ASPECTS OF MULTI-PARAMETER RADAR ATR IN COMPLEX ENVIRONMENTS: AN OVERVIEW OF THE WORK OF NATO TASK GROUP SET-163

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1 INTRODUCTION

Future military operations of all types are expected to involve more complex environments (e.g. urban areas, harbours, etc.) compared to former operations. There is a requirement to avoid collateral damage and high casualty rates among both combatants and non-combatants as this may complicate or defeat the goal of NATO´s involvement and reduce local support. This requires the accurate identification and location of vehicles and personnel that may constitute a threat, preferably from a distance. Synthetic aperture radar (SAR), and other forms of imaging radar, provide all-weather, high resolution images of large ground areas from stand-off ranges. Furthermore, the fullest characterization of the scene is provided by the use of multi-frequency, multi-polarization, multi-aspect and multi-temporal options. Automatic Target Recognition (ATR) using radar would provide an aid to both the decision maker and the war-fighter against the asymmetric threat, and towards enhanced situational awareness and persistent surveillance. Studies conducted by predecessor Task Groups (SET-113 and SET-111) established various techniques for both ATR and the evaluation of ATR performance. Further work has now been undertaken under SET-163 to investigate the benefits of multi-parameter radar in complex environments.

The group's main objective has been the development and evaluation of ATR techniques and capabilities in complex environments, such as urban areas and harbours with strong and manifold background clutter. The list of targets has included moving and static objects, with and without dynamic features. The objects of interest have been ground vehicles, ships, humans, or any object being of military interest. The group's activities have focused on current military needs (e.g. detection and recognition of humans for defence against terrorism, identification of hostile intent through behavioural patterns), fundamental theoretical approaches (ATR metrics, information content of radar signals, scene understanding and situational awareness), and more practical approaches based on data analysis, simulations and real life scenarios. This paper will focus on achievements in model-based ATR and change detection applied to ships imaged in Oslo harbour. However, there were many other significant achievements made by the collaborating nations which can be found in the Final Report on SET-163[1].

2 EXPERIMENTAL DATA: MULTIPLE SAR COLLECTIONS OVER OSLO HARBOUR

The SET-163 Task Group undertook an extensive collaborative experimental data collection over Oslo harbour using various SAR sensors, both airborne and space-borne, to support the activities of the Group. An overview of this experimental data collection is given in this Section.

2.1 Airborne Collection: PicoSAR

The PicoSAR sensor is a lightweight active, electronically scanned array (AESA) X band radar that FFI in Norway purchased from Selex Galileo Ltd. It comes with pre-set modes for spot and strip SAR at different resolutions, plus GMTI. The antenna can be decoupled from the processor unit (see Figure 1), and the radar is quite easy to mount in a helicopter. It has also been flown in a UAV. PicoSAR has been a good source of reference data for work related to SET-163. See Table 1 for the main parameters of the radar. The PicoSAR sensor was mounted in an AS350 helicopter and used to image Oslo harbour from all aspect angles using the nominal helicopter flight path shown in Figure 2. This allowed investigation of the variation of ATR performance with the use of multiple aspect angles.

Frequency	X band (~10 GHz)
Bandwidth	Up to 1.5 GHz
Resolution in spot mode	0.15 – 3 m
Polarization	VV
Beam width	6° in azimuth, 9° in elevation
Beam steering	Electronic in azimuth, mechanical in elevation
Peak transmitted power	100 W
Mean transmitted power	13 W
Size	33 x 23 x 23 cm
Weight	10 kg
Min/max range	5-20 km at 3 m resolution 5-10 km at 0.3 m resolution

Table 1: PicoSAR main parameters

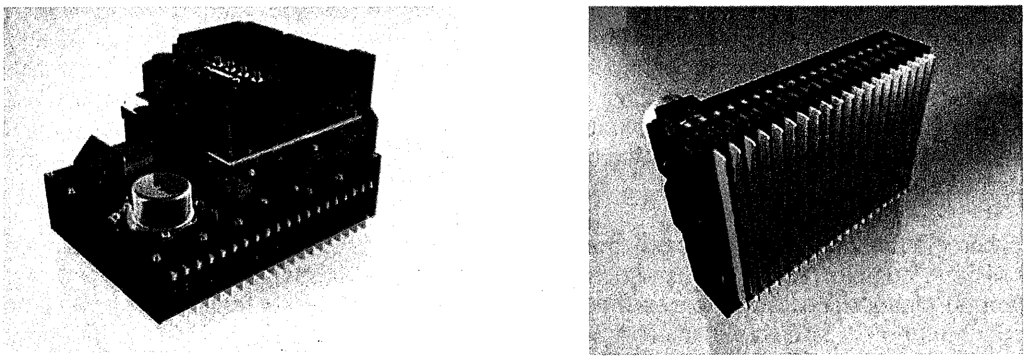


Figure 1: PicoSAR antenna with and without the processor unit attached.

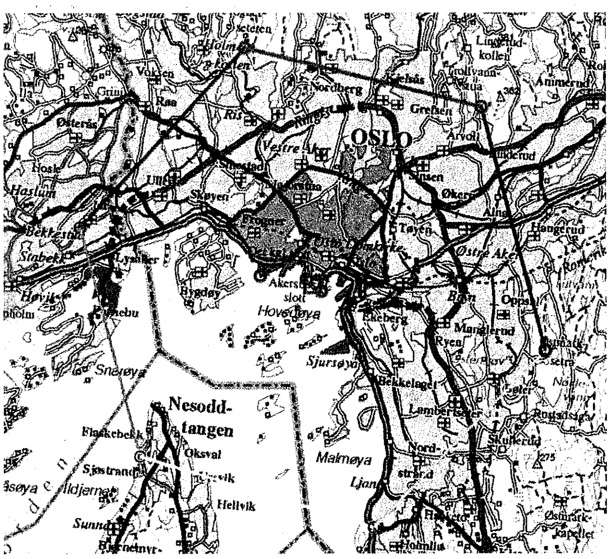


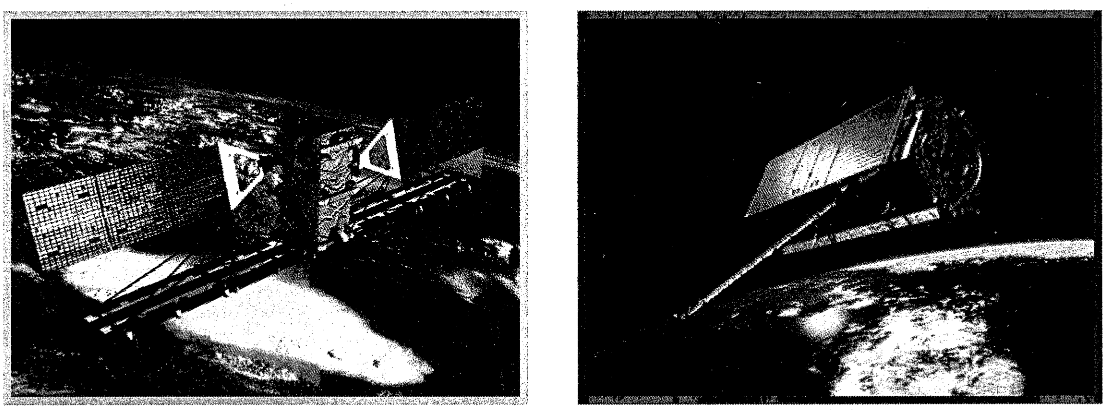
Figure 2: Nominal helicopter flight path during the trials

2.2 Satellite Collection: RadarSat2 and TerraSAR-X

The Canadian earth observation satellite RADARSAT-2, Figure 3(a), was launched on 14th December 2007 and is a commercial satellite. The weight of the satellite is 750 kg and it orbits the earth with the altitude of 798 km. It orbits the earth 14 times per day and will take 24 days to return to the original orbit path. RADARSAT-2 is both left and right looking, operates at C-band and is fully polarimetric.

The German radar imaging satellite TerraSAR-X, Figure 3(b), was launched on June 2007 from the Russian Baikonur Cosmodrome in Kazakhstan. The satellite is in a near-polar orbit around the Earth, at an altitude of 514 kilometres. Using its active radar antenna, it is able to produce image data with a resolution of down to 1 m, regardless of weather conditions, cloud cover or absence of daylight. TerraSAR-X has been fully operational since January 2008. It has a five-metre-long body with a hexagonal cross section and its primary payload is an active radar system. The radar beam can be electronically tilted within a range of 20 to 60 degrees perpendicular to the flight direction. The repeat cycle is 11 days and the revisit time for the same look direction is about 5-6 days.

These SAR sensors were used to image Oslo harbour at different times to allow change detection between sensors with very different specifications to be investigated.



(a) (b)

Figure 3: (a) Radarsat-2 (C-Band, Resolution > 1m, Orbit Altitude = 798 km, Repeat Cycle = 24d, Revisit Time = 3-4d), (b) TerraSAR-X (X-Band, Resolutions > 1 m, Orbit Altitude = 500 km, Repeat Cycle = 11d, Revisit Time = 5-6d)

3 MODEL-BASED RECOGNITION OF FERRIES IN OSLO HARBOUR

3.1 SAR Image Prediction using CAD Models

SAR ATR relies on having a database of example images of the targets of interest from all potential viewing angles. However, it can be time-consuming, expensive and impractical if not impossible to construct such a database using real SAR measurements. This motivates the development of model-based ATR techniques in which the database is populated using predictions of the SAR image obtained by applying electro-magnetic prediction codes to computer-aided design (CAD) models of the targets,

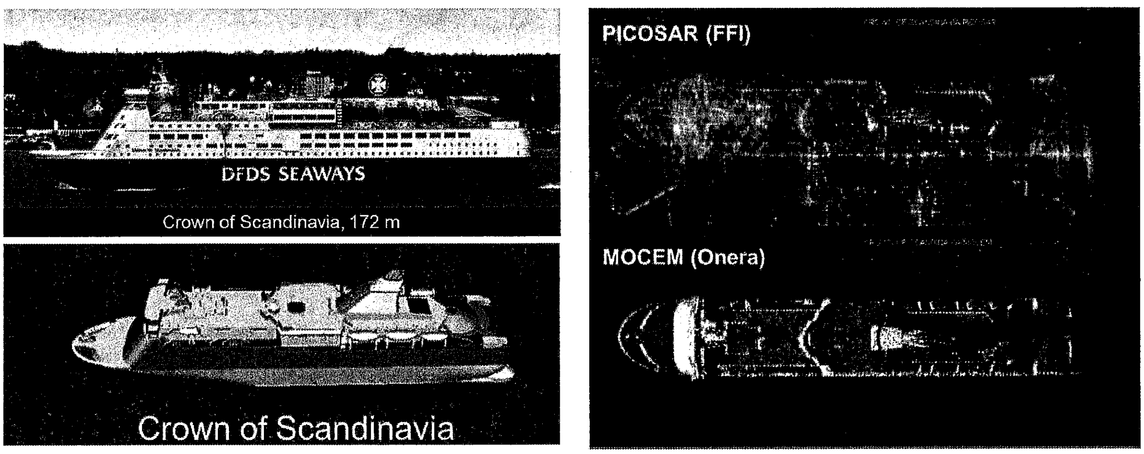
The quality of a CAD model will depend on the data that is used in the modelling process, such as line drawings, photos and additional knowledge of dimensions and surface materials. Drawings or photos with orthogonal views, most notably side view and top view, are particularly useful. Line drawings of many vessels can be found in Jane's Fighting Ships, various registers of merchant ships, shipping companies' web sites etc. High-quality aerial photos are also of great value for the modelling.

The most straightforward CAD modelling approach is to use a conventional 3D modelling software, e.g. 3DS Max, Maya, Cinema4D, Blender, Lightwave or Rhinoceros. The models can be built with the desired level of detail, but the modelling involves a considerate amount of manual work. The software that has been used to support SET-163 is the NURBS modelling tool Rhinoceros. An alternative CAD modelling strategy that in theory could provide automatic modelling is the use of software for automatic reconstruction from photos, e.g. PhotoModeler Scanner or Autodesk 123D Catch. Photos from many aspect angles are required, preferably high-quality aerial photos. Initial tests with 123D Catch indicate that the model will be rather rough and not meet the criteria for SAR simulations. It will however have fairly accurate proportions, and might be usable for silhouette matching after some manual finishing.

The SAR image prediction code that has been used to support SET-163 is MOCEM which is a French SAR image simulation tool developed by Alyotech under a DGA MI contract. MOCEM is designed for simulation of SAR images from 3D models within a very short computation time. The concept of MOCEM is to use an electromagnetic (EM) behavior model, rather than rigorous EM computations. It uses an original EM formulation based on object geometry analysis to locate major EM phenomena, which are diffuse and coherent effects from particular configurations like 'near dihedral' and 'near trihedral' geometries. It also takes into account reflections with up to 5 bounces from a surrounding surface like the sea.

The core capabilities of MOCEM makes it an 'all in one' SAR simulation software package. It includes 3D modeling, EM material property editing, SAR image calculation and 3D visualization for explaining the content of a SAR image using picking functions. A SAR image can be produced without calculating the raw data. Instead a 2D transfer function corresponding to the radar parameters is applied to a source image (an ideal SAR image).

Figure 4 shows the Crown of Scandinavia, one of the ships imaged in Oslo harbour. A photograph and corresponding CAD model are shown together with the PicoSAR image and MOCEM simulation.



(a) (b)

Figure 4: Crown of Scandinavia (a) photograph (top) and CAD model (bottom); (b) PicoSAR image (top) and Mocem simulation (bottom)

3.2 Single and Multi-Aspect Classification

ONERA has built an ATR chain where the reference dataset relies exclusively on MOCEM simulations[2] and so the PICOSAR images are only used in the test stage. Each SAR signature is compared with the simulated ones, and classification performances are derived using a threshold on a chosen similarity metric. Various classification metrics have been tested. In an earlier experiment the normalized cross correlation was used with limited success[3]. In the current work ONERA has investigated the Kullback-Leibler distance and the structural similarity (SSIM) index[4] as comparison metrics.

Eight 3D CAD models of ships have been used for testing the ATR chain: the first four ships have been imaged by PICOSAR, while the remaining four acts as classes of confusion. To speed up the process, it has furthermore been supposed that the orientation of the ships is known as they are docked on piers. Each available SAR image is then compared with the eight MOCEM simulated signatures using the SSIM based comparison metric. An example comparison is given Figure 5.

The overall similarity index has been measured for the eight models with about 800 PICOSAR images of the four ships under test. A ROC curve is built using a variable threshold on this index. Figure 6 gives the probability of correct declaration versus the probability of false declaration on a single look, and using the fusion of single looks results over 20° and over 80°.

It can be seen that very good target recognition performance has been obtained using only simulated imagery in the database. It is also clear that the performance improves significantly when multiple aspect angles are used. These results are quite unique and show a true potential application of such a model based identification, especially if we are able to turn around a target and collect SAR images with multiple orientations.

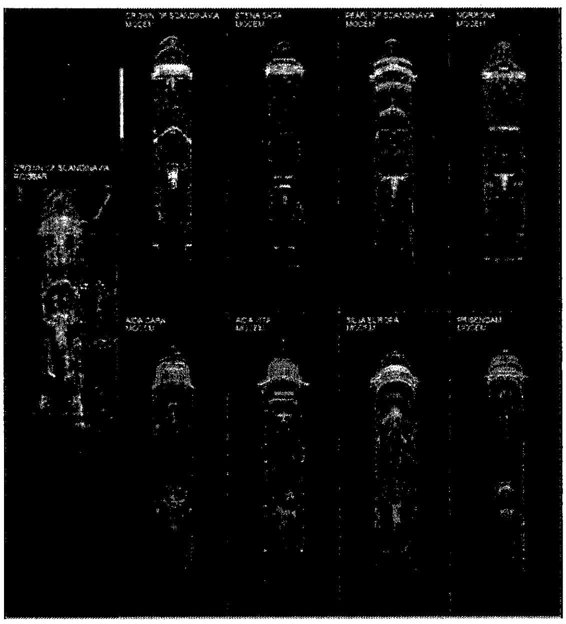


Figure 5: (Left) PICOSAR image under test; (Right) signature of eight ships simulated by MOCEM. Colour coding of local similarity with the PICOSAR image (green = similar, red = different)

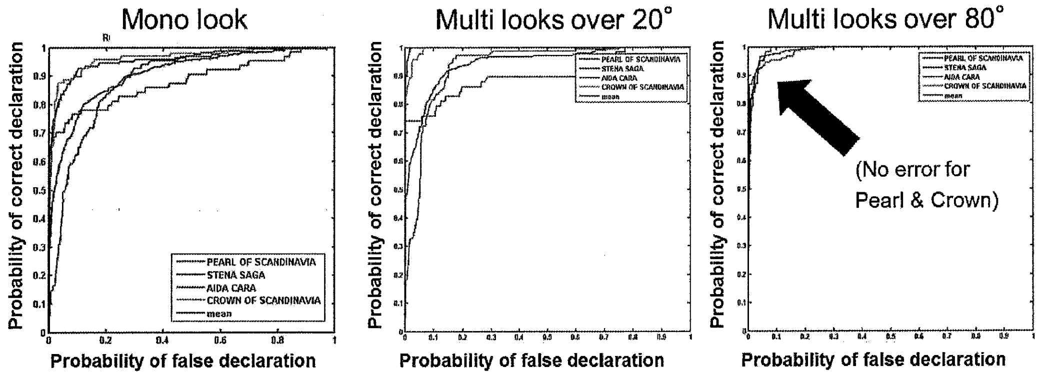


Figure 6 : Probability of correct declaration versus the probability of false declaration on a single look (left), and using the fusion of single looks results over 20° (middle) and 80° (right).

3.3 Influence of CAD Model of Level of Details on ATR Performance

The previous ATR chain has been used to study the influence of the level of details on the recognition performance. Various CAD model versions that had been saved during the creation steps have been used with increasing details (Figure 7). The ROC curves shown Figure 7 show that the more detail the better is the result, but some details seem to have more influence on the performances than others. A more systematic approach needs to be set up to better understand the relative influence of the model fidelity to the actual ship. This will be one of the topics of the follow-on activity to SET-163.

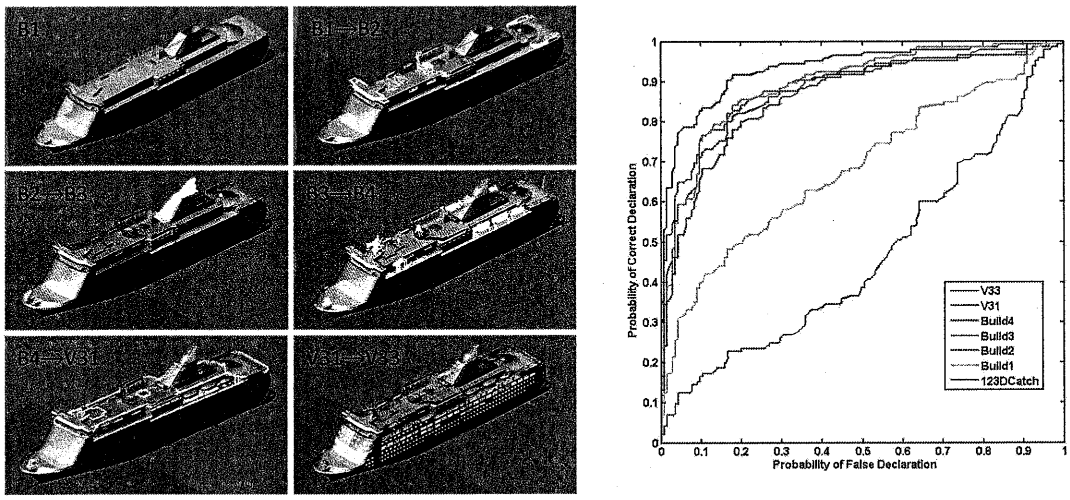


Figure 7: Influence of the 3D model level of details on recognition performances: 3D CAD model versions where yellow indicates the new structure added (left), corresponding ROC curves (right)

4 SATELLITE SAR CHANGE DETECTION AND MODEL BASED IDENTIFICATION

Change detection by space-borne high resolution synthetic aperture radar (SAR) images is a very powerful tool for reconnaissance tasks, as this is largely uninfluenced by weather conditions or the time of the day and additionally does not violate sovereign rights. The use of different space-borne SAR sensors would reduce the revisit time to a region of interest considerably, allowing a denser monitoring. Unfortunately, different sensors mean different system parameters like frequency, resolution or aspect angle, commonly leading to higher false-alarm rates in the change detection. Nevertheless, this Section demonstrates a successful image fusion of Radarsat-2 and TerraSAR-X data which have been exchanged within the framework of the NATO SET-163 group.

The two sensors used in this study deliver images on different grids, for different frequencies, in different resolutions, at different incidence angles and azimuth angles, and on different scene sizes. Figure 8 (left) shows a Radarsat-2 image of the Oslo Fjord from 18th January 15h54. The grid intervals are 1.33 m in range and 2.05 m in cross range, the incidence angle is 34.02°. Figure 8 (right) shows the TerraSAR-X image from 19th September 16h46. The grid intervals are 0.91 m in range and 0.86 m in cross range, the incidence angle is 30.76°.

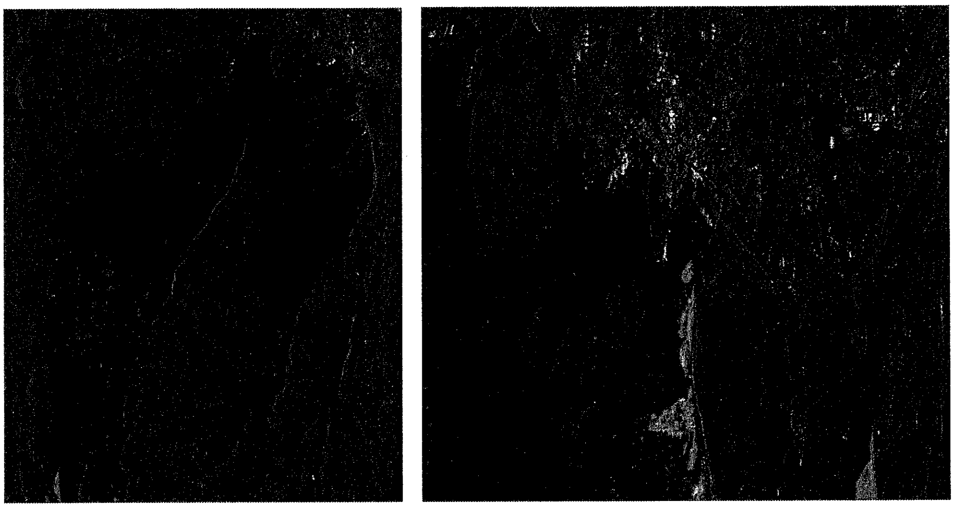


Figure 8: Radarsat-2 image of the Oslo Fjord from 18th Jan. 15h54 (left), TerraSAR-X image from 19th Sept 16h46 (right)

Incoherent change detection is useful to identify changes in the mean backscattered power of a scene on a pixel-to-pixel basis by using time series of images. A basic precondition of superimposing multi-temporal images is the availability of almost identical observation angles for the scene of interest. Angle-dependent projection effects and anisotropic scattering behaviour inherent in radar images can lead to false alarms, especially if repeat-pass orbits are not available.

The main processing steps of the change detection image generation are as follows. After de-weighting and speckle suppression of at least two SAR images (containing the magnitude and the phase information), a projection to the ground-range plane is performed. Afterwards, the pixel spacings are aligned by down-sampling the higher resolved image via multi-looking. The following two steps implement the important co-registration: First the coarse co-registration based on automatic landmark detection[5], second the fine elastic co-registration based on vector-spline regularization[6]. Finally, the co-registered images are visualized by different colour channels in a RGB-image. Here, the older image is put into the green channel, the newer one into the red. The blue channel is fed in a way to show unchanged image parts in an almost neutral grey colour. An example of the two registered satellite images and the change detection product is shown in Figure 9. Of particular note is the significant difference in resolutions that needs to be taken into account.

A detail of the change detection product is shown in Figure 10. In particular, a ship has arrived at the harbour in the interval between the image collections. It is possible using CAD models and the MOCEM tool to predict what profile would be seen for various ships. On the basis of the observed profile, it is possible to conclude that the ship that has arrived is the Stena Saga. This is a striking example of target recognition from change detection using two different SAR sensors with very different specifications.

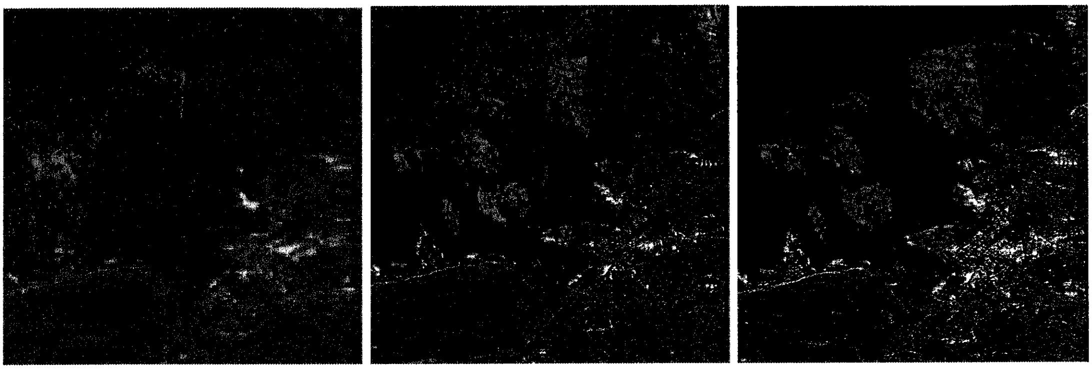


Figure 9: Registered images from RadarSat 2 (left), TerraSAR-X (middle) and change detection product (right)

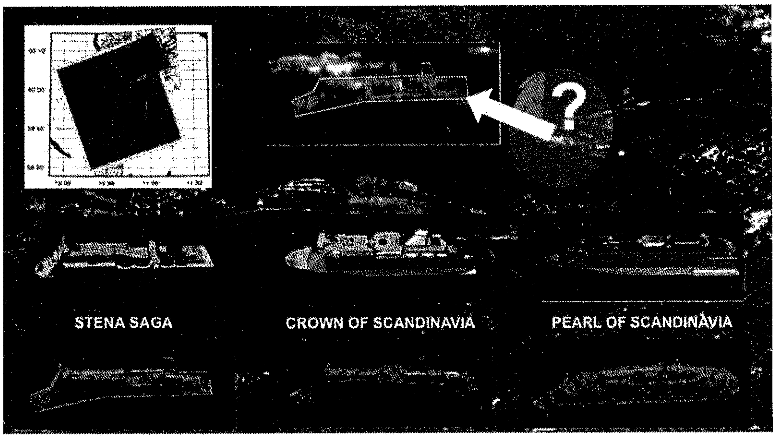


Figure 10: Change detection between RADARSAT-2 and TerraSAR-X images over Oslo Harbour, and model based recognition using 3D CAD models of ferries & MOCEM radar simulations

5 REFERENCES

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