ASSESSING THE OPERATIONALITY OF SHIP DETECTION FROM SPACE

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ABSTRACT
Since the launch of ERS-1 in 1991, a decade and a half of research has been devoted to automatic detection of ships in satellite radar imagery. However, it is only quite recently that this capability is operationally used; at present primarily in the fields of fisheries control and defence. The key has been the combination of remote sensing data with vessel position data from other sources. In contrast to detection, classification of ships in satellite radar imagery is much less developed, and will likely remain difficult in the near future. Concerning optical imagery, the recent high-resolution systems can readily detect ships from space, and their classification power is much higher than that of radar. However, much less effort has been devoted to development of automatic systems for optical, mostly because these sensors suffer more from the weather and are less suited for wide area surveillance. Nevertheless, there has been a recent catching up, and the first operational systems for automatic ship detection and classification in optical satellite images are starting to appear.

1. INTRODUCTION
For over a decade, researchers have explored the possibilities of applying space-based imaging for ship detection and maritime traffic surveillance. However, it is difficult to get a good overview of the operational status of these developments. Potential users of such systems are faced with a plethora of claims from suppliers regarding the capabilities of different systems to answer their operational needs. The project “DECLIMS” (Detection and Classification of Marine Traffic from Space) aims to clarify these matters. This concerted action project under the EC Fifth Framework program includes 23 partners that are active as developers or users of space-based ship information [1]. The partners are from diverse backgrounds: government, academia, institutes, industry, small and big companies; civilian and defence; European, American and Asian. Both optical and radar imaging are considered. The project is intended to be a focus for research activities; experiences and opinions are exchanged, and benchmarks are carried out by comparing the different algorithms employed by the partners on sets of standard data.

2. OPTICAL IMAGING
Considering optical imaging first, it has been relatively clear that present-day high resolution sensors such as QuickBird, IKONOS and SPOT-5 are able to find even small ships, and produce images that are detailed enough for classification of large and medium sized vessels. For vessels under 10-15 meters, however, classification is still difficult. Automatic ship detection in optical imagery is, on the other hand, not much developed. When DECLIMS started 1½ years ago, there was to our knowledge no operational capacity, and even in the research domain there was not much available. However, since then two developments have taken place. Software based on eCognition is being developed for automatic detection of ships in harbours in sub-meter resolution optical imagery (QuickBird, IKONOS)\(^1\). One of these packages has reached commercial prototype product stage\(^2\). Its focus is not a fully automatic analysis, but the development of an efficient harbour surveillance system, which combines automatic detection and categorisation of ships with easy and fast manual interaction for detection refinement and final ship recognition and identification. The current prototype can be embedded in the user’s workflow and can be combined with vessel-related information from other sources.

A second new line of development\(^3\) focuses on feature-based analysis of SPOT imagery (down to 2.5 m resolution). Here, genetic algorithms and neural network

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\(^1\) Independently by Doxiades GeoImaging and Definiens Imaging
\(^2\) Definiens Imaging
\(^3\) IRD, SPOT Image

approaches are used to deal with the feature-borne
information. This has not yet attained operational status.

The reason that optical techniques are not as operational
as radar methods is in part due to shortcomings in
coverage – the high resolution optical systems have
limited swath- and weather-windows. Operationally,
optical imagery is not suitable for wide-area
surveillance, but more for monitoring specific areas
such as ports or straits. It is also being suggested that
high-resolution optical image acquisition could be
triggered by other information, notably by wide-swath
satellite radar imagery.

3. SAR DETECTION

In satellite SAR (Synthetic Aperture Radar) imaging,
much more progress has been made. A large body of
research exists, most recently reviewed in [2]. Several
systems for SAR ship detection are now operational
and/or offered on a commercial basis\(^4\). DECLIMS has
given quite a complete overview of the various methods
and techniques that are in use today for automatic
detection of targets in maritime spaceborne SAR
imagery. Moreover, a detection benchmark test was
carried out on several operational and some research
systems, encompassing 8 different detection algorithms
[3]. This has quantified the performance that can be
expected on a uniform basis, and has revealed problems
both common to all and particular to specific
approaches. All SAR ship detection algorithms that are
operational today rely on finding image values that are
high with respect to the local image background; they
differ in the extent of background and target regions, in
their assumptions on the background statistics, and in
their “intelligent” ways to discard target-like noise
peaks. Some unique approaches use templates for the
targets\(^5\), wavelet-based analysis\(^6\), or SAR sub-
apertures\(^7\). The latter two have as yet only experimental
status.

SAR vessel detection rates depend on many factors,
which relate to ship, radar and environment. Concerning
the ship, the main factors that influence the detectability
are size, material, shape and speed. Concerning the
radar, they are resolution, number of looks, incidence
angle and polarisation. In addition, the orientation of the
ship with respect to the radar (head-on or broadside)
plays a role. Concerning the environment, main factors
are wind (speed, direction) and waves (length, height
and direction).

With so many independent factors that play a role in the
detectability, it is not only very difficult to accurately
predict detection performance, but even difficult to
obtain good quantitative estimates. It is impossible to
probe even a small part of the entire combination space
of possibilities, and in many cases not all factors are
known. In particular, verification experiments always
suffer from a lack of independent ship traffic data
concurrent with the satellite images. Nevertheless, for
users of space-based ship detection systems it is
important to know, in a given situation, what percentage
of ships may have gone undetected. There are several
studies published that try to answer this question
[referred to in 2].

The DECLIMS benchmark can give a small
contribution, but its main goal however was to
intercompare the performance of the various detection
algorithms. The main interest in the numbers quoted
below lies therefore in their spread, rather than in their
absolute values. The benchmark showed that in
favourable cases, detection rates of > 97 % can be
reached. Most common are situations with 85 – 95 %. In
difficult cases the detection rate can be down to 70 – 80
%. (Of course, in very unfavourable situations of low
resolution mode, small boats and high sea state, the
detection rate can be 0 % – however it has to be
assumed that such situations will be avoided in
operational circumstances.)

Common problems are related to: special types of
background clutter arising in particular meteorological
situations; imperfect land masks; errors in image geoposting;
image artefacts; and furthermore, fully automatic results can in many cases still be improved by
human corrections, such as manually adapting the
detection threshold or discarding some false alarms.
None of the benchmarked systems was consistently
better than all others; none is generically optimal. Some
algorithms perform better in some situations, others
better in other situations. This is due to the different
underlying algorithmic approaches.

To further improve our quantitative knowledge of
detection performance, efforts are currently underway at
JRC to analyze the large number of images collected in
their fishery monitoring pilot studies (see section 6). An
example is shown in Fig. 1. Such a figure lumps a
number of factors together (ship size, sea state, beam
mode) but in order to get enough points for meaningful
statistics this is often unavoidable.

\(^4\) KSAT, QinetiQ, Gen. Dyn., JRC; and OMW of
Satlantic, used in DECLIMS by CCRS and CLS
\(^5\) JRC
\(^6\) Univ. Pol. Catalunya
\(^7\) Mitsubishi H. Ind.
4. SAR CLASSIFICATION

Despite the advanced operational level in SAR ship detection, classification in SAR imagery remains fraught with some fundamental problems. Low resolution and motion distortion render the ship’s radar image rather featureless, providing few clues for classification. In favourable cases one can derive a size estimate for the larger (> 70 m) vessels, but with higher sea state even this becomes unreliable. At present, some of the operational systems give a target size estimate, but others deem such an estimate too unreliable and omit it altogether. No operational system exists that gives a type for its detected ships (such as fishing, navy, cargo), and indeed this kind of result is not expected for the near future.

Newer SAR sensors offer increased resolution and polarimetry. The use of a higher resolution (down to a few meters) will enhance the classification capabilities somewhat, but the ships’ motions on the waves will in many cases still frustrate the formation of actual high resolution ship images. Polarimetry will provide additional information on the targets, but its practical value for classification is not yet clear. Recent simulations [4] indicate that the use of polarimetry for classification will only be successful in combination with a resolution an order of magnitude higher than what will be available on the upcoming sensors. In addition, the enhanced resolution and polarimetry go hand in hand with a decrease in swath width, offsetting any classification gains with coverage losses. Therefore, although the high-resolution and fully polarimetric modes are expected to also improve detection, they cannot be used for large area surveillance.

5. SHIP WAKES

It is well known that ship wakes contain information about vessel heading and speed, and may aid detection. Early systems for ship detection developed for ERS-1 images detected and analysed ship wakes, which are very prominent in its VV polarisation and step incidence viewing. However, most of the presently operationally offered systems do not extract information on wakes anymore. This is in part due to the predominance of RADARSAT-1 as the sensor of choice for ship detection; there, the HH polarisation and shallower incidence angle do not favour wake imaging.

For the optical sensors, the only system operational at this time (as far as known to us) works with ships in harbours, so wakes play no role. Systems currently in development do include detection and analysis of the wake, which in optical images can show up quite prominently in white foam or sun glint.

6. USE

Satellite radar imagery provides only a limited amount of information on shipping presence and traffic. The imagery has a snap-shot nature, with typically at best daily repeats, and it does not lend itself to continuous monitoring or tracking of vessels. Classification of vessels is very limited, and identification (i.e., establishing the ship’s identity) is impossible. Therefore, satellite radar imagery is most useful when used in combination with other surveillance methods. A good case in point is the use of SAR imagery for fisheries control, where it can be combined with VMS (Vessel Monitoring System) data from fishing vessels. VMS is a system of transponders on fishing ships larger than 18 m that send the GPS position of the ship via a satellite communication link to shore. The receiving stations are the Fisheries Monitoring Centres (FMC) of the flag states. The system is obligatory in the European Union and in many other large fishing nations. VMS provides the authorities with a continuous awareness of the global whereabouts of their fishing fleet, and of all fishing activities in their national waters, in order to monitor compliance with fishing regulations. However, in addition to such a system that relies on a ship-borne component, another, non-cooperative layer is necessary to find any illegal fishing activity that does not register on VMS. For this, satellite SAR is very suitable. The countries of the European Union have during the past few years carried out pilot projects to test the integration of satellite SAR data into their VMS-based fisheries monitoring. In particular, the FP5 project IMPAST that was concluded in January 2005 has demonstrated that it is possible to combine in real-time known VMS fishing ship positions with positions of ships detected in a satellite image, in order to pinpoint those vessels that do not transmit a VMS signal [5]. Especially if this occurs within fishing grounds, this is a strong indication of...
potential illegal fishing activity. These ship positions can be available at the FMC within 30-60 minutes after satellite image acquisition, which is still fast enough to task local inspection aircraft for follow-up.

Much of the real-time communication is borne by internet technology. Transmission of the processed SAR image to JRC, where ship detection takes place, is via ftp. Communication with the FMCs is via email and internet. The results can be visualised over the web in an Image Server, which is basically a dynamic viewer in a geographic coordinate system, showing positions of VMS vessels, detections from the satellite image, correlations between these, and supporting information such as bathymetry, coastlines and EEZ boundaries (Fig. 3).

The pilot projects, especially IMPAST, have proved the operationality of this approach. In the near future, it will be decided whether remote sensing will be adopted as an obligatory monitoring tool within the Common Fisheries Policy. In the meantime, France has already set up a ground receiving station on the Kerguelen (South Indian Ocean) to monitor the EEZ. Since early 2004, all satellite overpasses are acquired, processed, correlated with VMS and followed up by ship patrol, to protect the local stocks from illegal fishing.

Currently, the other main user of maritime satellite SAR imagery is defence. Again, the radar imagery is combined with other surveillance tools that are in use such as maritime patrol aircraft. As with fisheries monitoring, the prime objective is large area surveillance, and the satellite is useful for complementing the coverage by traditional means, especially in extended, outlying regions that are less readily accessible to shore-based assets.

A key factor in operationalisation of any technology is cost. Costs of carrying out satellite monitoring are to be compared to (a) the savings on monitoring by traditional means and (b) potential damage that is prevented by the monitoring. Such comparisons involve many uncertainties. Nevertheless, concerning the first point, rough estimates on the basis of realistic maritime surveillance scenarios show that savings on aircraft time can more than match the costs of acquiring the necessary images to make those savings. Concerning point (b) in the context of fishery control, the market value of estimated illegal catches exceeds by many factors the cost of running a space-based surveillance system (per year, per area of fishing ground). Therefore, financial considerations are in favour of further operationalisation of satellite maritime monitoring.

7. FUTURE

Several new satellite radar systems will come available in the very near future: ALOS-PALSAR (Japan), RADARSAT-2 (Canada), TerraSAR-X (Germany) and Cosmo Skymed (Italy). Maritime monitoring will clearly benefit from the more frequent coverage that can be obtained. As these sensors all have somewhat different characteristics (frequency, resolution, polarisation), a continuing development effort is needed to adapt the existing systems to the new sensors. This effort must include a research part dealing with optimisation of the detection algorithms to the new sensor characteristics. Even now this research is still ongoing concerning the alternative polarisation modes of ENVISAT-ASAR.

The ample availability of VV polarisation with these new systems (including ENVISAT) will likely lead to renewed interest in wake detection and analysis. It is quite relevant to have an estimate of heading and speed of the detected ships, so that their position can be extrapolated for an interception in the framework of law.
enforcement or security operations. The ship wake is needed to give this information.

As the integration of radar imagery into existing surveillance means was a key factor for success in the case of fisheries and defence, likewise future developments should be aimed at fusing information from more sources. In particular, integration with AIS (Automatic Identification System) data is a logical next step. AIS is in a way comparable to VMS. The first ones to benefit from integrating AIS would still be the fisheries and defence users; it facilitates the creation of a recognised surface picture. For fisheries this would mean that satellite imagery can also be used over more congested areas – at present, a high concentration of traffic confuses the identification of illegal fishing. AIS will help resolve this confusion. When facilities for fusing satellite and AIS data are available, also the parties with an interest in marine traffic, for whom AIS was developed, will likely become more interested in satellite-derived shipping information. Such technological possibilities can be taken into account when developing new European maritime traffic regulations.

Whereas VMS is global through satellite communication, AIS in its presently foreseen implementation it is primarily local via line-of-sight links. This makes AIS data less accessible, and limits its use. Nevertheless, long-range versions of AIS are being considered, and people are already thinking about gathering AIS data from space [7].

Concerning the future of optical imagery, in 2005 the installation of a ground station in French Guyana is planned, with one of its main tasks the collection of SPOT imagery for fishery control. Again, combination with VMS is an integral part of the procedure. The automatic detection algorithms that are now under development will be used operationally there. This is expected to lead to considerable maturing of this technology.

8. REFERENCES

1. http://intelligence.jrc.cec.eu.int/marine/declims

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IRD, SPOT Image