Detecting aquaculture platforms using COSMO SkyMed

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Abstract

Aquaculture are a very valuable asset for many coastal countries and in the future they will play an important role in food security. Satellite remote sensing can improve the temporal and geo-spatial analysis of such marine facilities. Detecting platforms used for fish and shellfish farming provides a way to monitor assets and check they do not get damaged by storms. It also allows to identify illegal placement of structures in areas which should not host farms. In this work, we want to evaluate the use of COMSO SkyMed polarimetric acquisitions. In particular, we want to use a novel methodology called intensity Dual-Pol Ratio Anomaly Detector (iDPolRAD). Extensive work has been carried out on detecting ships using space-borne Synthetic Aperture Radar (SAR) systems. However, the identification of smaller and non-metallic targets is still challenging especially when the sea conditions are rough. This work presents an assessment of different detectors and polarimetric information for the detection of wooden mussels platforms. The results show that the use of dual polarimetric information can improve the detection performance.

1 Introduction

Synthetic Aperture Radar (SAR) provides a very useful system to perform maritime target detection. This is related to its capability to acquire useful information without relying on solar illumination and with almost any weather condition [1]. This work is focused on the monitoring of aquaculture platform, since these are very valuable assets and they play an important role in food security.
COSMO SkyMed is a constellation of radar satellites able to provide high resolution and multiple polarisation images with very short repeat time. It is therefore an ideal system to apply for monitoring maritime targets.

1.1 PolSAR

In the following, a very brief introduction to Pol-SAR is proposed with the only purpose of presenting the mathematical formalism exploited in the following. A single target has a fixed polarization in time/space and we can characterize it using the scattering (Sinclair) matrix or equivalently a scattering vector $\underline{k}$ [2]. It is possible to define a projection vector as a normalized vector $\underline{\omega} = \frac{\underline{k}}{\|\underline{k}\|}$. This is often refereed to as scattering mechanims (SM), however in the following we refer to SM as the process producing scattering vectors. The targets observed by a SAR system are generally not single SMs, but a combination of different SMs which we refer to as a partial target. In order to characterize a partial target the single scattering matrix is not sufficient since these are stochastic processes and second order statistics need to be considered. To most common way to do this, is by extracting the target covariance matrix as $C = \langle \underline{k}\, \underline{k}^{*T} \rangle$, where $*$ stands for conjugate, T for transpose and $\langle . \rangle$ is the finite averaging operator [2]. In this work, we propose an alternative to this formalism.

1.2 iDPolRAD

The algorithm is based on the observation that the most of the maritime targets exhibit a different polarimetric behaviour compared to the sea. Specifically, the cross polarization channel and the ratio between cross- and co-polarizations (here referred to as depolarization ratio) increases. One of the reason is that complex targets (e.g. shellfish platforms) will provide scattering which will resemble Volume scattering or reflections from planes (mostly wet surfaces) with random orientations. They are therefore expected to have a polarimetric backscattering that is different from the one of the sea which is surface scattering.
Two boxcar filters are applied over the HV and HH intensity images, exploiting two different window sizes: a smaller window or test window w_{test} and a larger window or training window w_{train}. Details on the dimensions are provided in

next section. The detector can be written as:

$$\Lambda = \frac{\langle |HV|^2\rangle_{test} - \langle |HV|^2\rangle_{train}}{\langle |HH|^2\rangle_{train}} > T_\Lambda. \quad (1)$$

where $\langle\rangle_{test}$ and $\langle\rangle_{train}$ are the spatial averaging using the test and training windows respectively and T_Λ is a threshold **??**. This methodology was initially proposed for detecting icebergs [3] The previous operator is built as a ratio between intensities and therefore it is scale invariant. This is a very valuable property for a polarimetric observable, however scale invariance may be disadvantageous for some detection task. For instance, if the signal is very low and close to the noise floor, the detector may become noisy. An easy way out is by multiplying the detector by an intensity or magnitude image. In this context, the cross polarization channel should be preferred because it shows a higher contrast between icebergs and clutter.

$$HV - iDPolRAD = \langle |HV|^2\rangle_{test} \frac{\langle |HV|^2\rangle_{test} - \langle |HV|^2\rangle_{train}}{\langle |HH|^2\rangle_{train}}. \quad (2)$$

Multiplying the intensity of HV by the previous operator forms the iDPolRAD. If a pixel of the HV intensity image presents an anomaly in volume or oriented reflections, then it is multiplied by a large number. If it presents a homogeneous area, then it is multiplied by zero and if it presents a decrease in volume or oriented reflections, then it becomes negative. This enhances the contrast between anomalies in volume/oriented reflections and clutter.
In this work we propose a new detector, where the filtered image is the HH and not the HV

$$HH - iDPolRAD = \langle |HV|^2\rangle_{test} \frac{\langle |HV|^2\rangle_{test} - \langle |HV|^2\rangle_{train}}{\langle |HH|^2\rangle_{train}}. \quad (3)$$

As explained more in the following, in this new version, we try to combine the highest probability of detection (P_d) of the co-polarisation, with the capability of reducing false alarms (P_f) of the DPolRAD.

2 Real Data analysis

In this section we test the algorithm over COSMO SkyMed PINGPONG images. COSMO data were provided courtesy of Italian Space Agency and Catapult by the CORSAIR call of opportunity (Corsair104). The data are acquired using COSMO multiple polarisation mode (PINGPONG) where HH and HV channels were acquired incoherently. The resolution of these images is about $10m$ in ground range and azimuth.
The area of interest is near the city of Vigo in Spain. We have ground information relate to wood platforms for mussel farms in the area. An image of the area with polygons over the platforms is presented in the following Figure 1.
In this abstract we will only present one of the 4 acquisitions we have tested. This was taken on the first of January 2019, with a 5 knot wind reported near Vigo. Clearly the complex topography of the estuary makes for possible different wind conditions in different parts of the dataset, however, we can state that inside the estuary the wind condition should be overall moderate.
A picture of the wooden platforms is shown in Figure 2. These are generally 20 x 20 m, made of wood, with nets containing mussel attached and submerged.

2.1 Results

The first test can be done using the single channels as they are. A preliminary 3x3 boxcar filter is applied to the data. This is shown in Figure 3. On the top raw we have the HH and HV intensity images. It is possible to observe that the co polarisation has very low performance for detecting this type of targets. The clutter background is extremely strong. It is hard to see the platforms. On the HV image instead we can easily see several platforms, however the number of pixels with similar backscattering in the nearby area is very large. This will lead to a very high number of false alarms.
In the second row we tested a very simple Cell-Averaging Constant False Alarm detector assuming the statistics of the background are exponential. This can be easily set by using a threshold obtained as the training backscattering multiplied by a factor (in this case 5 seemed to have the best performance). We also used a guard window to avoid contamination of the training window by the same target, however this will not avoid contamination from neighbour targets. The train window is a ring 7 pixels away from the middle pixel (so to be in line with the training window used for the iDPolRAD). We can see how the HH polarisation channels seems to miss lots of targets (due to the training done with a very high background, i.e. the power of the detector is very low), while the HV is affected by several false alarms.
In Figure 4 we test the iDPolRAD versions. In the top left there is the classic iDPolRAD which filters the HV channel, while top right is the new proposed HH-iDPolRAD which filters the HH channel. Interestingly we can see how both are able to reduce very drastically the clutter background. Please note that the scale for the HV and the iDPolRADs is the same, so the images are comparable straightforward. The capability to reduce background and therefore false alarms seems to be evident in this images. On the other hand, we can see how the capability to see platforms in the

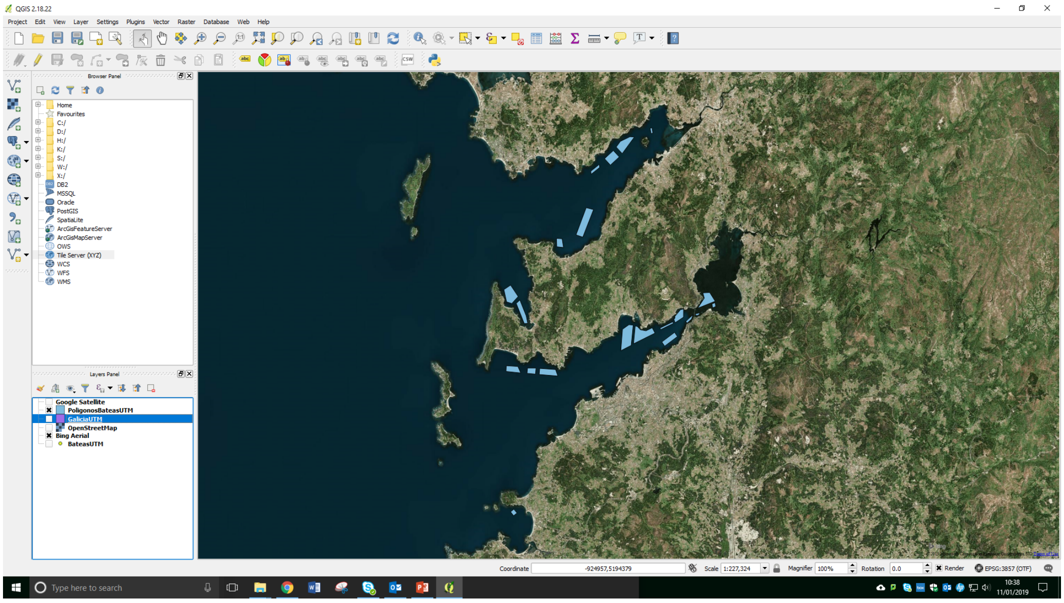

Figure 1 Aerial picture of area with polygons representing mussel farms.

Figure 2 A picture of the platforms in Vigo, Spain.

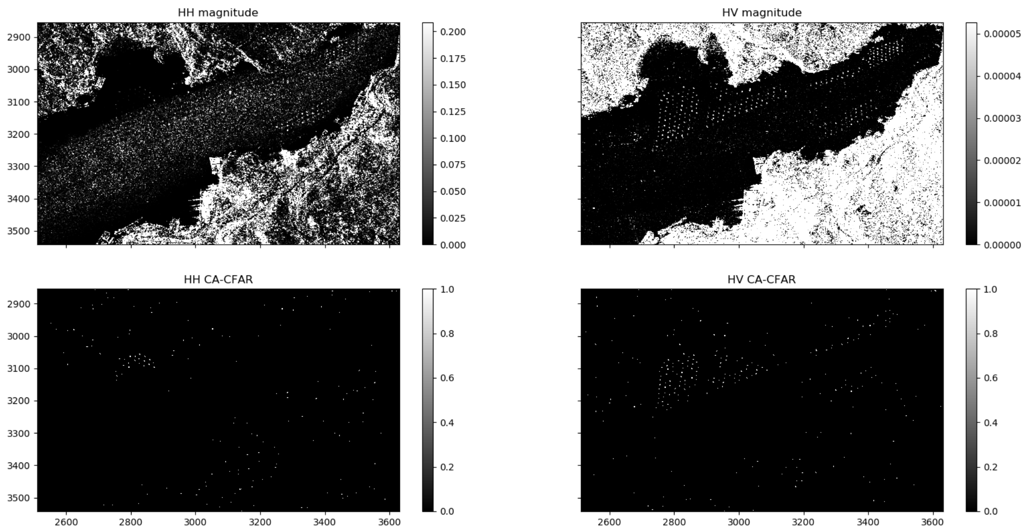

Figure 3 Detection using single channels: (Top-Left) HH magnitude; (Top-Right) HV magnitude; (Bottom-Left) CA-CFAR using HH; (Bottom-Right) CA-CFAR using HV. Boxcar: 3x3.

HV-iDPolRAD does not seem too good. It appears like some platforms may not be visible. This can be a matter of changing the image scaling, nevertheless we can clearly see that the intensity of platforms in the HV-iDPolRAD is lower then the HH-iDPolRAD. The HH-iDPolRAD seem to have the advantage of reducing the clutter background (due to the DPOlRAD filtering) but also keep a relatively high backscattering for te platforms, which is more characteristic of the HH channel.

The second row of Figure 4 presents again the results using a CA-CFAR. This time the factor has been increased to 15 since the background is much reduced and we can have more strict thresholding. It is important to keep in mind that the use of so high factors is a clear indicator that the iDPolRAD clutter is not exponential. We are at the moment working on a better modelling of the clutter. Nevertheless, the results using iDPOlRAD seem to be better, even using a rudimentary way to select the threshold. However, it is hard from these images to evaluate how much we are gaining in terms of detection performance. We therefore decided to do some quantitative analysis and produce Receiving Operating Curvse (ROC).

To produce the ROC we identified 300 platforms inside the data using the ground validation polygons provided. Each of these platforms were considered as a unique target of a size of 30 x 30 meters (3 x 3 pixels). If any of the pixels inside these 3 x 3 box was detected the platform was called as detected. For evaluating false alarms, we considered areas inside and outside the estuary where there was no evident target present. Around a million of pixels was used for this.

Figure 5 show the ROC. Here, the red is for HH intensity, the green for HV intensity, the blue for HV-iDPolRAD and the yellow for HH-iDPolRAD. We can observe how the worse performance is given by the HH intensity. This is due to the very high clutter and therefore very high P_f. The best performance seems to be given by the HH-iDPolRAD. To have a close up look at these curves for small P_f values we plotted this in Figure 6. Looking at these we can see that in theory is possible to obtain probabilities of detection around 0.9 with false alarms on the order of $P_f \approx 10^{-4}$. This is a very promising result considering the complexity of detecting these type of wooden targets.

3 Conclusion

In this work, we have used COSMO SkyMED PINGPONG polarimetric mode to detect wooden mussel platforms in the area near Vigo, Spain. We have showed that, keeping the resolution constant, the use of extra polarimetric channels can improve significantly the detection performance. In particular, a new version of the iDPolRAD detector was proposed, where we filter the HH intensity instead then the HV. Quantitative results using ground data show that using the HH-iDPolRAD and COSMO PINGPONG we could aim to achieve probability of detection of the order of 0.9 with probability of false alarm of the order of 0.0001. As future work some better methodology for the select of the threshold need to be developed, since the closeness of the neighbour platforms produce a loss of power due to contamination of the training window.

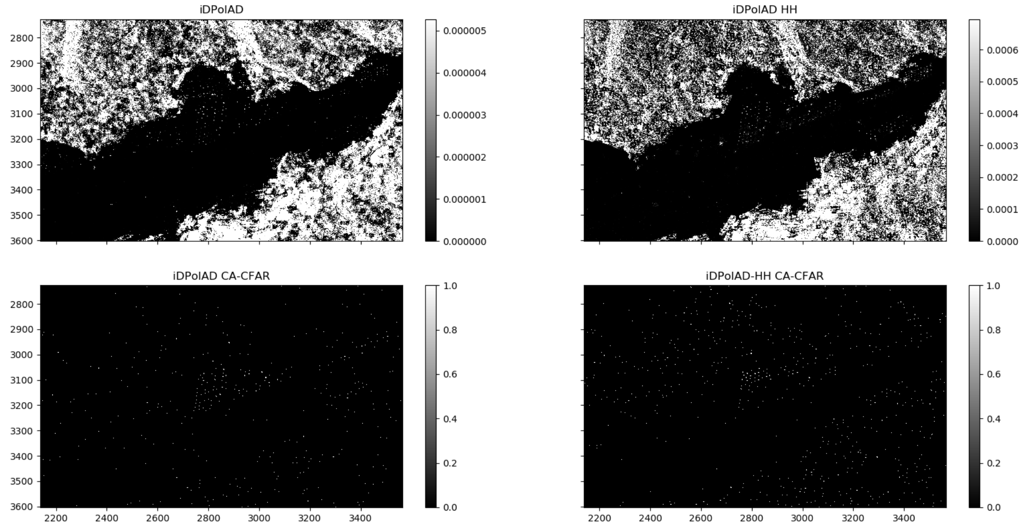

Figure 4 Detection using iDPolRAD (dual-pol): (Top-Left) HV-iDPolRAD; (Top-Right) HH-iDPolRAD; (Bottom-Left) CA-CFAR using HV-iDPolRAD; (Bottom-Right) CA-CFAR using HH-iDPolRAD. Train: 15x15; Test: 3x3.

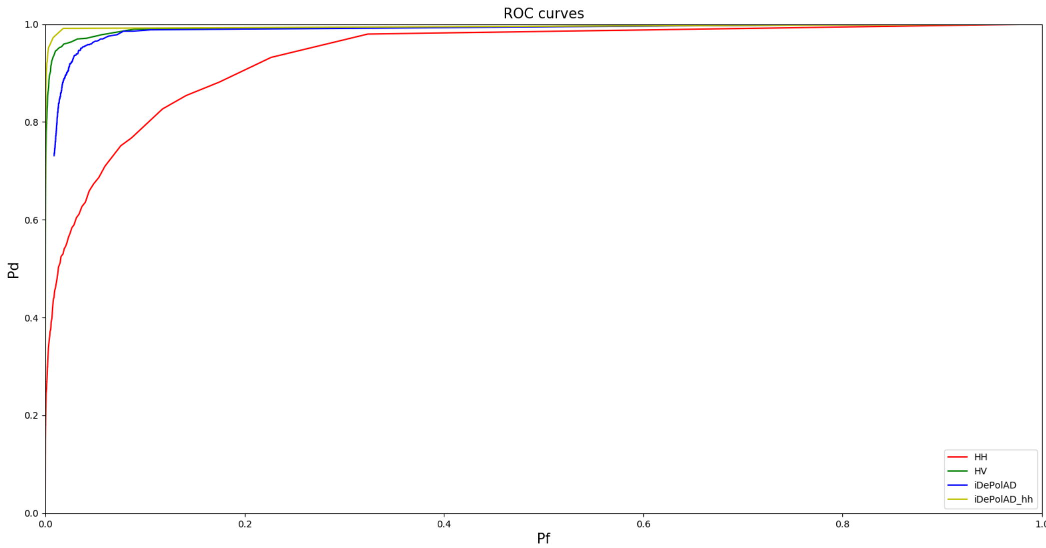

Figure 5 ROC curve: (Red) HH intensity; (Green) HV-intensity; (Blue) HV-iDPolRAD; (yellow) HH-iDPolRAD.

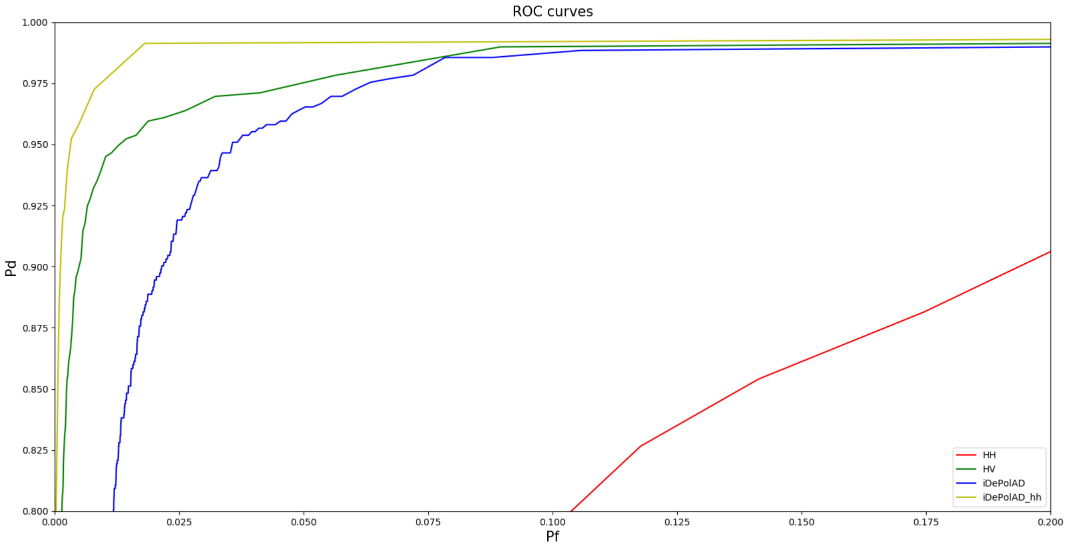

Figure 6 ROC curve: (Red) HH intensity; (Green) HV-intensity; (Blue) HV-iDPolRAD; (yellow) HH-iDPolRAD. Small P_f.

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5 Literature

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