Plenary talk

“Maritime Surveillance: Radar Technologies and scenario characteristics”

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Let’s pass the torch to space technology
Did you know?...

...the world’s coastline in numbers

- **x12**: The total length of the world’s coastline is approximately 500,000km – 12 times the length of the Equator.
- **Coastal regions**: 20 per cent of the Earth’s surface and yet contain half of the world’s population. By 2025 coastal populations will account for 75 per cent of the total world population.
- **More than 70 per cent**: The megacities (more than eight million inhabitants) are located in coastal areas.
- **Half of the world’s cities**: With more than one million inhabitants are sited in and around estuaries.
- **The average human population density in coastal areas is 80/km² – twice the global average.**

- **One-third of the European Union population is located near the coast.**
- **Europe**: 86%  
- **Asia**: 69%  
- **The most threatened regions are Europe, with 86 per cent of its coastal ecosystem at risk, followed by Asia (69 per cent).**
- **One-third of coastal regions are under threat of degradation by infrastructure development and pollution. In half of these the threat is increasing.**
- **In the Pacific, 60 per cent of the coast is eroding at a rate of 1 metre or more per year. In the Atlantic, this figure is 35 per cent.**
- **The cost of maintaining marine coastal ecosystems is 0.2 per cent of their actual value (from tourism and fishing, for example) per year.**

SOURCE: WORLD OCEAN NETWORK

https://digital-library.theiet.org/docserver/fulltext/et/13/7/20180709.pdf?expires=1566150362&id=id&accname=guest&checksum=83F361353ADB9B788FE52FD68C0E5874
Radar for VTS

VTS is the acronym for “Vessel Traffic Service”, i.e.: those services that national Coast Guards shall provide to ensure Safety of Life at Sea, Environmental protection of the maritime environment and Port Efficiency.

After World War II, it became clear that short range, audio-visual aids to navigation were not sufficient to enable the full utilization of port facilities in all conditions of visibility and traffic density.

The first radar based Port Control station was established in Douglas, Isle of Mann, in 1948. Later the same year, the port of Liverpool established a radar site and similar trials took place in Rotterdam.
Radar for VTS (cont’d)

In 1950, a number of shore-based radar chains were established in other European ports, including the approaches to the port of Amsterdam in 1952 and the entire Rotterdam port area in 1956.

In 1960-70 major shipping disasters made the public aware of environmental damages. The concern that such disasters might happen in port approaches and port areas further expanded the use of radar surveillance and vessel traffic management.
Today **IMO** (International Maritime Organization) states that VTS serves for:

- Enhancement of Safety of life at sea surface
- Environmental protection against disasters that affect marine environment
- Increase of the port efficiency level

**IALA** (International Association of Lighthouse Authorities) recommends the use of the following sensors for VTS Systems (not exhaustive list):

- Radar: S/X Band
- AIS: Automatic Identification System
- EOS: Electro-Optical System
- DF: Direction Finder
- Meteorological Sensors
  - …
AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport. When satellites are used to detect AIS signatures, the term Satellite-AIS (S-AIS) is used.

**AIS** is an automatic tracking system used on ships and by vessel traffic services (VTS). The AIS transponders send data every 2 to 10 seconds depending on a vessel’s speed while underway, and every 3 minutes while vessels are at anchor. These data include:

- The vessel’s Maritime Mobile Service Identity (MMSI), a unique, identification number.
- Navigation status (at anchor, under way using engine(s), or not under command).
- Rate of turn, Speed over ground, Course over ground, True Heading.
- Longitude and Latitude.
- Time stamp (UTC).
The VTS system
New challenges: the R-mode

• There is international recognition that the GNSS alone is insufficient for critical applications. IALA promoted experimental projects, to explore the possible utilization of commonly used RF emission (MF, VHF, ...), in order to increase the reliability of the E-navigation systems (e.g. triangulation) and employ GNSS-independent back-up systems.

• **R-Mode** (Ranging Mode) is the transmission of accurate synchronized timing signals from existing terrestrial maritime TX-RX radio:
  • **MF:** IALA Radiobeacon Service (used for DGNSS)
  • **VHF:** AIS-shore based service
  • Combination of MF, VHF and existing eLoran RF signals

• The **Baltic Sea** is the first operational test area for this technology (R-Mode Baltic, Oct-2017).
• Current status and preliminary results has been presented during last workshop on Ranging Mode (R-Mode) at IALA (Saint-Germain-en-Laye, 9-12 September 2019).

The VTS system: the Italian network

One of the largest system in the world for coastal surveillance

- Radar sensors are deployed in a large number to cover harbors traffic areas and the full coastline.

http://www.leonardocompany.com
**Scenario & challenges for VTS radar**

The VTS radars detect the movement of all the ships on the coast line, from large vessels and to small wooden boats used by fishermen.

- VTS radars exploits Magnetron and Solid State equipment, operating in S Band or X Band, depending on target, distance and environment characteristics. Typical performances are (*):
  - Maximum ranges are typically 12 to 48 NM
  - Targets RCS ranging from $0.5m^2$ to $1000000m^2$.
  - Antenna beam widths and pulse widths are defined according to a typical required separation of 0.5 deg in azimuth and 15 m in range (compressed or not coded pulse).

(*) IALA Guideline 1111 – Preparation of Operational and Technical Performance Requirements for VTS Systems
Edition 1.0 May 2015
Scenario & challenges for VTS radar: dynamics & resolution
Real data of a “fleet” fisher boats
Scenario & challenges for VTS radar: sea clutter

“Echoes from the sea as seen by high-resolution radar consist of short duration, somewhat repetitive bursts that have been called sea spikes. Typically, the durations of sea-spike radar echoes at X band might be of the order of one second. They reoccur, on average, from roughly 12 to 16 s (for Sea States less than 3).

When the sea is viewed with high resolution radar, only sea spikes are observed – usually nothing else. With low resolution radar the sea looks continuous and random-like (because numerous sea spikes are within their resolution cell).”


Sea clutter on A-scope display showing amplitude vs. time.

Scenario & challenges for VTS radar: sea clutter (cont’d)

Sea spikes have the same behavior of the echoes from real targets, even when detected at different Doppler filters.

Using solid state TX and coherency in TX-RX chain, the instantaneous radial velocity of the radar echoes can be extracted © and the sea spikes can be isolated and filtered out ©.
Scenario & challenges for VTS radar: 
sea clutter (cont’d)

Sea clutter (*sea spikes*) mitigation using SS TX, High stability, coherent processing filters during *sea storm* (sea state >3)
Tracking and Data fusion: Typical Target Tracking Scheme

Plots from data extractor

Data Association

Successful Association?

Yes

Predicted track

Filtering & Prediction

Yes

Display Output

No

New Track?

Yes

Track Initiation

No

Old Track?

Yes

Track Termination

No

The work horse of many tracking systems

e.g. Kalman filter (adaptive, multiple model, etc.)
Tracking and Data fusion:
Kalman Filter – single run, on a single target

Case study:
2D motion with constant velocity and small process noise

State covariance (ellipsoid areas) is reducing in size with time
Tracking and Data fusion: Multi-radar – Multi-sensor tracking systems

Example Data Fusion. Integration of multiple heterogeneous sensors, e.g.:
- land based radars;
- air-borne radars;
- space-borne radars;
- EO/IR sensors;
- hydrophones.

The use of multiple sensors involves engineering issues, such as:
- the role of sensors resolution;
- the “data incest” to be avoided/mitigated;
- the communication network and the exchange of information;
- the integrated architecture (decentralized, centralized, hybrid);
- the coordination of a Command and Control centre.

Monitored environment (scenarios: land, sea, air, …)

Communication Network

Coordination from a Command & Control centre, C2

Multiple sensors
Tracking and Data fusion: Paradigm for System of Systems of Surveillance
The conditional probability is obtained from the two sets of local measurements $Z_1^t$ and $Z_2^t$, which are observation random variables on the same state $s(t)$.

Since $\{Z_1^t \cap Z_2^t\}$ represents the information common to $Z_1^t$ and $Z_2^t$, the product of individual conditional probabilities is divided by $p(s(t)/Z_1^t \cap Z_2^t)$ to remove the double use of common information.

Possible sources of common information, when local estimators are dealing with the same random system, are:

- Initial conditions $s(0)$,
- Process noise $w(t)$,
- Communication network in a not hierarchical distributed architecture (e.g.: the info received by a node may contain info originating by the same node at an earlier instant).
Tracking and Data fusion:
Fusion System Errors ➔ a Budget to Mitigate

- **Processing Limitations**
  - Hardware Performance
  - Algorithm complexity

- **Processing Errors**
  - Correlation errors
  - Over-/Under smoothing
  - State estimation errors

- **Ground Truth Complexity**
  - Target maneuverability
  - Target spacing
  - Number of targets

- **Environment**
  - Cultivated features
  - Vegetation
  - Terrain
  - Weather

- **Sensor Errors**
  - Position errors
  - Velocity errors
  - Classification errors
  - False/missing target
  - Update rate

- **Fusion Process**
  - Fusion output errors
    - Position errors
    - Velocity errors
    - Classification errors
    - False tracks
    - Missing targets
Way ahead: continue the investigation on coherent sea clutter models and their mitigation.
THANK YOU FOR YOUR ATTENTION...
Maritime Domain awareness and the geospatial layer

• Maritime “Awareness” is today a top priority for Europe and on global scale. It is sought either in regards of maritime security, control against irregular immigration and safety of navigation or in regards of the marine environment and climate change.

• “Awareness” is sought both for sea-basins of traditional interest like the Mediterranean and the Atlantic as well as for basins currently trending like the Arctic.

• Maritime situation awareness is supported by a combination of satellite, airborne, and terrestrial sensor systems.

• To address solutions to process the complete set of sensors data – cooperative and non-cooperative - into information that supports operator decisions is a priority in the technology and product road maps.
Maritime Domain awareness and the geospatial layer

• Non-cooperative Satellite Earth Observation (EO) systems produce, in the optical and radar sensing domain, a very large amount of data that combined with other information layers serves as a fundamental tool to increase maritime domain awareness and surveillance and to support Public Authorities to carry-out their operations in a more efficient and effective way.

• Data fusion of optical and radar sensors is essential, but the key feature of radar systems is that they are all weather all conditions sensors

• The Copernicus flagship European program and national contributing missions like the Cosmo Skymed radar Constellation are essential in this respect and provide already today a powerful information layer to global maritime awareness.
A complete suite dedicated to the Maritime domain awareness to monitor large areas and detect even small boats, in near real time and everywhere.
Key Monitoring features

Maritime traffic monitoring & Vessel detection

Illegal activities monitoring
illegal fishing, smuggling, illegal immigration, drug trafficking, piracy

Coastal monitoring

Emergency Response
Search & Rescue
Generated Content

**Points of Strength of the Service**

- Ground Receiving Terminal Network
- Wide and Global coverage
- Multisensor solution

- Validated by Institutional User
- Secure data access

- Experienced Operators on maritime surveillance Satellite image analysis
- Operational 24/7
- Fully Automatic and/or supervised processing
Operational capabilities

24/7 availability NRT Services and Emergency Team (nearly 40 Engineers and Analysts) for:

- Customer interface for activation management
- Satellite data tasking, image downlink and processing
- Products and Map production and fast delivery
Operational capabilities

Example of operational service flow for Oil Spill detection
Operational capabilities

Law Enforcement eXploitation of EO
Coast! monitoring coverage

Open Sea
Vessel Classification

A (>100m)  
14%

B (50m - 100m)  
17%

C (20m – 50cm)  
29%

D (<20m)  
40%

go fast - small boat

Coastal Monitoring
SAR change detection integrated with Optical data for validation
Operational capabilities

Maritime processing chain

- vessel detection
- vessel classification
- data fusion
- persistent tracking
- behavioural analysis
Complete Environment for Analysis

- Near Real Time & Real Time Capabilities
  - Data Acquisition
    - Multi-platform
    - Multi-source
  - Data Processing and Feature Extraction
  - Product Delivery and Visualization
    - SEnSE Engine
    - SEnSE Portal
Complete Environment for Analysis

Integration of multi-source data for Maritime Awareness

AIS data, Vessel historical route and forecasting

Service Statistics
# Complete Environment for Analysis

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
</table>
| Multi-sensors & Multi-source         | Supported Earth Observation Missions:  
• SAR: COSMO-SkyMed constellation, Sentinel-1, Radarsat-2, TerraSar-X, ALOS-2  
• Optical: GeoEye-1, Pleiades 1, SPOT-6 and SPOT-7, Sentinel-2  
Other data:  
• met-ocean, weather, offshore oil platforms, AIS/SatAIS, vessel picture |
| Integration with main AIS providers  | ExactEarth (CSV and GWS), SPIRE, ORBCOMM                                                                                                                                 |
| OIL & Ship correlation              | AIS and SAR derived detection and correlation                                                                                                                                 |
| Online correlation                  | Online data fusion between different datasets (Sar2Sar, AIS, User data)                                                                                                                                 |
| Fully browsable datasets            | Search, Filtering, Querying and Downloading functionalities over the datasets: Ship, Oil, Sat Acquisition, AIS, User AOI and Offshore Platform |
| Full resolution SAR Clips visualization | Full resolution SAR clips related to each detected vessel or oilspill                                                                       |
| Geospatial Big Data analytics       | Anomaly detection  
Heatmap generation with different specializations  
Vessel Track Calculation             | Historical Track Calculation  
Historical Analysis Track Calculation  
Predicted Track Calculation  
Offline products delivery            | KML files through FTP repository  
Vessel parameters estimation         | Length, width, heading, speed, ship type  
Oil parameters estimation            | Dimensions, Confidence Level, ...  
Content Management System (CMS)      | Collaborative feature editing, live chat, document management  
Easy integration                    | Direct data feed into the Customers’ systems by using dedicated API |
SEonSE engine

Multi-sensor data ingestion
Data Fusion
Maritime features extraction and correlation
Analysis Tool: SEonSE Dashboard

The Dashboard module presents, in interactive way and by different aggregations, all processed information, giving to the user the possibility to easily extract service statistics and sharing through API standard APIs.
Pre defined rule and event based methodology for:

- Anomaly Detection
- Maritime Knowledge Discovery standard APIs.

<table>
<thead>
<tr>
<th></th>
<th>Satellite Ship Detection</th>
<th>Satellite Oil Spill Detection</th>
<th>Identification and Tracking Systems (AIS, SatAIS, ...)</th>
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<tbody>
<tr>
<td><strong>AOI</strong></td>
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<tr>
<td>Exiting</td>
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<td>Approaching</td>
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<td>Distance to Shore</td>
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<td><strong>Behaviour</strong></td>
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<td>Rendezvous</td>
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<tr>
<td>Sudden change of heading</td>
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<tr>
<td>Sudden change of speed</td>
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<tr>
<td>Speed Threshold</td>
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<td>No movement</td>
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<td>No position messages</td>
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<td>Pre-defined list</td>
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<td>Illegal, Unreported, and Unregulated (IUU) fishing</td>
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<tr>
<td>Own fleet</td>
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<tr>
<td>Knowledge discovery</td>
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<tr>
<td>Persistent/Recurrent feature detection</td>
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<td>Heatmap</td>
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<tr>
<td>Information consistency</td>
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<tr>
<td>Vessel dimensions comparison</td>
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<td>Change of IMO, Name, Destination during the voyage</td>
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<tr>
<td>Cloned identity</td>
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</table>
Historical Analysis Track
GeoAnalysis Anomaly Detection

<table>
<thead>
<tr>
<th>Target 1</th>
<th>Target 2</th>
<th>Target 3</th>
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<tbody>
<tr>
<td>Length</td>
<td>21.5</td>
<td>28.3</td>
</tr>
</tbody>
</table>
GeoAnalysis Anomaly Detection

2 small size targets (vessels) detected only by wake
Moving very fast, in parallel and close each to other

Wake detection

Pattern Analysis

2 fishing vessels
From a foreing country
Fishing in Somali EEZ with a close and parallel route
GeoAnalysis Anomaly Detection
Maritime Big Data Infrastructure
Big Data Analytics: Main commercial routes

Big Data Analytics: Port area monitoring

Big Data Analytics: Fishing activities monitoring

Big Data Analytics: Knowledge discovery
Geospatial Big Data Analytics
AIS main maritime routes per ship type
Geospatial Big Data Analytics
Systematic monitoring by Sentinel

1. RAW SATELLITE DATA
2. SAT SHIP DETECTION
3. MARITIME PATTERNS
Geospatial Geo Spatial paradigms are fast changing

Despite delay in some announced programs, the number of EO satellites in orbit and the corresponding amount of generated data starts to grow fast....

Use of EO data is exponentially growing, and large potential through analytics exists to feed new information-driven services.
Geospatial Geo Spatial paradigms are fast changing

- Data, more and more, are just a part of the game
- High temporal resolution to complement high and very high spatial resolution sensors
- Federation of space assets through smart multi missions tasking platforms
- EO data entered in the wider Big Data Analytics & IoT game
- Convergence in the data analytics and AI business for the EO
- Advanced algorithms, ML/DL/AI techniques are essential to address the Information driven market and pushing for timely delivery of reports/insights
Geospatial Geo Spatial paradigms are fast changing

Big data analysis

Information Products

Value Added Services

Data

COSMO-SkyMed

e-GEOS is the exclusive commercial worldwide distributor of COSMO-SkyMed constellation data

e-GEOS has renewed the concession agreement with ASI in Dec 2018 covering [2019-2027] and encompassing both CSK and Cosmo Second Generation

System owners, ASI and IT-MOD, want to maintain and further improve Italian leadership in Radar technology with CSG keeping the 4 sat configuration stable
Geospatial Geo Spatial paradigms are fast changing

federation of assets is a fundamental feature of our application platforms and the evolution path to information products and Geospatial Digital Services
Geospatial Geo Spatial paradigms are fast changing

New EO systems will give the possibility to cover much wider area in the spatial and temporal matrix \(\rightarrow\) data variety to derive timely information
Geospatial Geo Spatial paradigms are fast changing

Defense and Intelligence will largely benefit from a higher data variety as well as of advanced methods to derive timely information flow.
THE RACE OF THE FUTURE

Space assets evolution

Exploitation of information from Artificial Intelligence tools

the AI factory

Open innovation

Big Data Analytics and AI CC – The AI Factory

- Personal Dashboard
- Training-set preparation tools
- Deep learning mod design tools
- DL model evaluation
- Analytics pipelines & API

powered by e-geos
AI algorithms for maritime awareness

AI based Ship detection

New approach to detect small and fast vessel by the generated wakes in SAR images, using Deep Learning and Artificial Intelligence techniques.

Our model
- Input image shape: 800x800
- 10 convolutional layers
- Dense layers replaced by 1x1 convolutions, order to have a map instead of a single label
- Up to 64 features per layer
- ~60000 parameters
AI algorithms for maritime awareness

Ship classification by AI

- Convolutional neural network (CNN) for classifying 3 vessel categories.
AI algorithms for maritime awareness

SAR processing includes:

- Coregistration/Geocoding
- Land Classification
- Advanced filtering
- Target Detection

ATR – Automatic target recognition algorithm or device to recognize targets or objects

AI transfer learning

- SAR imagery is preferred because:
  - It is unaffected by atmosphere (clouds, illumination, ...)
  - It is unaffected by disguising (paintings, covers, ...)
  - SAR scattering is not invariant to rotations, neither to small ones.
  - Therefore hundreds of examples for each target model are needed to train the recognizer, increasing the costs.
  - We explored the solution to use a SAR simulator for the training.
AI algorithms for maritime awareness

Automated Ship Detection Based on Deep Learning
Construction of Synthetic Datasets

Deep Neural Networks for the detection & segmentation of specific objects from satellite images, the creation of fictitious VHR/HR datasets is key in the AI4EO community. 3 CNN models (Segnet, U-Net, and Mask R-CNN) for the detection of ships from VHR & HR optical images starting from annotated VHR datasets support near-real-time Maritime Domain Awareness services through the classification, detection and segmentation of maritime vessels and the generation of a digital report containing information such as position, length, width and heading of each detected vessel to generate Synthetic Datasets.

Deep Learning Wake Detection from SAR Images

Collected and labelled training, validation and test datasets
Designed and built a deep Convolutional Neural Networks (CNN)
6 convolutional layers alternated with max pooling layers, ranging from 4 up to 64 features per layer - 2 1x1 convolutional layers
~64000 parameters
Focus on cooperation and info sharing

- Integrate multiple sources of geo data into a single intelligence environment – enhance sensors and data collection
- Optimize collection, analysis, visualization and exploitation of geospatial data through advanced processing and learning Algorithms
- **Access new developments in satellite, aerial and imagery to identify more affordable, easy-to-access services**
- Tools to safely integrate classified geospatial data safely with open sources and Social Media
- **Improve geospatial intelligence sharing in civil-military operations**
- Map the threat landscape to predict where geospatial intelligence can best be deployed next
Focus on cooperation and info sharing

Intelligence and Info-sharing environment *to reduce the complexity behind geospatial data exploitation through* end to end workflows supporting the analyst during the whole life cycle

- European Geospatial Industries have consolidated good cooperation practices built to effectively respond to EU institutions/entrusted entities and actively support the needs

- Cooperation with national multi-national and international Institutions is highly recommended to share technology innovations, operational capabilities and to obtain a common enhanced situation awareness
EYES ON THE EARTH