to improve the overall accuracy

• Still lots to be done with polarimetric information
  – Even if full polarimetric data will not be systematically available

• Interest of interfacing echo (not vessel) detection with metocean measurement in order to improve their overall performance and accuracy
  – Toward and integrated wind-wave-current +VESSEL inversion
The End

THANK YOU
Bibliography


Acknowledgment

• Part of the results in this presentation were obtained in the framework of the FP7 DOLPHIN Project:
  • http://www.gmes-dolphin.eu/team
Appendix: Minimum detectable ship length for Sentinel-1 HH and HV

Sentinel-1: ESA’s Radar Observatory Mission for GMES Operational Services, SP-1322/1, March 2012

Figure 12.4. Minimum detectable ship length for Sentinel-1 HH (blue) and Envisat ASAR HH (green).
HH, $U = 12$ m s$^{-1}$, $\varphi = 0^\circ$; $\nu = 4$; PFA = 2.5e-009; PD = 0.9; margin = 3 dB.

Figure 12.5. Minimum detectable ship length for Sentinel-1 HV (blue) and Envisat ASAR HV (green).
HV, $U = 12$ m s$^{-1}$, $\varphi = 0^\circ$; $\nu = 4$; PFA = 2.5e-009; PD = 0.9; margin = 3 dB.