COSMO-SKYMED SAR DATA TO OBSERVE SMALL METALLIC OBJECTS FROM OCEAN CRASHED AIRCRAFT

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ABSTRACT

In this study the capabilities of full-resolution Single Look Complex Slant (SCS) ScanSAR Wide Region mode X-band COSMO-SkyMed© Synthetic Aperture Radar (SAR) data are exploited to detect metallic objects over the sea. A physically-based filtering technique is developed which, based on the coherent-to-incoherent field ratio (Rice factor), is able to detect even small metallic objects in X-band full-resolution SAR data. Experimental results show the effectiveness of full-resolution SCS ScanSAR Wide Region mode X-band COSMO-SkyMed© SAR data to observe small metallic objects at sea.

Index Terms— COSMO-SkyMed*, Metallic Objects, SAR

1. INTRODUCTION

Air France Flight 447 was a scheduled airline flight from Rio de Janeiro to Paris that crashed into the Atlantic Ocean on June 1th 2009, killing all 216 passengers and 12 aircrew [1]-[2]. Investigators have not yet determined a cause of the accident, but preliminary investigation found that the crash might have involved an icing-over of its air-speed sensors during the flight, which would have led to inaccurate airspeed data, although this claim has been contested [1]. The post-accident search and rescue operations were characterized by the severe weather conditions (Fig.1) and by the far and peculiar geographic location, over 1000 km far away from Brazilian northeast coast. The investigation into this accident has been severely hampered by the lack of any eyewitness reports and radar tracks. Therefore, the lack of precise aircraft position information became a very complicated task to be done only by rescue airplanes and ships. Thus in that occasion, Synthetic Aperture Radar (SAR) imageries were engaged as an attempt to help finding the aircraft or, even, its metal pieces over the sea. SAR is an active, coherent, band-limited microwave high-resolution sensor that can make day- and night-time measurements almost independent of atmospheric conditions. Among the currently available SAR system, the Italian COSMO-SkyMed© one is very interesting from an operational point of view since it is a constellation of four X-band SARs, characterized by a very short revisit time, and it is able to operate in full-resolution Single Look Complex Slant (SCS) ScanSAR Wide Region mode, which provides both a large coverage and a fine spatial resolution.

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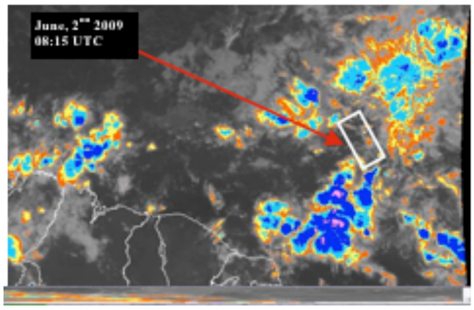


Figure 1. Weather conditions during COSMO-SkyMed© imagery acquired on June 2nd 2009 and its relative position on GOES-10 image. Clouds core temperature scale in Celsius degrees. COSMO-SkyMed product © ASI - Agenzia Spaziale Italiana - 2010. All rights reserved.

Physically, backscatter from metallic objects is determined by several scattering mechanisms depending on several factors, such as sea state, the construction material and the characteristics of the radar instrument, which cause a bright spot in SAR images [3]. SAR metallic object detection is a very non-trivial task, which cannot be handled by simple image processing techniques, since the detection problem increases in difficulty when the targets are small (e.g. tanks, small watercraft, personnel carriers) and the surveillance area is large. Furthermore, in the context of SAR metallic object detection at sea, there are many processes that can cause false alarms in SAR images. False alarms are most prevalent in non-homogeneous areas of the imagery, such as changes in ocean backscatter caused by variations in surface wind speed and direction or the transition regions between different wind conditions. Moreover, many other processes may generate false alarms, such as oceanographic phenomena, outlying rocks, shoals, sea currents, and coastal effects [3].

SAR-based metallic objects detection is typically undertaken by using multi-look techniques, i.e. SAR data in which the speckle noise has been reduced at the expense of spatial resolution. Although, in some cases these techniques work well, this is not the case when small metallic objects (such as the ones due to an aircraft accident) need to be detected. In this case, full-resolution speckled SAR data must be employed.

In this study, the SAR observation of a metallic object over the sea surface is investigated taking into account its peculiar scattering properties. In particular, its effects on the sub-resolution field formation, i.e. speckle, will be accounted for [4]. A metallic object at the sea surface calls for a strong and coherent return that can be distinguished from the mostly incoherent return, which characterizes the signal backscattered from the sea surface. As a matter of fact, the observation of metallic objects at sea can be reformulated as follows: a strong and coherent signal drown in an incoherent background is to be detected. Following this rationale, a physically-based filtering technique has been proposed, based on the coherent-to-incoherent field ratio (Rice factor), for metallic object observation purposes [5]. The technique has been successfully tested on a large data set consisting of VV-polarized Single Look Complex (SLC) ERS-1/2 SAR data. In this study, this technique is extended to the X-band case and applied to SCS COSMO-SkyMed© SAR data to observe small metallic objects at sea.

The remaining of the paper is organized as follows: in Section 2 COSMO-SkyMed© mission is described, the implemented technique is described in Section 3 and some meaningful experiments are discussed in Section 4. Conclusions are finally drawn in Section 5.

2. COSMO-SKYMED SATELLITE

COSMO-SkyMed© is an Italian Spatial Agency enterprise that has a satellite constellation with four full operational devices, carrying each one an X-band multimode SAR. Flying on a sun-synchronous dusk-dawn near-polar orbit platform at an altitude of 620 km, it has the capability to acquire different polarizations (HH, VV, HV, VH) and its main imageries modes are: Spotlight, Stripmap, and ScanSAR.

In the present study, a strip of five Level 1A full-resolution SCS ScanSAR Wide Region mode images (20º to 60º incident angle range; 100×100 km swath) were acquired, covering a 100×500 km oceanic area, off the Brazilian coast, in the area involved by the accident. The nominal ground range and azimuth resolutions are 7.0m and 16m, respectively [6].

3. METHODOLOGY

In this section, the physical rationale at the basis of the SAR metallic object detection approach is described.

In general, in single polarization SAR imagery, metallic objects appear as individual pixels or groups of pixels, which are bright compared to their surroundings. From an electromagnetic point of view, a metallic object can be considered as a dominant scatterer, characterized by a strong coherent component of its backscattered signal. This behavior is theoretically and practically confirmed by the physically based Generalized K-distribution model for full resolution, i.e., speckled, SAR images presented in [4]. The presence of a non-negligible coherent component in the backscattered sea surface signal can be highlighted by evaluating the corresponding Rice Factor (K) image of the area under study [4]. In fact, K represents the coherent-to-incoherent received power ratio of the backscattered signal and is expected to be very sensitive to the presence of a dominant scatterer such as a metallic target [7]. A filter technique described in [4] is used to evaluate the K of SAR image. According to this procedure, the calibrated SAR image is partitioned into 100×100 pixels sub-images and, within each of them, a moving local window of 3×3 pixels is applied. The incoherent power is evaluated over the entire sub-image, while the coherent power is evaluated over the local window. These are then compared to determine K as [8]:

$$K = \frac{\left| mean\left[\hat{E}_{LocalWindow} \right] \right|^2}{2 \cdot \left[var\left[\hat{E}_{Sub-image} \right] \right]} \approx \frac{|\mu|^2}{2\sigma^2} \quad . \qquad (1)$$

$\hat{E}_{LocalWindow}$ and $\hat{E}_{Sub\text{-}image}$ are the linear polarized component of the corresponding backscattered electromagnetic field phasor evaluated over the local window and the sub-image, respectively.

4. EXPERIMENTS

In this section, experiments, accomplished over full-resolution SCS ScanSAR Wide Region mode X-band COSMO-SkyMed© SAR data are presented and discussed for metallic object detection purposes.

The data set consists of a single strip of 5 Level 1A full-resolution SCS ScanSAR Wide Region mode X-band COSMO-SkyMed© SAR images acquired on June 2nd 2009, 08:15 UTC, off the Brazilian coast, in the area involved by the accident. Two meaningful results relevant to the first two scenes are shown and discussed to demonstrate the effectiveness of the physically-based approach described in Section 3 for SAR metallic object detection purposes.

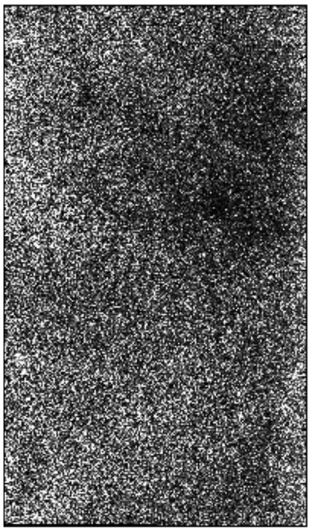


Figure 2. HH-polarized squared modulus of the first Level 1A full-resolution SCS ScanSAR Wide Region mode X-band COSMO-SkyMed© SAR scene, acquired on June 2nd 2009, 08:15 UTC, off the Brazilian coast in the area involved in the flight accident. COSMO-SkyMed product © ASI - Agenzia Spaziale Italiana - 2010. All rights reserved.

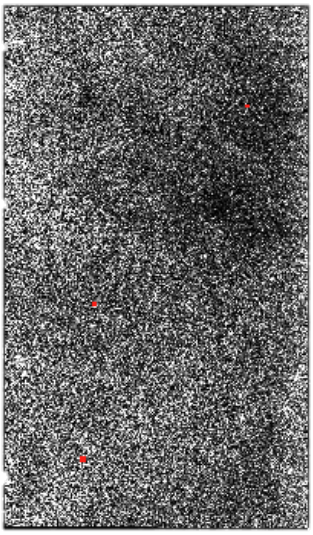
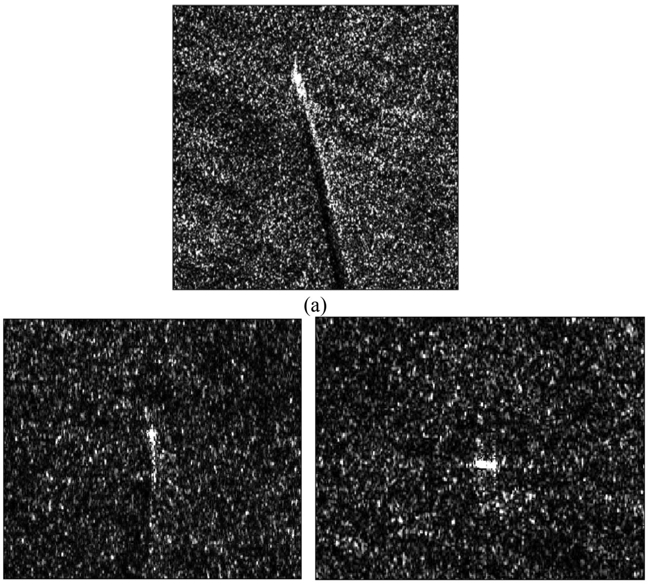


Figure 3. Filter's output (red spots) relevant to the first X-band COSMO-SkyMed© SAR scene. COSMO-SkyMed product © ASI - Agenzia Spaziale Italiana - 2010. All rights reserved.

The HH-polarized squared modulus of the first X-band COSMO-SkyMed© SAR scene is shown in Fig. 2. It can be noted that no features associated to metallic objects are clearly visible in the full-resolution SAR data of Fig. 2. However, the filtering technique detects 3 metallic objects, which have been highlighted as red spots over the full-resolution HH-polarized SAR data in Fig. 3. This is a very important result, which witnesses the robustness of the proposed approach in detecting non-negligible coherent component in the backscattered sea surface signal.



(a)

(b) (c)

Figure 4. Excerpts of the first full-resolution HH-polarized SAR data, where detected metallic objects are shown, respectively, a small ship (a) and other two targets probably related to the ocean-crashed aircraft (b-c).

A visual inspection accomplished over a magnified version of the full-resolution HH-polarized SAR data shows that one of these three metallic objects corresponds to a small ship, which can be clearly recognized by means of its wake on the sea (see Fig. 4(a)). The other two detected targets are probably related to the metal pieces of the ocean-crashed aircraft since the SAR image has been acquired in the area involved in the accident (see Fig. 4(b-c)). Such a result further confirms the powerful capabilities of the proposed approach which takes full benefits of Level 1A full-resolution SCS ScanSAR Wide Region mode X-band COSMO-SkyMed© SAR data for both small metallic object detection purposes and for saving people missions.

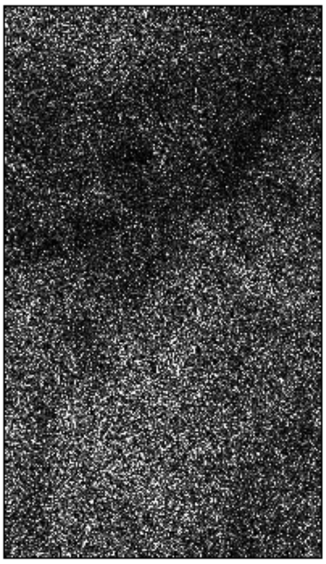


Figure 4. HH-polarized squared modulus of the second Level 1A full-resolution SCS ScanSAR Wide Region mode X-band COSMO-SkyMed© SAR scene, acquired on June 2nd 2009, 08:15 UTC, off the Brazilian coast in the area involved in the flight accident. COSMO-SkyMed product © ASI - Agenzia Spaziale Italiana - 2010. All rights reserved.

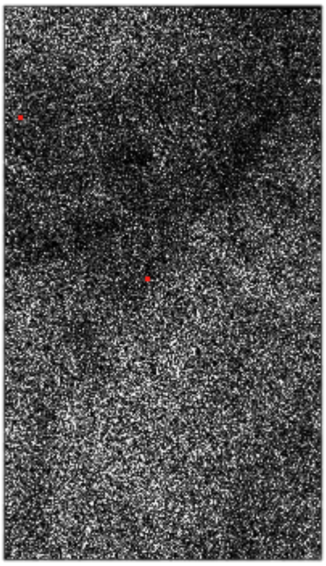


Figure 5. Filter's output (red spots) relevant to the first X-band COSMO-SkyMed© SAR scene. COSMO-SkyMed product © ASI - Agenzia Spaziale Italiana - 2010. All rights reserved.

The HH-polarized squared modulus of the second X-band COSMO-SkyMed© SAR scene is shown in Fig. 4, where, again, no features associated with metallic objects can be visually inspected. The output relevant to the physically-based filtering technique is shown in Fig. 5. As a result, 2 metallic objects are detected and visually represented as red spots in the SAR image. A visual inspection accomplished over a magnified version of the full-resolution HH-polarized SAR data shows that one of this metallic objects is a small ship clearly recognized by means of its wake on the sea (see Fig. 6(a)), while the second one is probably related to a metal piece of the ocean-crashed aircraft (see Fig. 6(b)). Experimental results agree with the previous one.

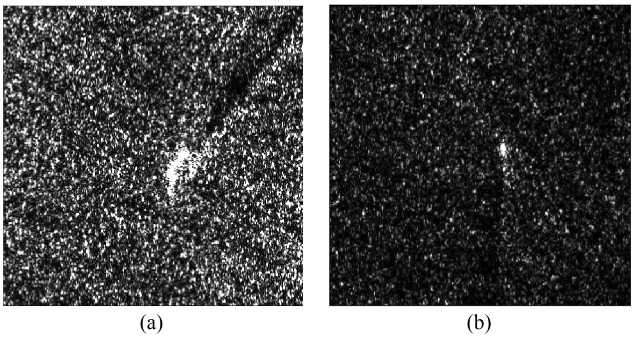


Figure 6. Excerpts of the second full-resolution HH-polarized SAR data, where detected metallic objects are shown, respectively, a small ship (a) and the other small metallic target probably related to the ocean-crashed aircraft (b).

5. CONCLUSIONS

In this study a physically-based filtering technique has been undertaken to detect metallic objects over the sea with respect to the Air France flight 447 accident off the Brazilian coast. Experiments show the effectiveness of the proposed approach taking full benefits of full-resolution SCS ScanSAR Wide Region mode X-band COSMO-SkyMed© SAR data for both metallic object detection purposes and saving people missions.

6. ACKNOWLEDGEMENT

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