Comparison of simulated and measured ISAR images flow of a ship at sea

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***Abstract*— The aim of this work is to simulate a flow of ISAR images for a ship at sea seen from an airborne radar, in rigorously the same configuration as it has been measured by a real SAR using the recorded motion data of both radar, ship and ship attitudes. We use MOCEM and DUEL simulation softwares to produce range Doppler profiles from CAD models and radar observation characteristics. Comparison examples are given with real data acquired by FFI with the PicoSAR® X-band COTS radar from Leonardo company.**

Keywords—Radar imaging, SAR, ISAR, simulation, ship

I. Introduction

This work takes part in an international Technical Agreement between DGA-MI (part of French MoD), FFI (part of Norwegian MoD), and ONERA (The French Aerospace Lab), whose aim is to study airborne radar imaging of ships with both experimental acquisitions and numerical simulations. Previous works have shown excellent comparison results on SAR (Synthetic Aperture Radar) images of ships docked at piers or slowly moving in Oslo harbour [1-3].

Here we propose to enlarge this comparison to ships moving in open sea using ISAR (Inverse Synthetic Aperture radar) imaging. This is a great challenge since relatively small attitude motions of the ship will lead to rather large motions of the radar image focusing plane [4-7]. This makes the dynamic matching between simulated and measured features a pretty difficult task without a great care taken in every step of this comparison procedure.

In section II, we give some details on the simulation tools used, namely the MOCEM and DUEL softwares.

Section III briefly presents FFI's X-band PicoSAR® and the radar measurements campaign. A sub section gives some details on 3D CAD models used for radar simulations.

Last section will present our comparative methodology. We describe the steps that lead to the simulation of the ISAR images flow, mirroring the one produced with real data. We will show the result on the cruising passenger boat Skutvik.

II. Radar imaging simulations tools

A. MOCEM

MOCEM is a French SAR image simulation software developed by Scalian/Alyotech under a DGA-MI contract [8-9]. MOCEM is designed for simulation of radar images from 3D models within a very short computation time. The latest version (V4) includes new features which make it particularly useful for simulation of ships at sea [10-11]. The software is able to compute raw data for both SAR and ISAR applications. It can simulate raw data of a maritime scene with coast, and it includes a dynamic sea surface which can be used to compute ship motions.

The concept of MOCEM is to use an electromagnetic (EM) behaviour 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 considers 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. It includes 3D modelling, EM material property editing, SAR image calculation and visualization for explaining the content of a SAR image using picking functions. A SAR image preview can also be produced without calculating the raw data. Compact 3D EM files may also be produced on a large domain of radar incidence and heading observations for later use (M3D format e.g. see Fig. 6).

Additional functions have been added for ship imaging applications. A 3D dynamic sea surface, based on ocean wave spectra, swell and wakes, can be computed in real time. A radar model is included which uses the radial and transverse speed of the scatterers in order to create the delocalisation and defocusing effects seen in SAR images of moving objects.

B. DUEL

For more complex motions such as realistic ship motions, a temporal technique is used. A separate module called DUEL has been developed to generate raw data, i.e. high-resolution range profiles over time according to an observation with both moving radar and target (including time varying attitude angles). At each pulse, DUEL computes the grazing angle and the azimuth angle in the ship referential. This observation is then linked to the proper 3D EM file computed in MOCEM with these angles. We can then handle very complex trajectories for both radar and ships and still activate the closest 3D EM model that the radar would observe in an actual scenario.

III. X-BAND RADAR DATA ACQUISTION BY FFI

A. *PicoSAR® radar short description*

PicoSAR® is a lightweight AESA X-band radar purchased by FFI. It comes with preset modes of spot and strip SAR in different resolutions, plus GMTI. The antenna can be decoupled from the processor unit (see Fig. 1), and the radar is quite easy to mount in a helicopter. See Table 1 for the main parameters of the radar. Fig. 2 shows the mounting frame produced by FFI for mounting the radar on the seat or the floor of a helicopter.

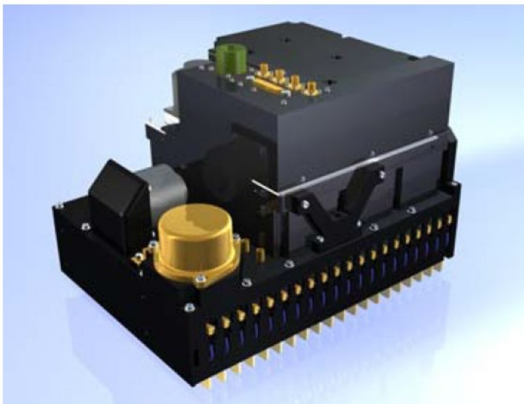

Fig. 1. PicoSAR® antenna with the processor unit attached

TABLE I. PICOSAR® MAIN PARAMETERS

Frequency	X-band (~10 GHz)
Bandwidth	Up to 1.5 GHz
Resol. in spot mode	0.15 – 3 m
Polarization	VV
Beam width (steering)	6° in azimuth (electronic) 9° in elevation (mechanic)
Peak trans. power	100 W
Mean trans. power	13 W
Size	33 x 23 x 23 cm
Weight	10 kg
Range	5~10 km at 0.3 m resolution

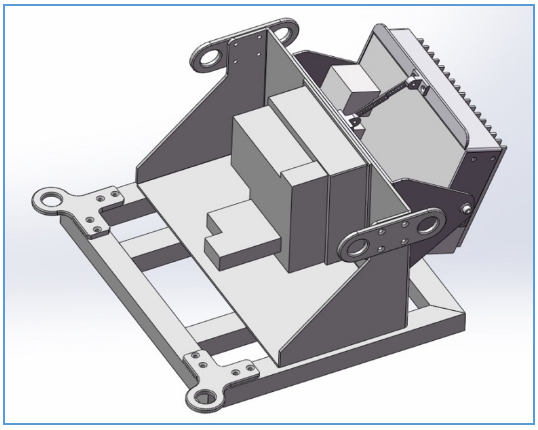

Fig. 2. Frame for mounting the radar on a helicopter

B. *Skutvik observation*

FFI and DGA participated in NATO Above Water Warfare Capability Group (AWWCG) NEMO 2016 Trials, which took place at Andøya in Norway in June 2016. PicoSAR® was installed in a commercial Norwegian helicopter. In addition to these trials, FFI imaged a ferry going from Andenes to Gryllefjord on the day before the actual trial started. A picture of the ferry Skutvik taken from the helicopter is shown in Fig. 3. When the ferry started sailing, the helicopter followed it while flying in circles around it. INS data of Skutvik was collected by an FFI employee on board. An overview of the elevation angles the ship was observed from is shown in Fig. 4.

Fig. 3. Ferry Skutvik

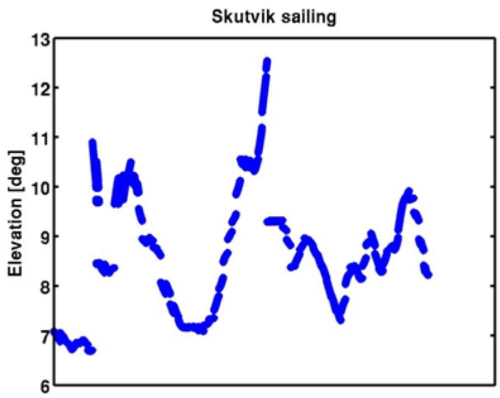

Fig. 4. Elevation angles for the Skutvik measurement

C. *Skutvik CAD model*

FFI has built several 3D CAD models including a very detailed one of the Skutvik ship (see Fig. 5). A short description of the process is given below.

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. The models can be built with the desired level of detail, but the modelling involves a considerate amount of manual work. FFI's choice of software is the NURBS modelling tool Rhinoceros® from McNeel Company. The modelling typically starts with orthogonal drawings or photos being placed as background images in the CAD tool. Curves are drawn based on the background images, and surfaces are swept between the curves.

Fig. 5. Skutvik 3D CAD model

Then many details are added. The important details are those that may give rise to high radar backscatter, such as complex metallic structures and corner-like shapes. Typical examples are parts of the funnel and mast structures, external stairs, railing posts, window frames and the hull frames that are often visible in the bow of a ship. The NURBS models are converted into polygon meshes for use in our target recognition applications. In order to obtain a well-structured model and avoid an excessive number of polygons, the model is divided into a suitable number of layers, and the polygon conversion is done on each layer individually with different settings.

IV. Comparison of Simulated and Measured Images

A. Methodology

The following methodology has been applied:

- Extract inertial motions from recorded motion data, and convert them in a format compatible with the DUEL simulation tool.
- Import a CAD model of the ship into the MOCEM simulation software (e.g. Skutvik Fig. 5), apply EM materials properties and generate the coherent and diffuse effects seen from all possible radar field of view (M3D format, see example Fig. 6).
- Use M3D files and ship trajectory within the DUEL software and generate simulated Raw Data HRRP (High Resolution Range Profiles see Fig. 7). Each pulse corresponds to a specific angular radar observation, and the closest M3D model is then used to compute the corresponding simulated complex range profile.
- Generate ISAR image flow for both simulated and real target using the target-radar relative motion and standard autofocus methods. (e.g. Fig. 8)

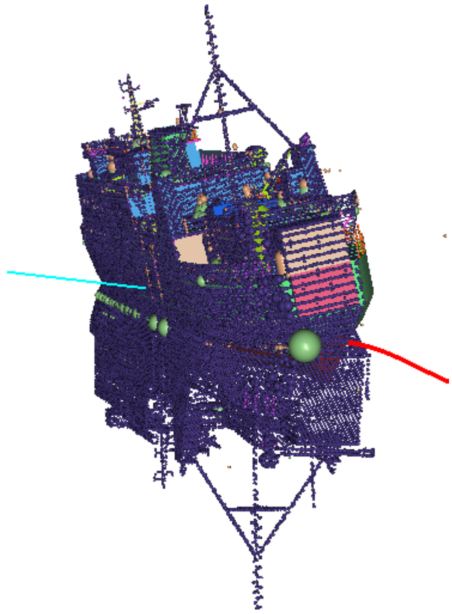

Fig. 6. Skutvik simulation (M3D) ; ship trajectory in red, radar LOS (Line of Sight) in blue

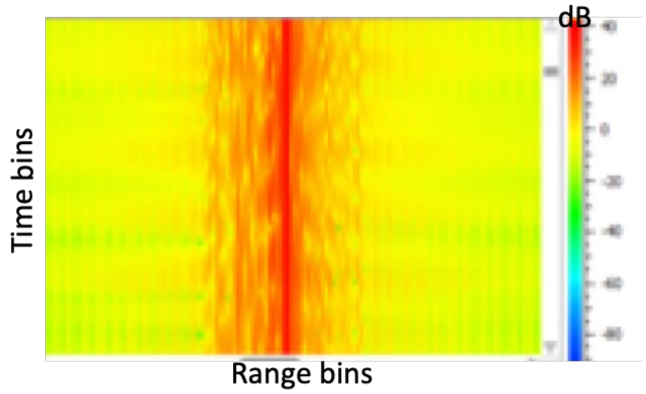

Fig. 7. Simulated High Resolution Range Profiles for Skutvik

B. Application to Skutvik ship at sea

Following the previous methodology, we have been able to simulate ISAR sequences of the Skutvik ship at sea in rigorously the same configuration as it has been measured by PicoSAR® (using the recorded motion data of both radar, ship and ship attitudes).

In Fig. 8, we only reproduce 2 snapshots taken from the longer sequences obtained. The ISAR images flow is of course better rendered when frames are shown as a movie.

For each frame:

- left image (a) is the real ISAR image observed by PicoSAR®. Images are produced using a Linear Range Doppler algorithm with 1 second integration time and basic autofocus. Cross-range scaling is derived from known motions.
- next image (b) is the corresponding simulated ISAR image (MOCEM & Duel software).
- image (c) is the ISAR-plane projection and radar illumination of 3D CAD model according to INS.
- image (d) represents the relative position of ship from the radar viewpoint.

V. Conclusion

We have shown how the combination of MOCEM & DUEL simulation tools is able to produce sequences of simulated ISAR images matching the actual observation of ships at sea. Application was shown on the Skutvik ferry. Future work will include the use of image-based comparison metrics (e.g. see [3]) for automatic simulation parameters optimisation, and possible extension to Non-Cooperative Target Recognition (NCTR) when no INS data are available from the ship.

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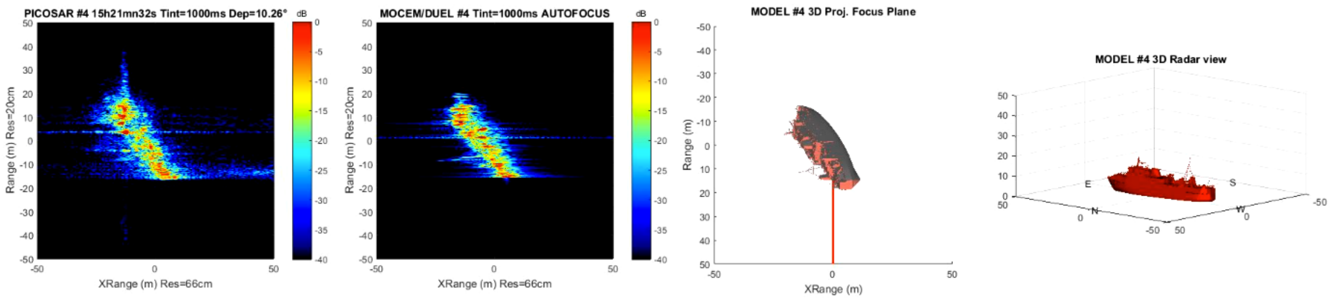
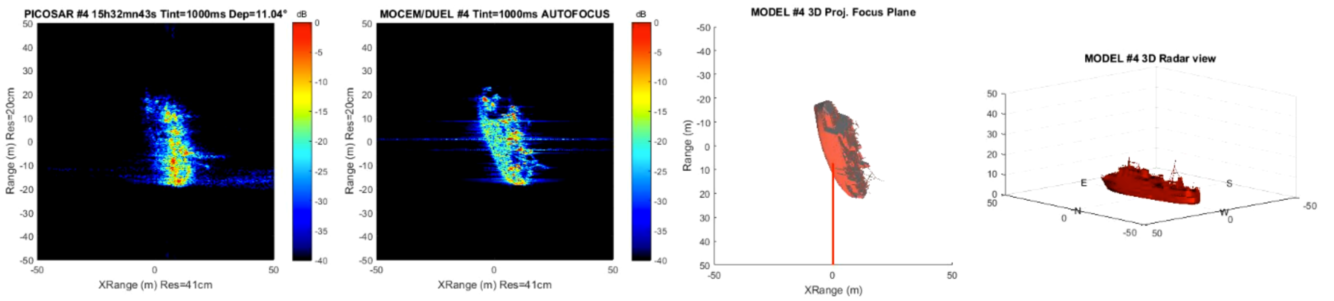


(a) (b) (c) (d)

frame 1



(a) (b) (c) (d)

frame 2

Fig. 8. Example of 2 frames taken from the ISAR images flow produced with Skuvik ship sailing at sea. For each frame, image (a) is the real ISAR image observed by PicoSAR®, to be compared with the simulated ISAR image produced by MOCEM/DUEL (image (b)); image (c) represents the projection of the ship CAD model in the ISAR focus plane and (d) the radar point of view on the ship.