Cosmo-Skymed Satellite SAR Image Improvement and Exploitation for Maritime Surveillance

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ABSTRACT

An add-on tool to be applied to COSMO-Skymed high resolution SAR images to improve maritime surveillance capabilities is here described. The proposed processing performs maritime targets detection, targets extraction and refocusing in an automatic, semi-automatic and manual manner. A deep knowledge of radar processing is not needed since an intuitive Graphic User Interface (GUI) guides the user through the whole processing chain. The high level processing chain and its integration in the GUI are described in this paper. Results on CSK dataset are given.

1. INTRODUCTION

SAR systems are widely used for a number of applications, both in civil and military scenarios [1]. Specifically, spaceborne SAR systems have the advantage of monitoring the earth on a global scale at a relatively safe distance. Nevertheless, the acquisition and the revisiting time are constrained by the satellite orbit characteristics. For this reason, constellations of satellites are employed to reduce the revisiting time. Cosmo Skymed (CSK) is one of such constellations, which is composed of four SAR sensors. CSK is a dual use system, which then serves as a source of SAR images for civil and military applications. CSK is able to produce down to 1m x 1m ground resolution SAR images for civil applications and even finer resolution SAR images for military applications. Such resolution, together with the aforementioned characteristics of a constellation of space-borne SAR systems, make CSK an appealing system for target detection, classification, recognition and identification in homeland security applications. Unfortunately, one of the major drawbacks of any SAR system is the problem encountered when focusing images of moving targets, especially in the case of complex motions (typical of maneuvering targets or pitching/rolling ships). In fact, such images usually appear defocussed as the target is non-stationary during the Coherent Processing Interval (CPI). Although some attempts may be made to refocus such images using motion estimation algorithms, the effectiveness of such techniques are bounded to simple motions and the accuracy and suitability of the models used. It has recently been demonstrated[2], that ISAR processing is a robust and viable approach that is able to effectively refocus SAR images of non-cooperative moving targets. The most straightforward justification to such effectiveness is that ISAR is designed to handle non-cooperative moving targets, also when they undergo fast maneuvers and/or pitch/roll/yaw motions[3][4][5].

The work done in the past relatively to the use of ISAR processing to refocus SAR images of non-cooperative moving targets has been demonstrate effective. Nevertheless, an automatic system that is able to function as a simple add-onto to existing acquisition and processing systems has been

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onlyrecently developed that implements the concepts expressed in[2].

This paper describes in details such an automatic system, namely ISAR-SKY.

2.   SYSTEM REQUIREMENTS

The ISAR-SKY technological demonstrator consists of a system capable ofautomatically detecting and refocusing targets in maritime scenarios from CSK SAR images. The requirements are defined in terms of performance, time and user interface.

The input of the ISAR-SKY system are COSMO-SkyMed Level 1 SLC Spot-light SAR images. The reason for this selection is the high resolution provided by Spot-light SAR images, which enables the best exploitation of CSK imaging capabilities. The outputs are the refocused versions of maritime moving targets that are detected in the scene. Some preliminary tasks are performed prior to refocussing moving targets, such as land masking, target detection and target selection. In order to let the user apply ISAR-SKY processing functions, an interactive Graphic User Interface (GUI) is integrated in the system. The GUI allows for a number of operations to be made without any requirements in terms of knowledge of the implemented code. Such tasks follow the operative modes that the ISAR-SKY system works with. In particular, the ISAR-SKY modes are:

- *Automatic mode*: within this operative mode, all the algorithm functions are executed automatically and without any user interaction, except for the only operation that needs user participation, namely the Sea/Land separation

- *Semi-automatic mode*: this operative mode allows for the user to interact with the GUI and select some system parameters.

- *Manual mode*: with such a mode, the user selects manually the targets of interest therefore avoiding the automatic detection processing.

The ISAR-SKY technological demonstrator is able toprovide:

- Refocussed and Scaled Images of non-cooperative moving targets;

- Original SAR image with refocussed targets superimposed;

- Parametric information on the detected targets.

At the end of the execution of the ISAR-SKY system, the original SAR image with superimposed refocussed target's images is stored and shown in the GUI. Refocussed and scaled target's images are organized in an array structure. The information to be provided to the user can be classified in three categories, as follows:

- *behavioural parameters*: the information in this category refers to the state of the movement of the target under test. The target can be stationary, linearly moving or with more complex motion.

- *geometrical parameters*: the information in this category refers to the geometrical features of the target such as area, length, width, orientation and the target coordinates withinthe whole SAR image;

- *dynamical parameters*: the information in this category refers to the radial velocity, acceleration and

the effective rotation vector.

Before defining the time requirements for the ISAR-SKY technological demonstrator, the CSK acquisition and image formation time should be considered. In particular, the CSK's response time is of the order of days (72h), which is a very long time if compared to the processing time. On the other hand, it is quite obvious that once a SAR image has been formed, any additional processing time would delay the delivery of a product. Nevertheless, being ISAR-SKY conceived as an add-on system, the processing time needed would be optional. Under these circumstances, any additional product that is produced by ISAR-SKY should be delivered to a potential user in the least time possible. Having said this,some time requirements according to the type of product that is issued by ISAR-SKY can be defined. The ISAR-SKY system has been designed to work in a quasi real time condition. This means that the technological demonstrator has to provide the final result to the user in the order of a fewminutes after the CSK SAR image is available to the final user. For this reason parallel implementation has been exploited.

Final users can perform tasks interactively through graphical controls such as buttons, slides, and selection tools by means of a Graphical User Interface (GUI). The GUI allows users to perform every processing step without having to work on a Command Line Interface (CLI). Every programmed task, including selection of standard configuration options can be done using the GUI. The user will be able to choose between the three previously defined operative modes: automatic, semi-automatic and fully manual.

3.   SYSTEM ARCHITECTURE

The system high level functional block is depicted in Figure 1 and each block is analysed in the following sub-sections. Details about parallel implementation are provided as well.

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┌──────────┐   ┌──────────┐   ┌──────────┐   ┌──────────┐   ┌──────────┐
│   DATA   │ → │ SEA/LAND │ → │DETECTION │ → │   ISAR   │ → │ RESULTS  │
│ LOADING  │   │SEPARATION│   │          │   │ PROCESING│   │ DISPLAY  │
└──────────┘   └──────────┘   └──────────┘   └──────────┘   └──────────┘
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Figure 1: High Level Functional Block

3.1.   DATA LOADING

The Data Loading block allows the user to load the CSK SAR image of interest. Both the whole image (.h5) or a subset (.dim) can be read. At the output of this block the complex (I/Q) image along with the header information of interest are made available to the following blocks.

3.2.   SEA LAND SEPARATION

The first operation to be performed is the evaluation of a mask to discriminate sea and land regions in the image. This is done for those images that show coastal areas or in the presence of islands in the scene and it aims to avoid that the system is distracted by ground clutter and ground targets, which are of no interest in maritime surveillance This operation is performed on the Intensity image. To obtain better performance, a despeckling operation based on wavelet correlator is performed first [add reference]. The output of this block is the black and white sea/land mask to be applied to the SAR complex image.

3.3.   TARGET DETECTION

This block aims to perform target detection within the maritime area under surveillance. In the ISAR-SKY system a two-step detector is implemented. This allows for the computation time to be reduced. In particular, the image under surveillance is split in regions with a marginal overlap and a first detection based on

significance is performed[6]. Since in maritime scenarios it is quite likely to have large areas to monitor and a relatively small number of targets, this first step aims at excluding areas where it is very likely to not have targets. In this way, the more time consuming fine target detection scheme can be applied to a significantly reduced area, therefore significantly reducing the processing time. For this reason, a large value of P_{fa} is admitted in order to minimise the risks of missed detections. The second step consists of an optimized CFAR detector applied to those regions the presence of targets (one or more)has been detected by the first step. It is evident that a parallel architecture can be exploited to process each region at the same time. Techniques to deal with region close to the coast and clustering operations to reduce the P_{fa} are implemented and optimized as well. The refined BW map and its connected components proprieties are the output of this block. It is quite intuitive that the computational time of the detection can be reduced by exploiting parallel computing. It is worth pointing out that no parallel computing is needed for the significance computation. This because it is a very fast operation and using parallel computing would require a resource allocation step that may worsen the computational time.

3.4.   ISAR PROCESSING

This is the core of the ISAR-SKY system. This block performs ISAR processing to all the detected targets. In order to do that, an inversion step is performed first. Then, the motion compensation is performed by applying the Image Contrast Based Autofocusing (ICBA) [7]technique and finally the refocused image is obtained by means of the conventional Range-Doppler processing. Techniques to automatically select the optimum Coherent Processing Interval (CPI) and to discriminate moving and stationary targets are provided. Cross-range scaling operation to scale the Doppler axis in spatial coordinates is an important part of this block[8]. In this case parallel computing can be used to reduce the computational time since each crop can be processed separately. It is worth pointing out that a different parallel implementation has been designed for the cross-range scaling operation. In fact, executing cross-range scaling in parallel on each target may be strongly inefficient when targets of different size have to be processed. This is due to the fact that cross-range scaling performs the chirp rate estimation of each point-like scatterer which strength pass a threshold [8]. For this reason, the computational time of the cross range scaling algorithm increases with the dimension of the target on which it is applied, as more of such scatterers are likely to be extracted. As a consequence, the cores assigned to smaller targets may remain inactive while the larger targets are processed. It is quite obvious that this represents a waste of resources that should be avoided. A more efficient parallel implementation consists of applying the cross range scaling in a sequential manner to all the targets but performing the chirp rate estimation of the selected scatterer in a parallel manner. Since the chirp rate estimation execution takes more or less the same time for all the scatterers, this implementation represents a more efficient exploitation of the available resources.

3.5.   RESULTS DISPLAY

This block aims to show to the user all the information of interest. In particular, the refocused version of the target images are provided as well as some information about their motion (behavioural, geometrical and dynamical parameters).

4.   CASE STUDY

Results relative to the application of the ISAR SKYsystem so a sample CSK-SAR image will be shown in this section.

The SAR image under test was acquired by Satellite 3 of the CSK constellation and the illuminated area is the harbour of Messina (image taken on July 31th, 2010). The whole SAR image is shown in Figure 2 (a) with the areaunder test highlighted in red. The sub-SAR image under test is zoomed-in in Figure 2 (b).

The SAR image in Figure 2is shown in dB scaleand it is generated by means of the Omega-Key imaging algorithm. Other information of interest about the dataset are summarized in Table 1.

A photo of the same area is taken from Google Maps© and shown in Fig. 3. The coordinates of such image have been obtained from the information present in the SAR image header, specificallythe "Scene Centre Geodetic Coordinates".

Firstly, the image is despeckled by meansof the Wavelet-CORrelator (WCOR) algorithm.Image despeckling is an important pre-processing stage as it boosts the performancesof the detection algorithm.In fact, speckle noise often affects sea SAR images and may cause difficulties inthe SAR image interpretation including the correct land/sea separation and targetidentification.The result of the image descpeckling is depicted in Figure 4, where the despeckled image is compared with the original SAR image. As it can be noticed, the speckle noise is reduced and the SAR image contrast is enhanced at the same time.

(a)   (b)
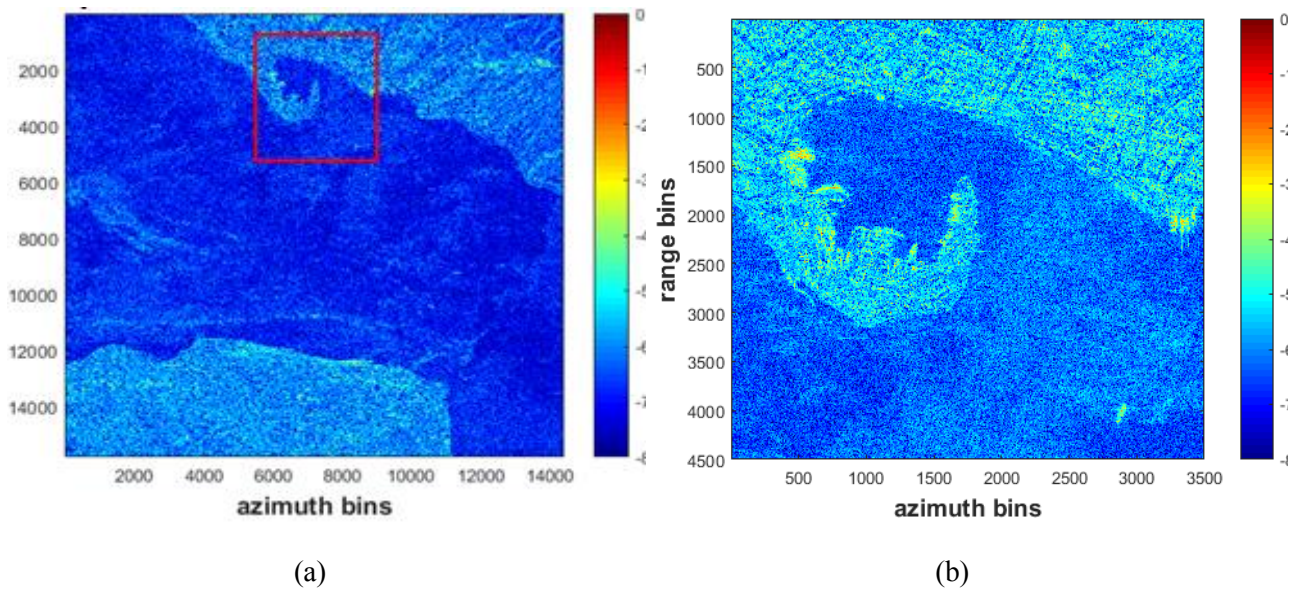
Figure 2: SAR image of interest. (a) Whole SAR image with crop highlighted in red; (b) SAR crop under test (b).

	Messina dataset
Image size [pix]	4500×3500
Radar frequency [GHz]	9.6
Bandwidth [MHz]	354.3457
Synthetic aperture duration [s]	1.3411
PRF [KHz]	3.0687
Range spacing [m]	0.3132

Azimuth spacing [m]	0.7021
Mean incidence angle [deg.]	28.9697
Scene centre geodetic coordinates (latitude)	38.202223 N
Scene centre geodetic coordinates (longitudes)	15.601992 E

Table 1: Messina dataset – Information of interest

The following step is the sea/land separation. The result is the binary mask shown inFigure 5.
The sea/land separation task is the only stepthat requires the user tointeract with the ISAR-SKY GUI. The reason for this interaction is due to the lack of robustness of the sea/land separation algorithm in the presence of high variability in the sea clutter intensity.The sea/land separation algorithm is based on the image magnitude histogram thresholding. The threshold is set on the histogram local minima and ,if more than one local minima are found, more than one thresholds will be calculated. As a consequence, the user has to select the optimal threshold by comparing the resulting masks with the SAR image under test through the GUI. If any of the shown results looks acceptable, the user can either manually set the histogram threshold, or edit a particular sea/land mask, or, alternatively use a different approach(e.g. the contrast stretching approach, which is also implemented in the ISAR SKY system).

The black and white mask resulting from the detection processing is depicted in Fig. 6, where all the detected target are highlighted in red.
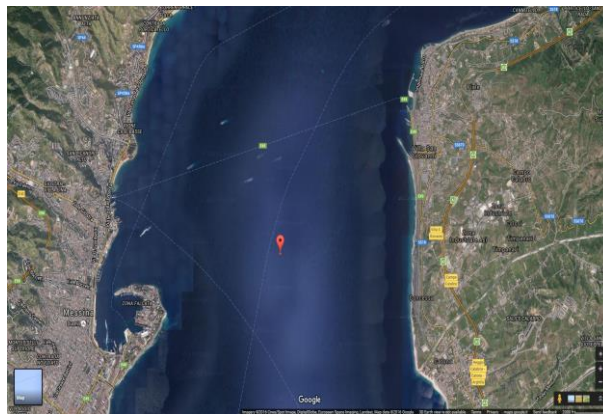

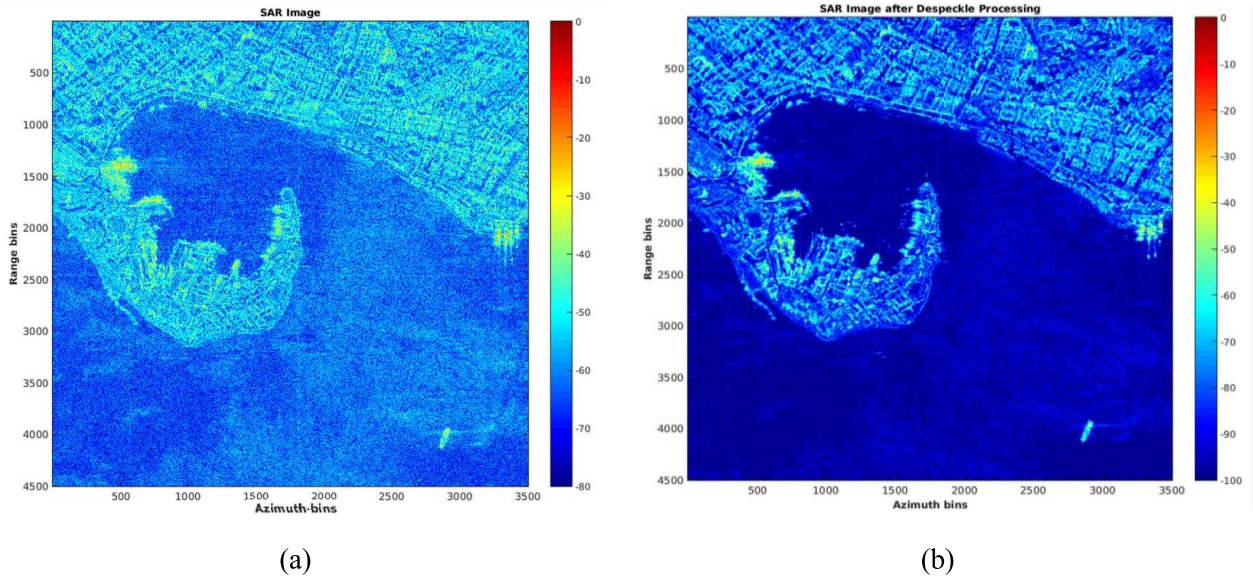**Figure 3:Messina scenario representation (Google Maps©)**

(a)   (b)

Figure 4: SAR image before (a) and after (b) despeckling processing
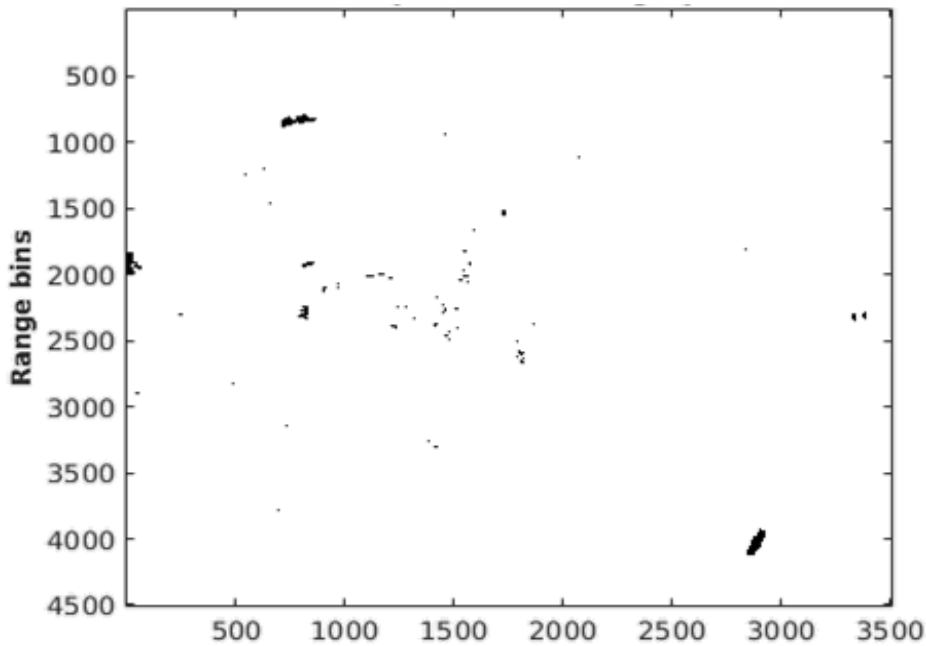

Figure 5: sea/land mask

Figure 6: Detection map

As described in the previous sections, the detection step exploits the W-CFAR algorithm, which is applied only to the image segments that have been selected by the S-Detector. The output is a binary map showing the detected targets.

After that, the clustering algorithms refine the map by removing possible false alarms and microdoppler residuals. Moreover, the target area is better defined by filling the gaps within the target shape in the binary map.

The occupancy of each target is evaluated, the optimal bounding box around every detection is calculated and then cropped from the complex image. This allows the target crops to be processed separately.

For each target, the target motion is compensated through the estimation of motion parameters. At this stage, the target is also labelled as 'stationary' or 'moving'. If the target is declared as stationary, the cross-range scaling is not applied. The image resulting from the ISAR processing is shown in Figure 7, where the detections are depicted with the respective optimal bounding box. Cyan colour means that the target has been classified as moving while yellow colour means that the
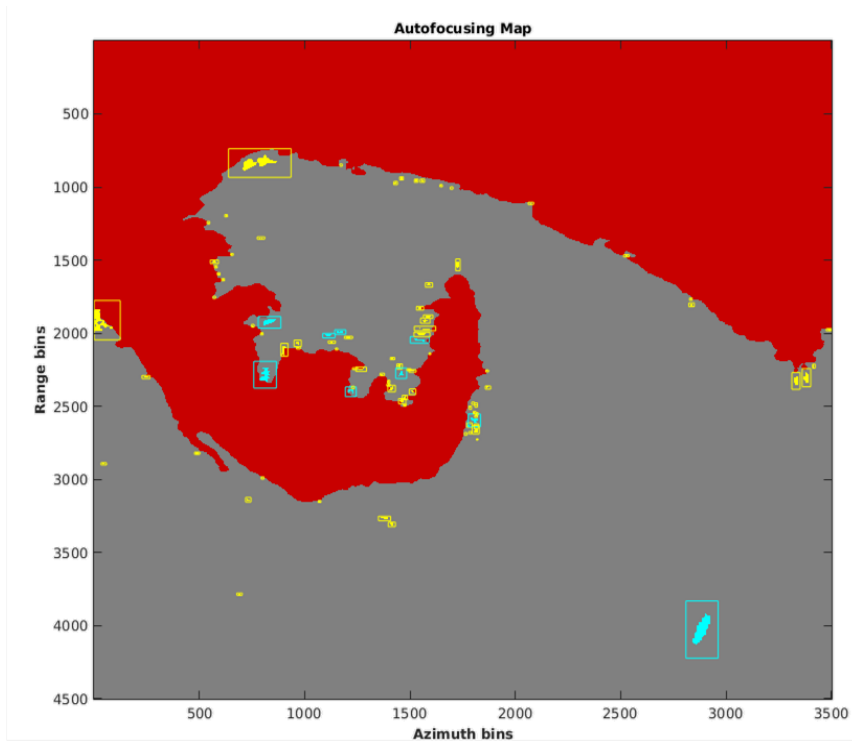
Figure 7: Autofocusing map

target has been classified as static. Original SAR image with refocused crops superimposed is shown in Figure 8.

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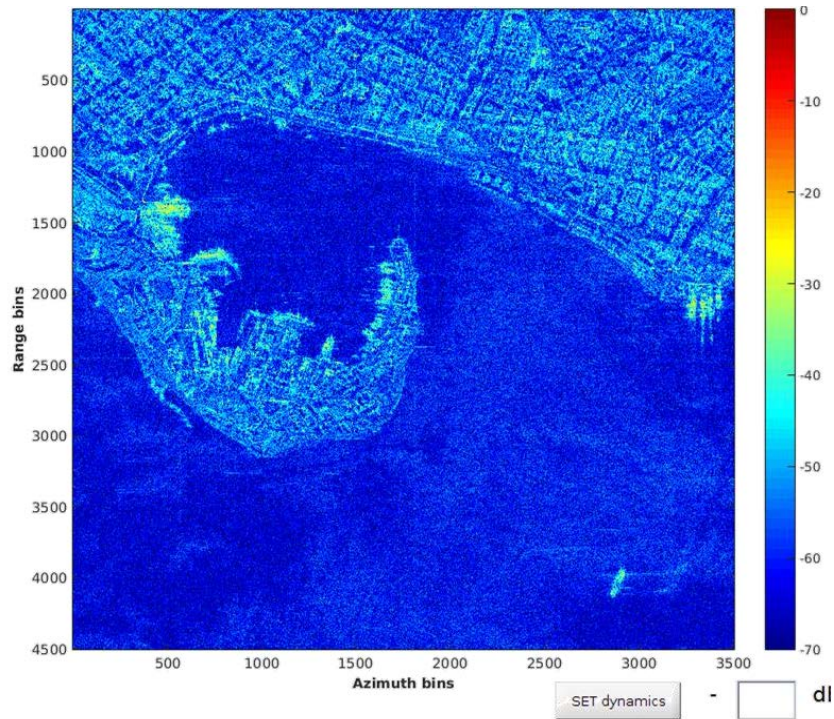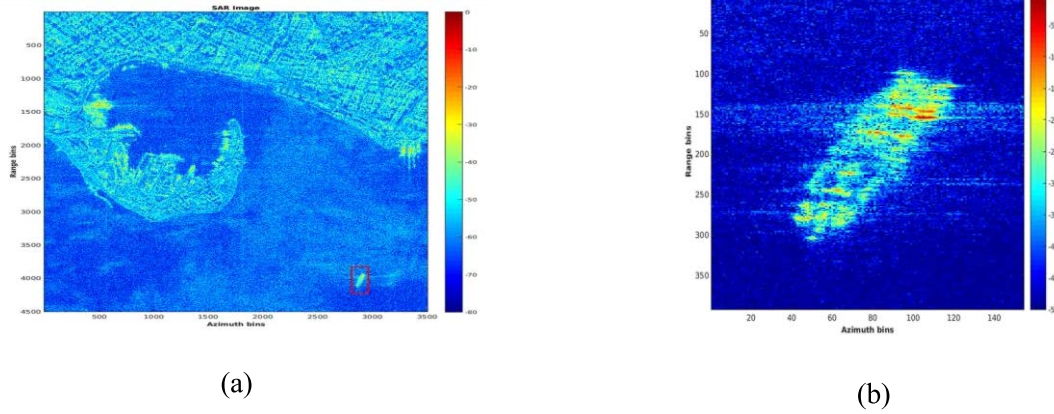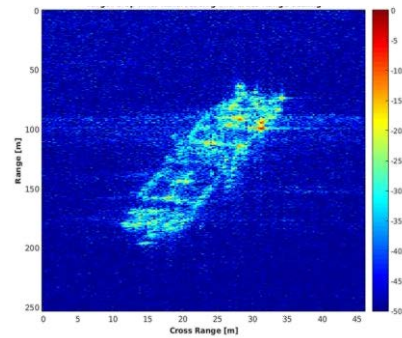Image Improvement and Exploitation for Maritime Surveillance**

Figure 8: Total refocused image

An example of single target refocusing and cross-range scaling is depicted in Figure 9.

(a)

(b)

(c)

Figure 9: (a) Original SAR image with the target highlighted in the red square; (b) ISAR image of the target;
(c) Refocused and scaled ISAR image of the target

For this case study, the total processing time of the sub-SAR image under test is about 45 seconds. The processing time for the entire SAR image (15821 x 14386 pixels) is about 306 seconds. seconds. In general, the system is able to achieve the expected results in a very short time if compared with the SAR image acquisition, transmission and processing time.

Figure 10 shows the Graphical User Interface of the ISAR SKY technical demonstrator at the end of the automatic processing, where all the above mentioned results are illustrated.
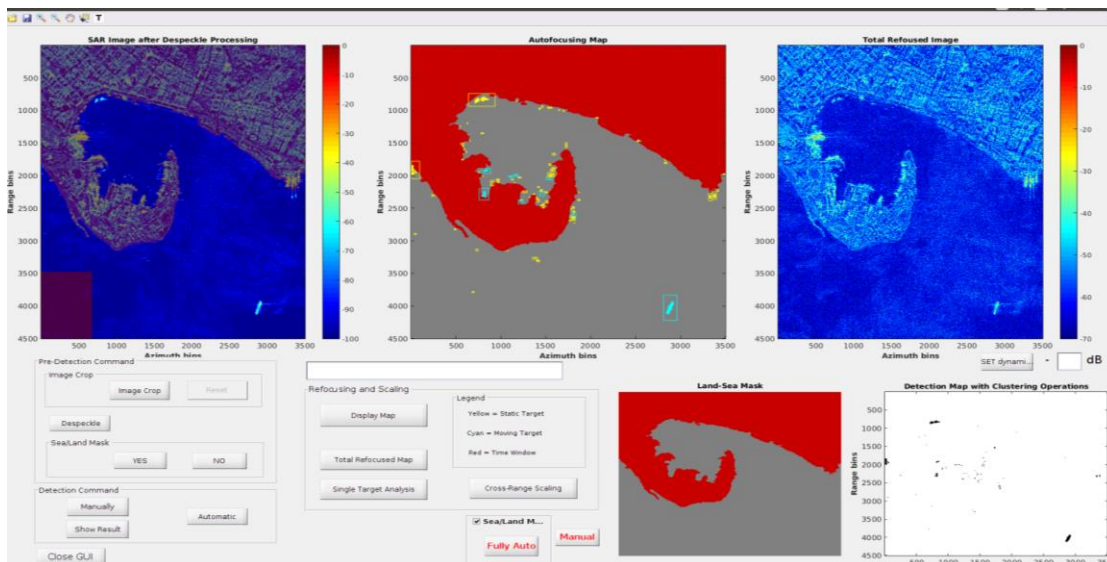

Figure 10: GUI of the ISAR SKY system showing the results of the automatic processing

When the total refocused image is shown, it is possible to view the targets table by means of the specific T button in the toolbar. In this table, information about the targets behaviour (stationary or moving) and geometrical parameters are summarized for all the detected targets, as shown in Figure 11. The parameters of

interest of the target shown in Figure 9 are highlighted in Figure 11 and zoomed in Figure 12.
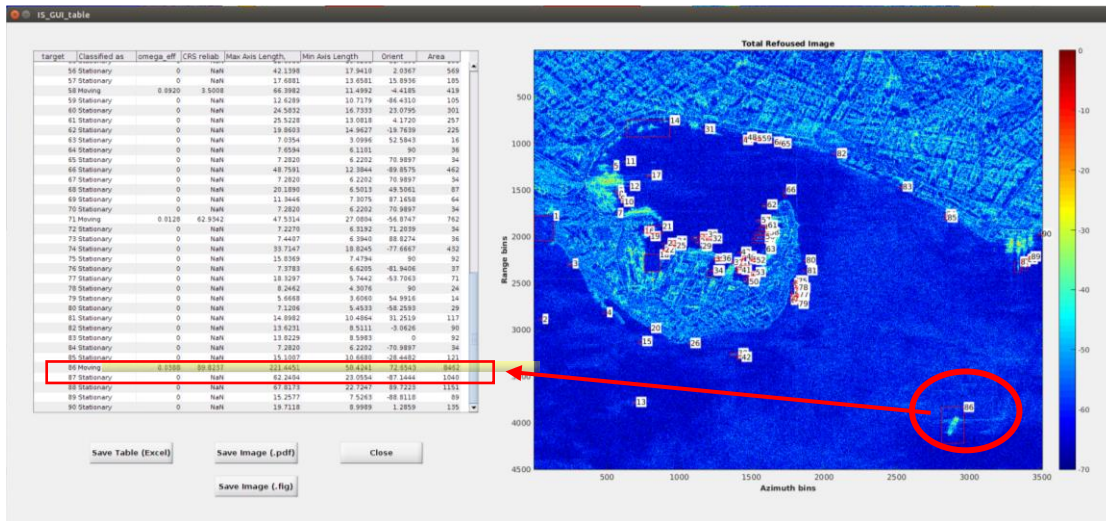

Figure 11: Targets table – Messina dataset

target	Classified as	omega_eff	CRS reliab	Max Axis Length,	Min Axis Length	Orient	Area
86	Moving	0.0388	89.8237	221.4451	50.4241	72.6543	8462

Figure 12: Target parameters

5.   CONCLUSION

In this paper, the ISAR SKY technological demonstrator has been described and examples of results have been shown when applied to a CSK SAR image of a maritime scenario. The example provided shows the effectiveness of the ISAR SKY system when detecting and refocusing maritime targets. Thesystem is also able to extract valuable parameters from the moving targets, such as position,size and velocity. The ISAR SKY system is also able to understand if a target is stationary,cruising or manoeuvring, which can be considered as behavioural parameters of interest forsurveillance and intelligence operations. Furthermore, the data is processed in a very short time, if consideredagainst the data acquisition, transmission and processing time that are required to obtain aSAR image.

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