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Automatic decision support system based on SAR data for oil spill detection

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ABSTRACT

Global trade is mainly supported by maritime transport, which generates important pollution problems. Thus, effective surveillance and intervention means are necessary to ensure proper response to environmental emergencies. Synthetic Aperture Radar (SAR) has been established as a useful tool for detecting hydrocarbon spillages on the oceans surface. Several decision support systems have been based on this technology. This paper presents an automatic oil spill detection system based on SAR data which was developed on the basis of confirmed spillages and it was adapted to an important international shipping route off the Galician coast (northwest Iberian Peninsula). The system was supported by an adaptive segmentation process based on wind data as well as a shape oriented characterization algorithm. Moreover, two classifiers were developed and compared. Thus, image testing revealed up to 95.1% candidate labeling accuracy. Shared-memory parallel programming techniques were used to develop algorithms in order to improve above 25% of the system processing time.
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1. Introduction

Oceans are essential both for life and for every society's economy. International trade is mainly supported by maritime transport which represents around 80% of global trade by volume and over 70% by value (Asariotis et al., 2012). This intensive traffic along Exclusive Economic Zones (EEZ) of countries generates important pollution problems such as oil spills. Contrary to what is mainly accepted, only 7% of oil spills come from catastrophes like tanker and oil platform accidents. Half of the total oil pollution can be attributed to operational discharges from vessels (usually, the cleaning of ship bilges) (Esa, 1998).

Oil spills affect coasts and marine life generating ecological as well as economic losses. Thus, surveillance agencies should have adequate decision support system (DSS) to manage intervention means as well as to ensure proper response to environmental emergencies.

Radar has proved to be a useful tool for detecting hydrocarbon spillages. This technology consists in an active detection system assembled in a platform which basically sends microwave beams to the surface. Beams are reflected and backscattered from the surface so part of the energy is collected again by the radar antenna. The intensity of the signal received by the antenna is measured and recorded for later use in the image construction of the studied area. Due to their backscattering specular behavior, oil spills appear as regions with less brightness in radar images, just like other natural phenomena (Hovland et al., 1994) such as low wind, grease ice and upwelling.

Traditionally, ships and aircrafts equipped with specific tools, like radar systems, have been widely used as surveillance means. Their disadvantages, such as local coverage, high cost and dependency on meteorological conditions make them a limited solution.

Radar devices aboard satellites improve coverage, reduce cost and provide day and night imaging capability regardless of weather conditions. Due to radar fundamentals (Jackson and Apel, 2014), unfeasible antenna dimensions would be necessary to get useful resolutions. This handicap is solved by using a special type of radar called Synthetic Aperture Radar (SAR). Its operational principle is based on collecting several measurements of the same target location from different points during the satellite pass. This process simulates an antenna aperture equivalent to the distance between the first and last measured point, and can produce image resolutions of a few meters.

Traditionally, SAR images have been analyzed by human operators. Basically, they localize dark areas and try to distinguish natural

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phenomena, called look-alikes, from hydrocarbons. Literature describes many efforts to develop automated and semi-automated DSSs which avoid depending on the operator's experience and improve the system's accuracy as well as its processing time. A concise state-of-the-art is offered by Brekke and Solberg (2005) and Topouzelis (2008). Apart from pre-processing steps, most documented oil spill detection systems have 3 common phases:

- *Dark spot segmentation*: Since backscattering is lower in oil spills than in clean areas, several threshold techniques based on simple (Fiscella et al., 2000) as well as adaptive thresholding (Solberg et al., 2007; Del Frate et al., 2000) have been widely used. Also, other techniques have been traditionally applied such as artificial neural networks (ANN) (Singha et al., 2013; Topouzelis et al., 2007; Garcia-Pineda et al., 2009), methods based on textures (Benelli and Garzelli, 1999; Marghany, 2004) and techniques focused on edge detection (Chen et al., 1997; Migliaccio et al., 2005).
- *Feature extraction*: Though there are some research works focused on finding a valuable set of characteristics to describe the segmented spots (Topouzelis et al., 2009) (Topouzelis and Psyllos, 2012), there are no systematic studies about characteristics and their influence on the classification phase.
- *Spot classification*: Relevant literature describes many options and techniques to develop classifiers which analyze candidate characteristics to distinguish look-alikes from oil spills. ANNs (Del Frate et al., 2000; Topouzelis et al., 2007; Garcia-Pineda et al., 2009) as well as statistical classifiers (Solberg et al., 1999, 2007; Brekke and Solberg, 2008; Fiscella et al., 2000) are some of the approaches most largely used.

A reliable detection procedure is the basis for a complete surveillance system since its outputs can be used to forecast the spillage's evolution (Periáñez and Pascual-Granged, 2008; Kulawiak et al., 2010) and to backtrack it to find its source.

Regarding the study location, Galicia, located in the northwest of the Iberian Peninsula, is a region whose economy and way of life are closely related to the ocean. Due to its geographic location, Galicia bears an intensive maritime traffic and it has suffered important oil tanker catastrophes such as Urquiola in 1976, Aegean Sea in 1992 and Prestige in 2002. Besides these fairly infrequent events, oil spills derived from routine maintenance operations are regularly discovered. Specifically, most of them are located around the Finisterre Traffic Separation Scheme (FTSS), shown in Fig. 1, which is used to regulate the maritime traffic.

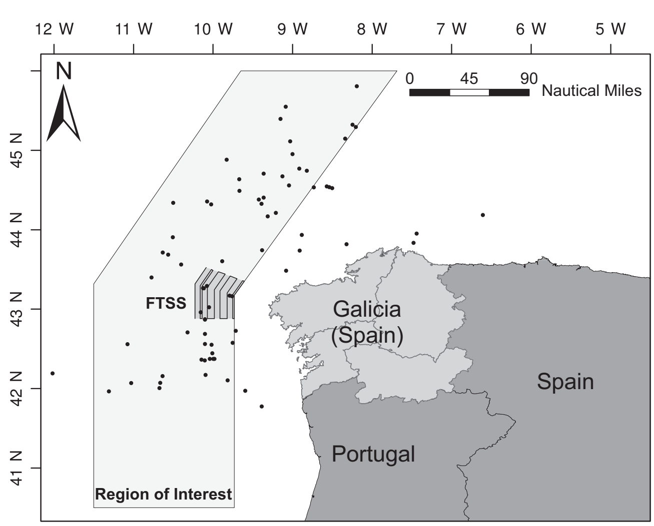

Fig. 1. ROI which contains the FTSS. Black dots symbolize spillages of the database.

Spanish Maritime Safety and Rescue Agency (SASEMAR) is the public authority responsible for monitoring the Spain EEZ including the Galician coast. SASEMAR's surveillance procedures are based on flight missions as well as limited SAR detection reports supplied by European Maritime Safety Agency (EMSA) via an agreement with the Spanish government. According to the 2012 SASEMAR report, 146 oil spills were detected by flight missions, whereas 102 were revealed by satellite reports.

In this paper, we describe an automatic oil spill detection system based on SAR imaging which makes the best of a previously published oil spill segmentation algorithm (referred to here as the "previous paper", Mera et al., 2012). The present work shows several improvements which were done to the segmentation process and describes the remaining system phases, including the development and comparison of two classifiers. We encourage readers to read the previous paper for a deeper context.

2. Datasets

A database with 47 Advanced Synthetic Aperture Radar (ASAR) products from the Envisat was used to develop the detection system. Main product characteristics are shown in Table 1. Specifically, the Wide Swath Mode (WSM) product was selected for oil spill detection because it provides large coverage and enough resolution for finding small-medium spillages. Furthermore, the ocean backscatter is expected to be above the noise floor under most conditions (Olsen and Wahl, 2003).

Database ASAR images cover the Galician coast from 2007 to 2011 and most of them are centered on the FTSS, which is the core of the Region Of Interest (ROI). This collection was obtained by way of an agreement with the European Space Agency (ESA). Images can be split into two subsets: on one hand, data from 2007 to 2008 contain oil spill candidates located by EMSA experts. These candidates were labeled with a pollution probability (low, medium, high). On the other hand, images from 2009 to 2011 have confirmed oil spills detected by SASEMAR aircrafts missions.

A subset of images captured in 2011 was saved for testing purposes, while the remainder was used to develop the oil spill detection system.

3. Methodology

The described oil spill detection system comprises three main phases: initially, a segmentation process highlights all the pollution candidates over the image background; after that, a characterization process is applied to calculate a set of characteristics for each segmented candidate; finally, a classification process analyzes every set to classify the associated candidate either as an oil spill or a false positive (look-alike). Moreover, both pre-processing and post-processing steps are carried out. On one hand, the pre-processing step is used to tailor the dataset for detection algorithms. On the other hand, a post-processing process is applied to system outputs in order to improve the shape of detected oil spills. A detail of these processes is shown next.

3.1. Segmentation

The segmentation process is based on a previously published adaptive threshold (AT) algorithm (Mera et al., 2012), which exposed the relationship between SAR image intensity values and both wind intensity and satellite Incidence Angles (IAs). Wind data were estimated by the CMOD5 model (Hersbach et al., 2007), which is a C-band geophysical model function. It relates the radar backscatter from roughened sea surface to wind speed and direction.

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