Semi-automatic Oil Spill Detection in Sentinel-1 SAR Images at Brazil's Coast

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***Abstract*— This paper reports a methodology proposed on the matter of semi-automatic detection of oil spills using Sentinel-1 Synthetic Aperture Radar (SAR) images to improve the capability of management of government agencies for oil spills incidents over the seas. This is an initiative to create a semi-automated system of detection based on free images of Sentinel-1 using an intelligent database of samples statistics of oils, confirmed by vessels or airplanes and photo-interpreted, and oceanographic features that continues improving itself over time. The results indicate that both the VV and HH polarizations of the Sentinel-1 detected probable oil-spills and look-alikes, however, the utility of the Sentinel-1 cross-polarizations (VH and HV) in oil-spill detection could not be discarded. Other parameters will be improved and included in this study, as parameters of segmentation, besides process of data mining.**

Keywords-semi-automatic; sentinel-1; sar; oil spill; seas monitoring.

I. INTRODUCTION

One of the challenges that the oil and gas industries face is the management of oil spills at seas. Brazil has a huge coastal zone with over 7,000 kilometers of extension and with many activities of offshore oil exploitation, oil transportation and a constant high vessels traffic. Monitoring constantly such an extensive area with the existing paid Synthetic Aperture Radar (SAR) increases substantially the costs of any projects in this area, making most of them inviable. As a low-cost alternative, the Sentinel-1 Satellite radar images are made available by the European Space Agency (ESA) free of charge on the Sentinel data hub. However, this is a recent technology (launch year 2014 for satellite 1-A and 2016 for satellite 1-B), and the revisit time is of 12 days for most Brazil's areas, thus, one of the project problems to solve is the shortage of oil spill samples. Other difficulties are the needs of a valid compatible database with spills and look-alikes for algorithms improvement [8].

The SAR monitoring of the oil spills over the oceans had proved its efficacy during daytime, nighttime, and any kind of weather. In the last decade, a lot of researches on automatic and semiautomatic methods of oil spill detections have been documented [2][6], and they provided a lot of knowledge for the creation of a methodology with the usage of Sentinel-1 satellite images.

The main objective of the proposed methodology is to create a semi-automated process capable of helping the interpretation of oil spills using Sentinel-1 SAR images as a primary input.

This work is presented in four sections, as follows: Section II presents the methodological approach initially adopted to solve the problems mentioned in the introduction, including information about the studied area, the statistics used, the processes applied to the images and the digital resources used. Section III presents the preliminary results, since this work is under implementation now, and a discussion about these results. Section IV exposes the conclusions that could be obtained, so far in the research process.

II. METHODOLOGICAL APPROACH

This proposal was initially inspired by the methodology for automatic oil spills detection in Envisat, Radarsat and ERS SAR images, as described in [1] and adapted to work with Sentinel-1 images. Most of the adaptations were made by: (a) using sensor specific modules; (b) generating the wind data from the input image; (c) including combined filters before segmentation and; (d) including specialists control of classification quality, alerts and warning reports through the interface of the system.

A. General explanation

The SAR images chosen to work with in this project were Sentinel-1A and 1B with the beam mode of Interferometric Wide and the polarization VV. After the availability of the image on the ESA website, Ground Range Detected (GRD) data are downloaded and passed through seven preprocessing/processing steps consisting of: (a) Orbit corrections and radiometric calibration to sigma naught to generate the Normalized Radar Cross Section (NRCS) values; (b) The direction of the wind for the image is estimated through frequency domain method and the speed is estimated through C-band Geophysical Model 5 (CMOD5); (c) The image is resampled to 40 meters and then filtered with Median Filter followed by a Low-Pass Filter as suggested [4] for better results in suppressing the speckle noise; (d) The land parts of the images, if there are any, are masked and the dark spot segmentation step is applied through a process of Adaptive Threshold as described [2]; (e) The object resulting of the segmentation has its statistics calculated and the more significant samples are chosen to fill the samples database in order to improve continually the process. (f) The statistics of the new objects area compared

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with those of the database and through Support Vector Machine (SVM) classification returns a percentage to the object to be in the class of oil spill; (g) Through a web interface the users of different agencies can decide the importance of the dark spot visualized, if it is a case of oil spill verification or alert, this information also returns to the database of samples, helping to improve the classification.

B. Information About the Statistics

The statistical analysis was based on researches like [7]; however, those which were tested in this work are:

- Area of the object in square kilometers.
- Length of the border of the object in kilometers.
- Perimeter to Area ratio.
- Object complexity [10].
- Object mean value.
- Object standard deviation.
- Object power to mean ratio.
- Background mean value.
- Background Standard Deviation.
- Background power to mean ratio.
- Ratio of the power to mean ratios.
- Mean contrast.
- Max contrast.
- Mean contrast ratio.
- Standard deviation contrast ratio.

Also, three additional statistics were added to the previous list to complement the attributes of the dark spots polygons:

- Area in pixels
- Minimum value
- Mean wind field intensity.

C. Representation of the processes

In Figs. 1-4 it is possible to visualize the whole process and the decisions associated with the automatic part and the user decision part.

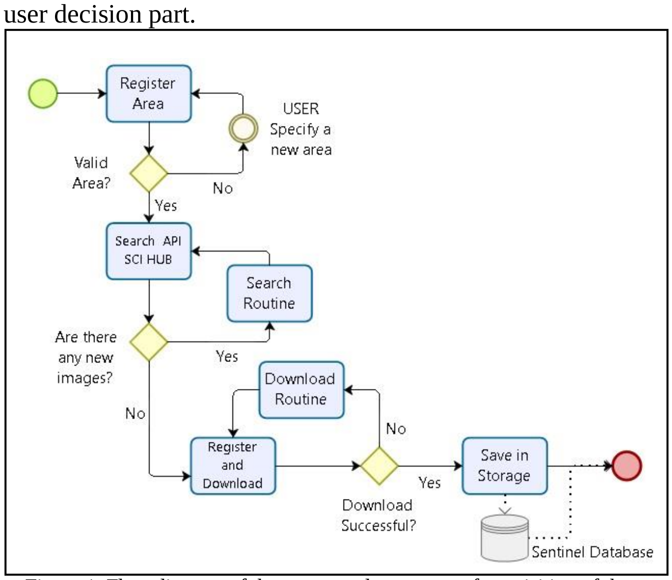

Figure 1. Flow diagram of the automated processes of acquisition of the proposed semi-automatic oil spill detection.

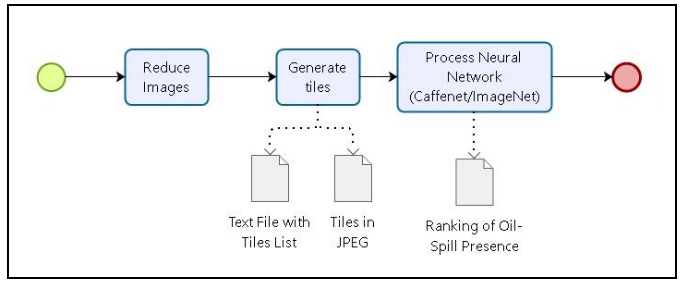

Figure 2. Flow diagram of automated processes of image qualification of the proposed semi-automatic oil spill detection.

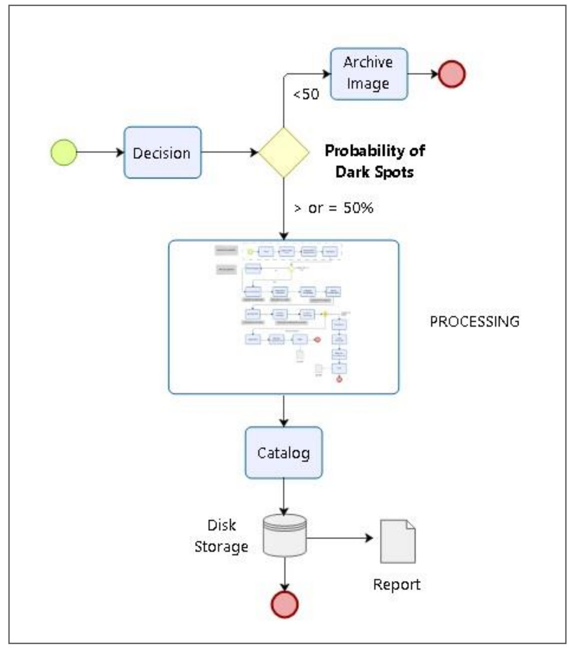

Figure 3. Flow diagram of decisions to processes or to archive the images of the proposed semi-automatic oil spill detection.

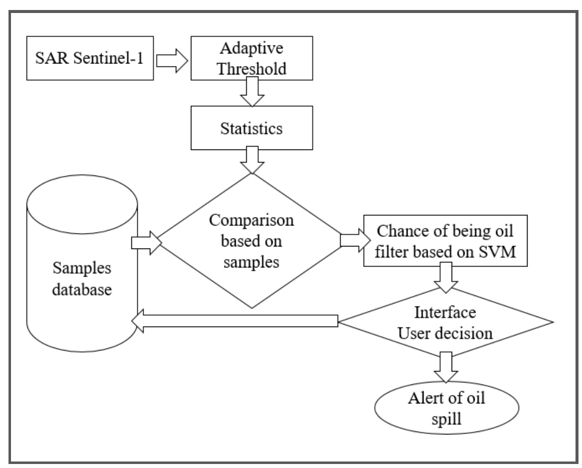

Figure 4. Flow diagram of the image processing part of the proposed semi-automatic oil spill detection.

Figure 4 presents the image processing methodology based on [8] adding an extra part at the end for the user interaction and decision.

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D. Development

All processes are already automated using python scripts together with the modules of the open source software and extensions: (a) SNAP (Sentinel Application Platform); (b) S1TBX (Sentinel-1 Toolbox); (c) QGIS; (d) GDAL (Geospatial Data Abstraction Library) and; (e) PostGIS.

E. SAR Images and Study Area

One hundred Sentinel-1 images were analyzed, most of them over the Campos sedimentary basin, located on the coast of the states of Rio de Janeiro and Espírito Santo - Brazil, one of the most relevant regions for oil exploitation and with a great volume of vessels traffic. Fig. 5 shows the location map of Campos basin and the research area.

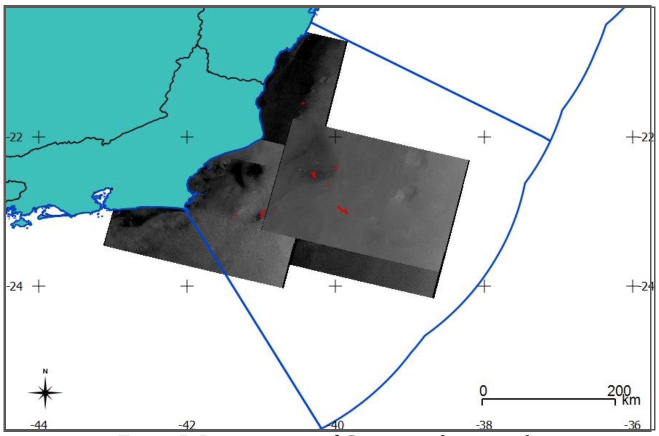

Figure 5. Location map of Campos sedimentary basin.

The Brazilian Institute of Environment and Renewable Natural Resources - IBAMA is helping the project with oil spills interpretations, reports and verified samples. Two groups of samples were created to contribute with different weights:

1) Samples photo-interpreted by speciatlists;
2) Samples confirmed with flights or other sources.

Bellow, in Figs. 6-8 are presented some of the samples with the respective delimitation generated by the Adaptive Threshold segmentation process:

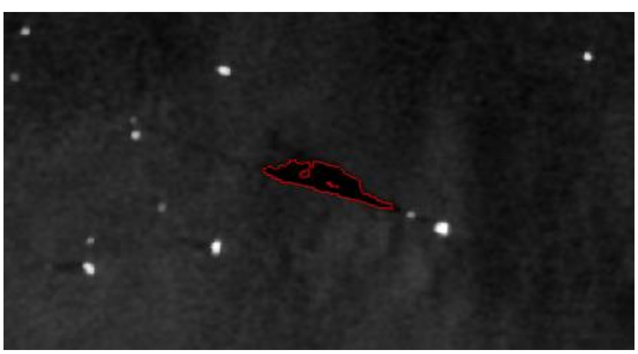
Figure 6. Oil spill in proximity of a platform at Campos Basin.

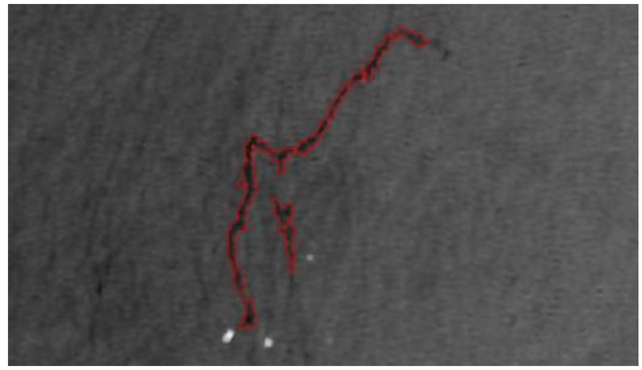
Figure 7. Oil spill in proximity with a vessel at Campos Basin.

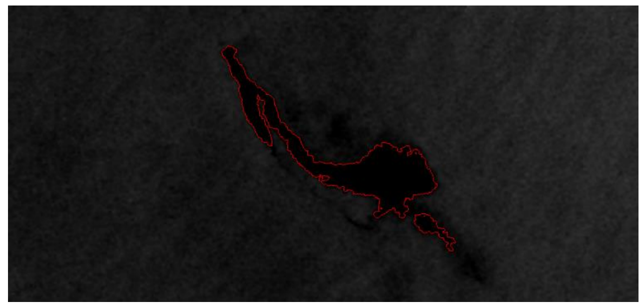
Figure 8. Orphan possible oil spill at Campos Basin.

The statistics of the samples are weighted and then used as a data input to the Support Vector Machine Classifier - SVC to set scores for each class to each polygon generated by the Adaptive Threshold segmentation. The SVC was initially chosen for its ability to classify data that is non-linearly separable. These scores are then used to compose a filter to display only the relevant polygons to the users interact on the web interface.

III. RESULTS AND DISCUSSIONS

In the scientific research mentioned in [9], it seems that using X-band SAR images can provide better results for oil-spill detection than using L-band or C-band SAR images. The Sentinel-1A and Sentinel-1B have C-band SAR sensors. Also, it is observed that many researches mention that the VV polarization gives better results for interpretation of oceanographic features. In this project using the proposed methodology we detected probable oil-spills and look-alikes in both polarizations VV and HH.

When the backscatter of the ocean reaches, or stays close to the noise floor of a SAR sensor, it may produce a non-adequate signal with limited interpretation capability reducing the utility of that data. In most cases, it is visible a stripe pattern in the parts where it stays close to the noise floor along the image; that pattern was identified along many cross-polarized Sentinel-1 images. The Sentinel-1 noise floor in sigma naught is -25dB.

In Figs. 9-12, it is possible to see the results on a prior stage with manual attribute filters, before the SVC, where the green features are selected for the interaction with the users and the red features are filtered.

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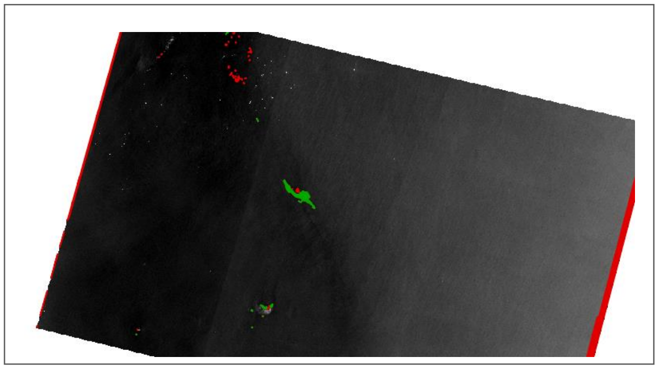

Figure 9. Classification results at image 0451 on Campos Basin at 2016 January 29 on an early stage.

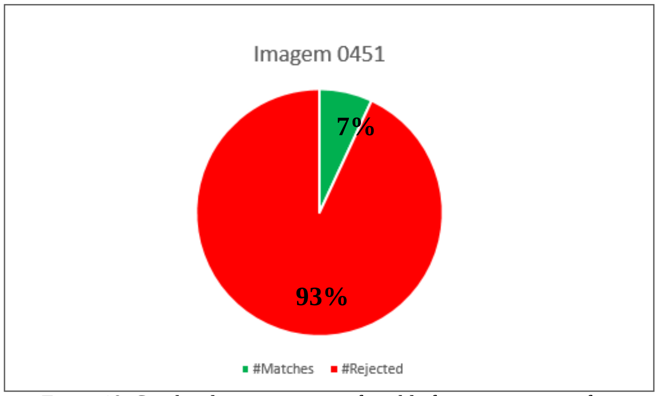

Figure 10. Graphical representation of visible features, in green, for user interaction on the web interface for the image on Figure 9.

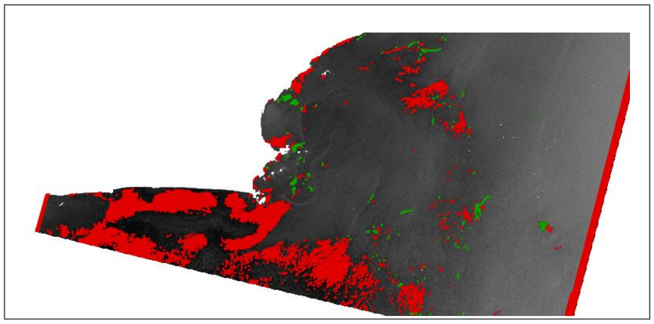

Figure 11. Classification results at image 2D51 on Campos Basin at 2016 July 20 on an early stage.

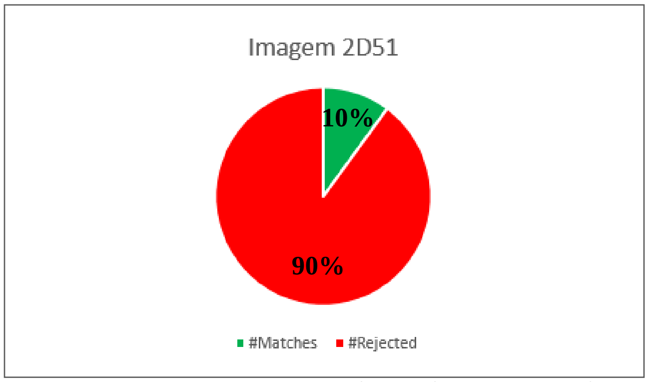

Figure 12. Graphical representation of visible features, in green, for user interaction on the web interface for the image on Figure 11.

The resample to 40 meters described in the methodology was adopted after a comparison between the segmentation results from the same images with and without resample. The comparison results were that the polygons generated had different areas, perimeter and shapes; however, the comparison between the values extracted from the features of the sample groups, the 10 meters and the 40 meters, shows that the results were very similar. More studies about these results could describe the differences more precisely with efficient comparison methodologies, and the impact that these differences can cause on the features extraction or on the results of the classification. The implementation of this resample improved the processing time of the images from 5 to 6 times and the result is clearer and with more defined bounds.

IV. CONCLUSIONS

The cross-polarizations (HV and VH) of all the Sentinel-1 images tested on the ocean areas, could be responding close to the noise floor, as the dark spots are not visible or recognizable. Thus, the entire research is being conducted with co-polarization (HH and VV). However, the utility of the Sentinel-1 cross-polarizations in oil-spill detection could not be discarded since it would need further researches.

Using as a reference a table taken from [7] with the 25 most used features for oil-spill detection, we implemented only 15 to achieve the results presented in this paper, and the implementation of the other 10 features could be used for further implementation of the processes to achieve better results. The selection and implementation of the additional features is a difficult part, since it is necessary to analyze the features that give a better separation between the samples of oil and the samples of each type of look-alikes, modifying the features set and each weight to be applied. In the current work, the 15 features listed on subsection II.B were initially selected based on the project contingency, considering: (a) the speed of the research; (b) the speed of the implementation and; (c) the influence of the feature on the results. Since the system was developed to attend a governmental necessity to speed up the manual process of generating vectors and reports, the speed was an important matter. Also, it was based on classification learning through samples and user decision. One of the main objectives of the project was to reach an operational version as soon as possible while the research continues to run in the background.

With the system implemented, the expectations are that with the increase of evaluations of the samples, the database will become more robust and reliable, with many different samples shapes in many different conditions, solving the problem of shortage of oil-spill samples. In Figs. 13-14 is possible to see the evaluation process in the application.

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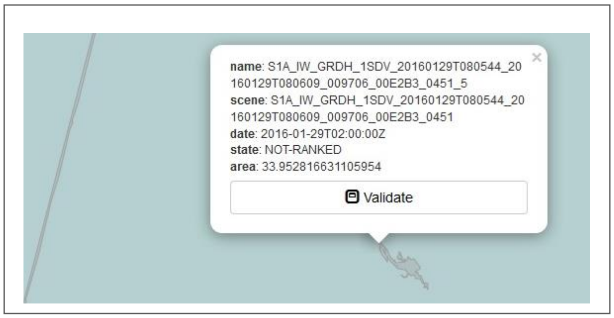

Figure 13. Selection of the pre-classified Oil-Spill.

Figure 14. Classification options available for the users.

As seen in the previous figures, the user can select the dark regions in the application window or from a list and choose a predefined class to classify or reclassify them. The application also keeps record of the changes and the person who changed it.

The team is continuing analyzing Sentinel-1 images and improving the parameters of segmentation to have the best possible delimitation of the samples to extract the statistics. More statistical data could be included in the set. Once the project keeps running its development phase, the characteristics that are on the row to be included are:

- First invariant planar moment
- Slick width
- Distance to coast
- Quantity of objects in the proximity
- Proximity of big areas
- Chorophyll-a information
- Sea surface temperature information

A process of data mining is going to be applied to create the best number of classes with a good combination to be used in the SVC process. Other classifiers can also be used to compare results. Besides oil, the classes could be low wind, coastal wind shelter, upwelling, and further classes that become more suitable to improve the classification success rate. Also, more studies on the interchangeability of statistical data from another sensor could be made and an integration of the system with other sources of images will be on the schedule.

The main contribution to achieve with this project is to reach the best features set to automatically classify the oil-spills. Another contribution is the creation of a large database with the statistical characteristics of oil-spill, oceanographic and weather features derived from Sentinel-1 images. Specialists will continuously analyze and validate each pertinent dark region as the system is implemented.

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