Detection and Classification of man-made Offshore Objects in TerraSAR-X and RapidEye Imagery: Selected Results of the DeMarine-DEKO Project

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The project DEKO (Detection of artificial objects in sea areas) is integrated in the German DeMarine-Security project and focuses on the detection and classification of ships and offshore artificial objects relying on TerraSAR-X as well as on RapidEye multispectral optical images. The objectives are 1/ the development of reliable detection algorithms and 2/ the definition of effective, customized service concepts. In addition to an earlier publication, we describe in the following paper some selected results of our work. The algorithms for TerraSAR-X have been extended to a processing chain including all needed steps for ship detection and ship signature analysis, with an emphasis on object segmentation. For Rapid Eye imagery, a ship detection algorithm has been developed. Finally, some applications are described: Ship monitoring in the Strait of Dover based on TerraSAR-X StripMap using AIS information for verification, analyzing TerraSAR-X HighResolution scenes of an industrial harbor and finally an example of surveying a wind farm using change detection.

I. INTRODUCTION

With the globalization ship traffic is continuously rising, demanding for enhanced traffic monitoring to enable safe shipping. In addition, illegal maritime activities and threats have been increasing significantly in recent years calling for enlarged maritime surveillance. As today’s monitoring systems like coastal RADAR and terrestrial AIS have a limited range of 30 to 40 km, only a small part of the entire exclusive economic zone can be continuously supervised. Therefore, the benefit of the complementary use of Earth observation satellites for maritime surveillance has been recognized.

The DeMarine-Security project is funded by the German Government¹ and is part of the GMES (Global Monitoring for Environment and Security) program which is aimed at achieving an autonomous and operational capability in the exploitation of geo-spatial information services. The project DEKO (Detection of Artificial Objects) is integrated in DeMarine-Security [1] and focuses on the detection and classification of ships and offshore artificial objects relying on TerraSAR-X as well as on optical images. The DEKO project started in Mai 2008 and finished in March 2011. The main objectives of the DEKO project are 1/ the definition of concepts for GMES downstream services based on the obtained results, 2/ the development of new detection and classification algorithms for the analysis of ships and offshore artificial objects. In a previous paper [2] an early state of the project work has been presented.

II. DEFINITION OF SERVICE CONCEPTS

Based on user consultations, different service concepts have been analyzed with regard to their potential to satisfy existing user needs. Amongst these concepts, a centralized service, being directly operated in the satellite ground receiving station, showed the most advantages: it enables information delivery in near-real-time due to the possibility of optimized image processing and information transfer. Moreover, a multi-mission concept, integrating multiple high spatial resolution Radar satellites, is recommended, being the prerequisite for a frequent, reliable, weather and daytime independent monitoring service.

The following main requirements for the image exploitation algorithms are derived:

- Extraction of position, object geometry (length, width), and heading. The detections and the extracted parameters should be reliable under varying scene conditions.
- Optional: velocity, ship type (tanker, cargo, passenger, ferry, etc.), AIS correspondence, maritime parameters (e.g., waves or wind).
- Applicable to offshore area beneath the range of coastal radar and coastal AIS. Experimental investigations for near shore areas and non-ship object extraction should be considered, too.

Due to the varying target image quality of the SAR sensor, the reliability of the algorithm results is not always given. In ATR (automatic target recognition, [3]), algorithms compute a figure of merit (FoM, real number in the range of 0 to 100%) for each individual result. The FoM indicates the estimated reliability of the detection and its result parameters. Using the

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FeM for reliability scoring, uncertain results (at presence of blurring, waves, ambiguities, etc.) could be distinguished from output of easier tasks (e.g. in regions with calm sea) by using a ROC approach (receiver operator characteristics, [3]).

Additionally, from a technical point of view, the algorithm output should be simple and easy to handle for displaying (e.g., by googleearth) and for importing into existing systems for visualizing the maritime situation. Finally, for Near Real Time (NRT) applications, the total processing including image exploitation should take no more time than half an hour.

III. DEVELOPMENT OF ALGORITHMS FOR TERRASAR-X

Following [4], ship detection in large SAR imagery is performed in several subsequent steps: (1) preprocessing (landmasking and filtering), (2) screening (detection of object candidates with the sea as background), (3) discrimination (reduction of false alarms), and (4) further SAR signature analysis (object-background separation, object parameter estimation and classification). While the steps 1 and 2 have to be optimized towards low object missing rate and fast data throughput, the steps 3 and 4 are responsible for reducing false alarms and extraction of correct object characteristics, e.g., object position, size, and heading. In [2] we have already discussed the related work on SAR ship detection. A comprehensive review of this task can be found in [4], more recently work is described in [5].

In the following, several aspects of the DEKO processing chains are described, with contributions from both Astrium and Fraunhofer IOSB.

A. Data preprocessing and screening

Based on the detection algorithms described in [2], Fraunhofer IOSB has extended its approach:

- The landmasking, basically uses the raster data of the SRTM global DEM (within 60° north and 54° south).
- For extending the landmask, both vector data (e.g., high resolution coastal lines from electronic navigational chart ENC) and an image based approach is used.
- The screening step is based on a combination of threshold techniques and spot extraction operators.
- Using a combination of adaptive and absolute threshold and an operator response for point reflections, see [2].

Fig. 1 shows some situations which should be discussed: the land mask is not complete, since (a) in the harbor region additional land based harbor installations have been built. The sea background of the ships is influenced by (b) azimuth ambiguities of the harbor installations and by (c) hail and rain clouds. These cases show that trusting on a correct landmask or trusting on some statistical models of the sea background will lead to degradation in detection when using simple threshold techniques, e.g., the often used CFAR-approach, [4].

To overcome this drawback, a hybrid detection approach is applied: adaptive and absolute thresholds take care that areas with strong radar reflection will be found in the screening process. Additionally, a spot extraction operator based on a non-linear ranking mask [2, 6, 8] yields point reflections which give hints of man-made objects. Clustering and filtering these results will lead to the detection candidates which are the output of the screening step.

Fig. 2 shows an example ship signature (near the cloud in the Boulogne image from Fig. 1). For visualization of the high dynamic amplitude data, a false color representation is used for high gray values. The second image shows the extracted reflection points (overlaid on the gray image with white saturation) corresponding to a certain parameter set. In both images, the outer contours of the ship are visible.

B. Ship segmentation and geometry estimation

In [2] the core components of the Astrium detection algorithm had been described. Based on this early development the algorithmic chain has been extended by Astrium to an improved measurement of the object size and to the treatment of special situations. Indeed due to the high quality of the input TerraSAR-X data the detection of artificial objects is rather robust and for further improving the overall performance situations like side-by-side ships have been analyzed.
Fig. 3 shows the first step of the processing as described in [2], where both ships are segmented and characterized by a region of interest and the main axis. Based on this data a bitmap of the object is generated as input data for the newly developed histogram-based analysis. The processing steps of the histogram analysis are described in Fig. 4. The refining of the object size is based on the analysis of an accumulation histogram of the pixel contained in the bitmap. The bitmap is prior to the histogram generation processed for erasing small thin structures. The accumulation histogram is then generated along the main axis of the object. This histogram contains the borders of the objects which are characterized by the local minima and maxima. The processing then consists in detecting the local minima and maxima in the histogram and to recombine the minima and maxima in object boundaries.

As the objects have been successively affine transformed during the whole processing, the final result can be obtained in the original image by performing the inverse transform applied to the generated position and orientation.

This histogram-based analysis can improve the object detection and measurement in poor segmentation conditions as shown in Fig. 5. In this case, a single object is not represented by a unique blob; instead the segmentation splits the objects in four main blobs. This is probably due to different reflection properties on the surface of that ship.

Under the assumption that a ship is present in that region of interest, the histogram analysis allows the determination of the object size despite the over-segmentation of the object.

An even more interesting application of the histogram analysis occurs when several ships are side-by-side. In such cases the blobs corresponding to the objects fuse to a common blob, where with standard blob analysis methods the separation in different objects is not possible or at least not robust. Fig. 6 presents an example of the processing in this case.

This processing example indicates that even complex situations can be successfully analyzed in TerraSAR-X data but further tests with a larger data set are necessary for optimizing the algorithms.
C. Signature analysis and classification

After the screening and segmentation step, the SAR signature is further analyzed. Fraunhofer IOSB has developed and implemented the following processing steps:

- Feature extraction and separation into the categories ship / non-ship by a trained classifier, see [6]. This classification conforms to the discrimination step of [4].
- Enhanced object segmentation and estimation of geometric parameters, and deriving a FoM, see [7].
- Extraction of the turbulent ship wake (dark tape abaft the ship’s tail) in the case of presence, see [8].

In the following, we describe an interesting result representation (see Fig. 8) of the ship signature analysis, which has been developed in [8]. The segmentation mask is used to colorize the SAR image inside the segmented object. After filtering, a false color table is applied to the highly dynamic amplitude data. Thereby the reflection spots, areas of less reflection on deck, and linear structures can be distinguished by a human interpreter. Additionally, a profile of the accumulated intensities along the ship’s major axes is computed. It can serve as some kind of silhouette, as it is common in nautics to identify ships at the horizon. But, unfortunately, the SAR signature and these representations, too, are strongly influenced by the incidence angle and the orientation of the ship relative to the range direction. So some more algorithmic work has to be done for utilizing this for ship classification. On the right side in Fig. 7, the extracted ship parameters are listed. If the ship wake is present and has been extracted, the corrected moving direction is computed (maybe slightly different from the ship’s body and resolving the 180° ambiguity). The azimuth component of the offset yields an estimation of the speed. The results are overlaid on the false color picture: ship direction by red triangle, ship wake by green line and true ship position by red rectangle.

Fig. 8 shows some more examples of ship signatures. The body end with the higher integral intensity is assumed as stern, and the profile is oriented from stern to bow. The images are all oriented with near range on the left hand side. In these examples various effects can be observed: waves and roughness of the water surface, strong scatterers with side lobes, different inner structures of the ships. The segmentation (color-gray transition) is quite good since the smearing and side lobes are suppressed. But the fitting of the rectangle seems in some cases to be biased. The rectangle corresponds to the estimated parameters for width and length, its validation is discussed in a chapter later on.
IV. Development of Ship Detection for RapidEye

In optical data a challenge for automatic detection and classification algorithms is to distinguish ships from clouds. In contrast, radar images can be interpreted independent from clouds or illumination. According to [9], this is one of the reasons why considerably fewer examinations are available for the detection and classification of ships in optical data in contrast to radar data. However, optical data also has its advantages: a comparison of methods for radar and optical data in [10] led to the result that the estimation of ship sizes was more precise in optical data. Furthermore, two parallel ships can be distinguished in optical data which may be impossible in radar data, and ships at a pier can be identified more easily.

A typical approach for detection and classification of ships in optical images consists of the following steps: preprocessing is used to distinguish land from water, to divide a large image into easier manageable parts, to smooth background or to improve contrast. It is followed by a detection algorithm that builds the core of the procedure. In postprocessing the detected objects are classified into ships or other structures, and measurements may be made. In this examination the strategy is pursued to do little preprocessing, let many objects pass the early stages of the detection, and refine the results by thorough postprocessing that analyzes the objects for resemblance with ships. Thereby, the probability of missing ships is decreased. In contrast, extensive preprocessing may not only affect undesired background noise or clouds but also the objects to be detected, possibly jeopardizing their detection because of deformation.

In the following a short overview about the state of the art in the literature is given. For preprocessing some preparatory techniques are described in the literature like land masking and dividing images into smaller parts to gain advantages regarding processing time and local application of operators [9, 11, 12]. Preprocessing may also include filtering in order to smooth background [13] or histogram stretching for contrast improvement [12]. The problem with clouds is approached in literature by filtering in the Fourier domain [11] or by defining a threshold based on the histogram [12]. The techniques described in the literature for the actual detection vary dependent on the available images as well as specific application areas. For example, in [13] a method is described that combines images from different spectral regions which may not always be available. In [9] and [11] images are first characterized into "grey" or "black" images, and the detection is implemented based on image processing methods like thresholding, edge detection and dilation. The application of Genetic Algorithms and Neural Networks for ship characterization showed dissatisfactory results in [14]. The same authors proposed a promising approach in [12] on the basis of the component tree segmentation.

During postprocessing the identified objects shall be rejected or verified as ships. The applied methods are closely linked with the goals of the examination and the type of ships to be detected. In [13] the contours of the detected objects are examined regarding size and shape. In [12] wavelet analysis and Radon transform are used for classification of objects. Edge detection and Hough transform are used in [9] to find parallel and perpendicular lines as well as circles. Interesting approaches are described in the literature but a fully mature method is not available yet. Particularly the false alarm rate is always too high for an automatic detection and classification of ships.

In the current examination preprocessing was limited to dividing large images into smaller ones on a manual basis. The issues connected with automatic portioning were out of scope here (e.g., objects on the boundary of several tiles) and may be examined in future work. Other preprocessing techniques like filtering or special operators for cloud removal were omitted due to the strategy to emphasize postprocessing over preprocessing to decrease the probability of missing ships. As core of the detection, the component tree technique described in [12] was chosen. It allows identifying connected objects which can be processed further separately. For this purpose a representation of the gray-level image in form of a tree is built. Each node corresponds to a component with a certain gray level, the edges define the connection of the components, the leaves are the highest gray levels of the respective component, and the root gives the lowest gray level of the image. A method for constructing a component tree is described in [15].

The component tree is then subjected to filtering. For the present application a combination of gray level and area can be used for filtering. The area of a node is built by adding the area of all nodes above up to the leaf of the respective component. For the gray level the lowest level of the currently examined component was considered. Choosing a suitable threshold is important for the success of the detection algorithm. An adaptive method based on [16] computes the threshold \( t(x, y) \) for each pixel dependent on average and standard deviation inside a specified window:

\[
 t(x, y) = m(x, y) \cdot \left[ 1 - k \cdot \left( \frac{s(x, y)}{R} - 1 \right) \right]
\]

where \( m(x, y) \) is the average, \( s(x, y) \) is the standard deviation, and \( R \) is the maximum standard deviation of the image (\( R=128 \) for gray-level images). A window of 16x16 pixels was used, and \( k = 0.4 \). Due to the use of the integral images method, the computational effort was rather low. The performance of this method decreased for very dark images so that the threshold was set to \( t = m + 3 \cdot s \) in that case (see also [11]).
The binary image that was constructed with the component tree was then processed by the same techniques used for radar images: labelization and clustering [2]. Parameters like contour and orientation were computed, but also bounding boxes and regions of interest.

Further postprocessing is done separately for each object. Edge detection with a Canny algorithm is followed by a Hough transformation. For each Hough line angle and length is computed, and angles and lengths are subject to clustering. Analysis of the clustering results gives indications if the object is a ship: if only one cluster is found, it is assumed that the lines correspond to the main axis of a ship. If several clusters exist, but at least half of the lines belong to one cluster, it is also assumed that the object is a ship. Hough lines with many differing angles belong with high probability to the irregular pattern of a cloud. More distinguishing features could also be included like distance between the lines.

Another analysis regarding classification of the objects is done via measurements. The smallest bounding box, length and width are computed for each object. The ratio between length and width is checked for its resemblance with a ship. To decrease the probability that a ship is falsely omitted, the threshold was set to 0.4. The results show that these postprocessing techniques are able to distinguish many clouds from ships. Further improvement may be achieved by checking overlapping of objects. During the examination this situation was noticed in larger clouds but it does not happen with ships.

In the following some results of the present examination are shown. Data from the green spectral range has been used as input. For each image the original, the segmented image, Hough transformations of the separated objects and the resulting image is displayed (red: region of interest, green: bounding box, blue: measurement results (only done for objects classified as ships)).
V. APPLICATIONS

A. Analysis of harbor scenes in HighResolution TerraSAR-X

For the following reasons we examine harbor regions:

- Many objects as buoys, groins, bollards, pylons and additionally all kinds of ships can be found there.
- The static in-place objects can be extracted from maps or from optical high resolution imagery.
- The ships’ anchor places are attached to certain harbor installations specific for each ship type (crude oil vessel, container ship, bulk carrier, ferry, passenger liner, etc.)
- The water is calmer than in the open sea and the interaction of the objects with the waves can be studied.

As test sites the coastal regions and harbors of Bremerhaven and Emden have been used. Fig. 13 shows a port basin in an optical image and in 2 TerraSAR-X HighResolution Spotlight images with ground sampling distance of 0.7–1.0m. Overlays are spot extractions of a certain parameterization. Since the co-registration of the 2 SAR images is very accurate, spots from both images can be overlaid onto one single image. A simple method for change detection clusters spots in each image. It labels those clusters in one image than have no corresponding cluster in the other image (blue respectively red cluster). In the 2 images, the following observations can be made:

- In the left image, the pile moorings in the middle of the basin are bright and distinct, the 3 left ones match to the spot extractor. In the right image however the reflections of the pile moorings are smeared in range direction (vertically). This is assumed to be caused by agitated water due to wind or tidal stream. But on the contrary, the roughness of the water surface does not seem to be very distinctive as in the case of strong wind it should be.
- In the bottom part of the image there are harbor installations for container loading and container vessels.
- The top part of the images shows bulk ships (coal) and appropriate installations (heaps, mobile cranes).

The aligned reflection points on the ships, the quay, the cranes, etc. indicate the corresponding objects, their geometric proportions, and some kind of their interior structure. The objective now is to propagate these observations to analyzing SAR signatures of objects on the open sea.

B. Ship monitoring with TerraSAR-X StripMap

Using shipping straits (e.g., Strait of Gibraltar, English Channel, Danish Belt) as test sites for ship monitoring has the advantage of dense traffic of varying ship types (ferries, tankers, freighters, etc.). Additionally, coastal radar and terrestrial AIS (Automatic Identification System, based on transponders, obligatory for ships longer than 20m) may be available for algorithm validation purposes.

Our data set consisted of about 20 TerraSAR-X StripMap images with 30km x 50km coverage and a ground sampling distance of 1.2–2.5m containing numerous ships in diverse situations (speed, heading, sea state, weather etc.). For some few images, AIS data were present and could be examined with respect to their correspondence to the algorithm results.
Figure 14: Ship monitoring in the Strait of Dover with TerraSAR-X StripMap. The image is overlaid on googleearth (left), the AIS ship parameters are taken from marinetraffic.com (right) and the algorithm output is popped up (middle).

Fig. 14 shows a screendump of the result presentation by googleearth. The TerraSAR-X image, the algorithm results, and the AIS data are imported into googleearth via kmz files. The detections and the AIS positions are sensitive to mouse clicks and pop-up html windows show the corresponding attributes and the characteristic false color signature image. It can be seen in Fig. 14 that there exist some detections without corresponding AIS and vice versa. As example for a corresponding pair, the detection no. 26 is shown. The ship’s length is almost equal in both data, while the heading has a small difference (after incorporating the ambiguity of 180°), and the width has a significant deviation. Unfortunately, our AIS data are quite incomplete and therefore not appropriate for further algorithm validation.

After examining our complete data set, we have to mention the following drawbacks of the algorithms: it is difficult to distinguish small ships from clutter and from real non-ship objects. The presence of hail clouds and azimuth or range ambiguities (of objects on land or outside the imaged scene) maybe cause misses or false alarms. We did not observe sea ice in our images, but we expect this to be another difficulty for the detection task.

The Fraunhofer IOSB processing chain takes few minutes for the overall exploitation of a StripMap scene with up to 0.6 Giga pixel. While the wake detection takes some more time (depending on the number of detected ships), the pure screening step is very fast and is in principle appropriate for near real time applications, as described in [5].

C. Validation of the ship detection algorithm

For the ship detection and parameter estimation an algorithm validation has been performed. Basis were the TerraSAR-X StripMap images where the ship signatures are marked interactively by a human operator using his visual impression of the ships’ contour. The resulting truth is called “sensed truth” (see [3]) which is more related to the sensed image than the often used “ground truth”, where objects contained in the scene are listed independently from their appearance in the image.

The table below summarizes the validation results for the Astrium ship detection algorithm.

Table 1: Validation results for the Astrium ship detection in TerraSAR-X StripMap. The training data were used for algorithm optimization and are disjoint from the validation data.

<table>
<thead>
<tr>
<th>Training data set</th>
<th>50 objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Validation data set</td>
<td>103 objects</td>
</tr>
<tr>
<td>Detected ships</td>
<td>99</td>
</tr>
<tr>
<td>Not detected ships</td>
<td>4</td>
</tr>
<tr>
<td>Detected non existing ships</td>
<td>0</td>
</tr>
<tr>
<td><strong>Detection Performance</strong></td>
<td><strong>96.12%</strong></td>
</tr>
<tr>
<td>X deviation</td>
<td>3.54 [pixel]</td>
</tr>
<tr>
<td>Y deviation</td>
<td>3.09 [pixel]</td>
</tr>
<tr>
<td>W deviation</td>
<td>5.27 [pixel]</td>
</tr>
<tr>
<td>H deviation</td>
<td>9.47 [pixel]</td>
</tr>
<tr>
<td>Orientation deviation</td>
<td>8.77 [deg]</td>
</tr>
</tbody>
</table>

The StripMap images have a ground sampling distance of 1.2–2.5m, dependent on the incidence angle and on the processing type. It should be mentioned, that for the length and width estimation no distinction has been made with respect to the overall ship size (only absolute instead of relative deviation) or with respect to the detection quality, e.g., by leaving out outliers.

From the detection rate of 96% and the false alarm rate of 0% can be stated that the algorithm is very well adapted to the visually interpretable ship signatures. That means that it yields almost the same results as a human operator. This is fulfilled for the detection part and a little less for the parameter estimation part.

On the other hand, due to the SAR mapping, there are several sources for systematic errors which until now not yet have been considered in the parameter estimation part: Depending on the 3-dimensional ship geometry and on the incidence angle, the SAR signature is rather a ship silhouette than an ortho-projected floor plan of the ship. Other influences such as smearing reflections and agitated water will cause the signature to be larger than the object, too (see [4]).

Real ground truth, e.g., from AIS (even if not complete) is indispensable for a future product validation. But beforehand, these truth data are necessary for a further step in adapting and optimizing the parameter estimation part of the algorithms.
D. Surveillance of offshore wind farms

For inspection and surveillance purposes, static in-place objects like wind farms can be continuously monitored and compared to reference data (change detection). In the frame of the DeMarine-DEKO project two wind farms in front of Rostock and Copenhagen were subject of tests. In a first step, the developed surveillance system detects and measures the objects being present in a predefined area containing a wind turbine. In a second step, the object shape is compared to reference data of the wind farm. In case of discrepancies between both data sets an error file is generated. This information could be further used to alarm maintenance units.

Figure 15: Change detection example applied to a wind farm near Copenhagen.

For demonstrating this change detection application example the original TerraSAR-X SpotLight image contents were manually modified to simulate damages of the wind farm (one wind mill is completely removed and another one is only partially erased), see Fig. 15. The detection algorithms are the ones developed by Astrium for the ship detection and measurement with adapted parameters. The red marks in the result image show the position of the damaged wind mills. This application example shall illustrate how TerraSAR-X data combined with the developed object detection algorithms can be used in completely different contexts.

Another windfarm example using TerraSAR-X SpotLight shows Fig. 16. The two objects inside the image are a wind turbine (left) and a research platform (right) with lattice mast. The mast is recognized pointing into near range direction (to the left), the isolated blob is an image of the turbine cab on top of the mast. The bright large reflections of each the objects is assumed to correspond to the water line with agitated water and service installations. The long thin reflection ray on the left is assumed to be caused by the turning rotor blades.

Figure 16: Signature analysis example of a wind turbine and research platform (false color left, spot extractions right).

Thanks to the high quality of the TerraSAR-X data and the configurability of the detection algorithms different kind of maritime applications can be envisaged.

VI. SUMMARY AND CONCLUSIONS

In this paper and in [2] we have reported the development and the investigation of algorithms for ship detection in TerraSAR-X images. Both Astrium and Fraunhofer IOSB implemented an algorithm chain consisting of processing steps corresponding to screening, segmentation, discrimination and parameter estimation.

The algorithm application can be extended to other man-made maritime objects like wind turbines, pile moorings, buoys, etc. Due to the high resolution and the high quality of TerraSAR-X, further object analysis is possible like extraction of the geometric size of ships. A validation using visually sensed truth yielded a good detection performance.

Overall application to StripMap and SpotLight data showed the commonly known drawbacks of ship detection for small ships, clutter, confusion objects, ambiguities and extreme adverse weather conditions (waves, hail). While for several correspondences to AIS the algorithm results could be verified, a real and comprehensive ground truth is recognized as remaining gap for algorithm optimization and validation.

For ship detection in optical satellite images, we reviewed the state of the art in literature and described an implemented approach for RapidEye imagery. Experimental studies were accomplished and the results show the successful detection of ships and their discrimination from waves and clouds.

By our work, the feasibility of using automatic ship detection in TerraSAR-X and RapidEye images for downstream services in principle is proven. Topics for future work are (1) optimizing the reliability of the algorithm results with respect to the varying application tasks and (2) taking advantage of the potential of the TerraSAR-X data for classification including also future data products like full-
polarimetric or interferometric SAR data. It is expected that (3) the combination of SAR and optical imagery will be important in future multi-mission tasks, which anyway have to be addressed to for monitoring tasks with short time intervals.

The analysis of different service scenarios under consideration of the results of a user requirements query showed that on the basis of a centralized service being directly operated in the satellite ground segment, information can be provided to the customer meeting his requirements. Even one of the most important and demanding requirement in terms of Near Real Time data delivery can be fulfilled in \( t < 30 \) min after image acquisition within the ground segment reception cone today due to the possibility of optimized processing techniques and pure extracted information delivery.

REFERENCES