

OIL SPILL DETECTION TECHNIQUES USING SATELLITE IMAGES IN GULF OF MEXICO REGION

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Abstract — In this research work oil spill detection techniques were used using Advance synthetic aperture radar images in Gulf of Mexico region. As we know oil spills become bigger issue in ocean water which effect marine species and animal's life. We know oil and sea water does not mix because oil is less dense than water and density of water depends on temperature and salinity. Ocean water density is about 1027 kg/m^3 . Main objective of doing this research is to compare algorithms to determines dark patches, bands and tracking of oil spills in given input radar images with less time consuming. This research work helps to regular monitor oil spill area and region which help agencies for further process. After comparing algorithms morphological closing techniques act as good tools for oil spill detection and monitoring. Advance synthetic aperture radar image serves as a good sensor for surveying of oil spill. In conclusion, after comparing seven algorithms, morphological technique serves as excellent method for detection of oil spill with low time complexity.

Keywords- Oil spill, Gulf of Mexico, Morphological Techniques, Advance synthetic aperture radar image

I. INTRODUCTION

Oil spill is one of the most important problem occurs in the world which become one of the biggest issue in marine life. So regular monitoring is important, which helps to solve problems based on oil spill. Extraction of oil from ocean is a fundamental work done for agencies to regular monitoring the sea. In this scenario satellite image play an important role for data acquisition. In ever year oil spill accident take place in history it was on the Gulf of Mexico in Deepwater Horizon on April, 20, 2010, with explosion in July 15, 2010. It effected on wildlife habitats and maritime spices. To overcome this problem radar image was used for regular monitoring which improves over all oil spill problems by various approaches. To survey oil spill SAR image provide various advantage for detection and tracking of oil spills. Several satellite SAR sensors are involved in the oil spill detection and survey. These data are from ERS-1/2, (Brekke and Solberg 2005) ENVISAT (Marghany 2013), ALOS, (Zhang et al. 2011, 2012), RADARSAT-1/2, (Zhang et al. 2012) and TerraSAR-X (Velotto et al. 2011) which have been globally used to identify and monitor the oil-spill. Recently, the multi polarimetric SAR high-resolution data have become a vital research area for oil spill detection (Skrunes et al. 2012; Shirvany et al. 2012). Oil spill detection and monitoring using SAR technology, data are scarce job, because of barely discrimination between oil spill and other features of look-alike ,shadows, wind speed that appear patches in SAR data as Dark patches (Topouzelis 2008). The problems faced in oil spill automatic using SAR data, is achievements in past decades. Simultaneously, Frate et al. (2000) proposed semi-automatic oil spill detection by using neural network, in which a vector defining features of an oil-spill is used. Topouzelis et al. (2007, 2009) and Marghany, Hashim (2011) confirmed that neural network technique could give precise difference among look-alike and oil- spill in SAR data. Topouzelis et al. (2007) has used neural networks in finding both oil-spill and dark patches detection. Experimental results shows, 89 % accuracy and 94 % dark patches segmentation but certain disadvantages like they cannot efficiently detect small and fresh spills. Skrunes et al. (2012), reports that there are several disadvantages associated with SAR sensors based oil spill detection. So they suggested using multi-polarization acquisition data, such as Terra SAR-X satellites and RADARSAT-2.



II. DATA ACQUIRED

In this study, RADARSAT-2 SAR data acquired by RADARSAT-2 operating with Scan SAR Narrow single mode beam on 27th April, 2010; 1st May 2010; and 3rd May, 2010 are investigated for detection of oil spill in the Gulf of Mexico. The satellite armed with Synthetic Aperture Radar (SAR) with multiple modes of polarization, which includes fully polarimetric mode of operation in which HH, VV and VH polarized data's were acquired (Maurizio et al. 2012). It has got highest resolution of 1 m in Spotlight beam mode (Ultra Fine mode of 3 m) with 100 m of positional accuracy. In the Scan SAR Wide Beam mode (WBM), the SAR has nominal width of 500 km and 100 m imaging resolution. The ground data obtained are based on study of Garcia-Pineda et al. (2013) where majority of oil types are emulsion and silver sheen.

Sl. No	Beam mode	Place	Date	Nominal pixel spacing(m)	Resolution (m)	Incident angle	Polarization
1.	ENVISAT	Gulf Of Mexico	27 April 2010	25 x 25	79.9-37.7 x 60	20-55	HH
2.	ASAR	Gulf Of Mexico	1 May 2010	25 x 25	79.9-37.7 x 60	20-46	HH
3.	ENVISAT	Gulf Of Mexico	3 May 2010	25 x 25	79.9-37.7 x 60	25-50	HH
	ASAR	Gulf Of Mexico					
	ENVISAT	Gulf Of Mexico					
	ASAR	Gulf Of Mexico					

Table1. ENVISAT ASAR IMAGE

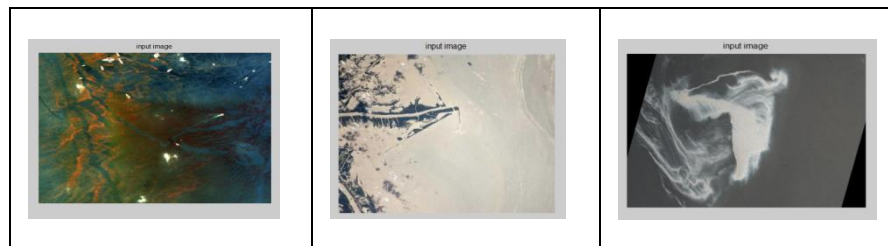


Figure1. Input images

III. MATERIAL AND METHODOLOGY

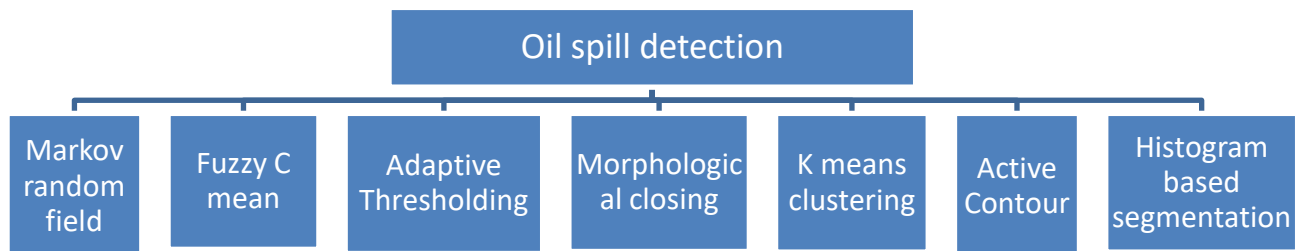


Figure2. Methodology

A. Markov random field

Markov random field technique provides mutual influences in given data, which helps to provide more clear detection on oil spills in images with objective function modification. With the help of modification process it helps in reducing speckle noise effect in radar images. It works together with membership function using neighborhood pixels. Steps are as follows- (1) initially two satellite image has to be taken, consider as $P_1 = \{P_1(I, h), 1 \leq I \leq M, 1 \leq h \leq N\}$ and $\{P_2(I, h), 1 \leq I \leq M, 1 \leq h \leq N\}$, where $M \times N$. (2) in second step generate logarithmic and mean operator to cover over all area taken for monitoring it is denoted with $l = \frac{k_1}{f_1}$, $mean = 1 - \min(\frac{k_1}{f_1}, \frac{k_2}{f_2})$, Where as, f_1 & f_2 , k_1 & k_2 are logarithmic and mean values. Here Mean

produces difference images using information of pixels. Log value used to find out intensity for images and it covers larger area. Let us considered iteration $x=1$ with standard deviation σ_r^1 and mean μ_r^1 values. Now find out energy function E_{pq}^x with iteration 'x'. Now apply Gibbs expression, to find out prior probability (π_{pq}^c)

$$\pi_{pq}^c = \frac{\exp(-E_{pq}^x)}{\exp(-E_{pq}^x) + \exp(-E_{pq}^x)}$$

Now (p_r^c) determine conditional probability then generate the distance matrix (d_{pq}^c) for the given input image.

$$p_r^c \left(\frac{y_j}{\mu_r^c, \sigma_r^c} \right) = \frac{1}{\sigma_r^c \sqrt{2\pi}} \exp \left[-\frac{y_j - \mu_r^c}{2(\sigma_r^c)^2} \right]$$

$$d_{pq}^c = -1n \left[p_r^c \left(\frac{y_j}{\mu_r^c, \sigma_r^c} \right) \right]$$

$$\text{Now compute objective function- } d_{pq}^c = -1n \left[p_r^c \left(\frac{y_j}{\mu_r^c, \sigma_r^c} \right) \right],$$

$$|J_{pq}^c - J_{pq}^{c-1}| \leq \delta$$

Now determine Membership matrix $\{\mu_{pq}^{c+1}\}$

$$\mu_{pq}^{c+1} = \frac{\pi_{pq}^c \exp(-d_{pq}^c)}{\pi_{pq}^c \exp(-d_{pq}^c) + \pi_{pq}^c \exp(-d_{pq}^c)}$$

Update deviation and mean values σ_r^{c+1} and μ_r^{c+1} respectively, $c=c+1$

$$\mu_r^{c+1} = \frac{\sum_x (\mu_{pq}^c y_j)}{\sum_x (\mu_{pq}^c)}$$

$$\sigma_r^{c+1} = \sqrt{\frac{\sum_x [u_{pq}^c (y_j - \mu_r^{c+1})^2]}{\sum_x (u_{pq}^c)}}$$

B. Fuzzy c-Mean

It is a clustering technique, which allows one object belongs to two or more object in clusters form. Similarly object or data will be placed in one place and other place. This method improves frequently using pattern recognition.

Minimization object function

$$J_x = \sum_{p=1}^M \sum_{q=1}^b u_{pq}^n \|x_p - c_q\|^2, 1 \leq n < \infty$$

Whereas m, belongs to real number which is greater than 1, u_{pq} is a degree of membership, p is a dimensional measured data, C_q is a cluster center. $\| * \|$ it denotes similarity between center and measured data.

In fuzzy c- mean clustering, with the help of iterative optimization objective function, fuzzy partitioning can be done, using update membership u_{pq} and center of cluster c_p .

$$u_{pq} = \frac{1}{\sum_{i=1}^b \left(\frac{\|x_p - c_q\|}{\|x_p - c_i\|} \right)^{\frac{2}{n-1}}}, c_{pq} = \frac{\sum_{p=1}^M u_{pq}^n x_p}{\sum_{q=1}^b u_{pq}^n}$$

$$\text{Iteration stops when } \max_{pq} \|u_{pq}^{(i+1)} - u_{pq}^{(i)}\| < E_s$$

E denotes terminal point between 0 and 1 for k^{th} iteration; it also covers local minimum point J_x .

Following steps are

1. First initialize process U so it denoted as $[u_{pq}]$ matrix, $u^{[0]}$
2. Now calculate center of vectors $c^{(i)} = [c_q]$ with $u^{(i)}$, $c_{pq} = \frac{\sum_{p=1}^M u_{pq}^n x_p}{\sum_{q=1}^b u_{pq}^n}$
3. Update the process by using $u^{(i)}$, $u^{(i+1)}$

$$\text{Therefore } U_{pq} = \frac{1}{\sum_{i=1}^b \left(\frac{\|x_p - c_q\|}{\|x_p - c_i\|} \right)^{\frac{2}{n-1}}}$$

If $\|u_{pq}^{(i+1)} - u_{pq}^{(i)}\| < E$ then stop the process for further operation otherwise return to step 2.

C. Adaptive Thresholding

It helps to determine dark patches, bands and pattern for the given data set. Adaptive is important because radar contrast depends on condition of weather for detection of dark spot, look alike and surrounding water, which may change in investigation. In image threshold levels depends on angle incidence even in constant conditions in image. According to pre determined rule threshold level should changed. In mask operation mapping from one pixel to a new one's process take place, pixel modifies according to equation and are not dependent on neighborhood.

$f(p,q)=F[g(p,q)]$, Where 'F' is input and output image with one to one mapping.

$$f(p,q)=(p+1,q),(p-1,q),(p,q+1),(p,q-1)$$

Adaptive help to produce segments with similar intensities, to determine boundaries and shape for the given images. It produces gray scale value with global and local image information.

$$\sigma_q^2 = n_1 (\mu_1 - \mu_2)^2 + n_2 (\mu_1 - \mu_2)^2$$

If denotes variance for the threshold silk smooth extracted using

$$(R)=1-\frac{1}{(1-\sigma^2)}, \text{ with standard deviation.}$$

D. Morphological operation

Morphological operation is based on the structure analysis, in which some components are selected among all, which satisfy Gestalt principles such as (1) Proximity state that two objects are easier regard as a single object by a human being if those objects are close to each other. (2) Good continuation states that objects are easier regard as a single object if they can be continued from one to other. According to these principles criteria have been developed. If both analyzed components are lines then first group of criteria is applied. Based on this criteria proximity is state as minimum of Euclidean distances between starting and ending points of these lines and the excellent continuation is determined by checking orientation difference. If both objects are not lines then second group of criteria is applied. Relation of lines to non-lines then third group of criteria is applied. The analysis is done by two routines: In-level routine and inter level routine.

In-level routine: It Analyzes level $N = \{3, 2, 1\}$ component to gain oil slick structure. Structure is consist element that satisfy proximity criteria and good continuation criteria. The oil slick structure is selected from each component of level N that calls the inter-level routine to group or cluster it with the structures levels from lower.

In Inter-level routine the component is given from a level $N > 1$, all component are search from level N-1 and component are find that satisfies criteria of Gestalt-based. Set current component, set level as $N = N-1$, then call Inter-level routine again, then stop the analysis when current level show $N = 1$ or no components present to analyze. Analysis start for gray level mask from level 4. This level represents lowest backscatter area in radar images. If level 4 gray contain few pixel then merge level 4 and level 3 that represent dark areas of the Synthetic aperture radar fragments with slick correspond look-alikes areas. The levels $N = \{3, 2, 1\}$ routine is run to find oil silk structure which correspond to less-dark areas of SAR image. Then this structure passed to subsequent analysis for inter-level routine analysis. Components are selected in stages of analysis are retained in the image and other considered as noise.

E. K-mean clustering

K mean clustering is a vector quantization method used for oil spill detection. Here each element is partition into k clusters which belongs to nearest mean, act as prototypes for the cluster. It works on dividing data cell into voronoi cells. K mean cluster determine comparable spatial extent clusters. It classifies data which is new into existing clusters which called as centroid nearest classifier.

Let as consider set observations $(a_1, a_2, a_3, \dots, a_n)$ with D real vector dimensional. Here 'c' means clustering partition number of observation into $c \leq n$ sets which is denoted as $S = \{set_1, set_2, set_3 \dots set_k\}$, it will minimize sum of squares with cluster.

$\arg_S \text{ minimum } \sum_{set=1}^c \sum_{a \in set_i} ||a - \mu_p||^2 = \arg_{set} \text{ minimum } \sum_{p=1}^c |set_p| \text{ vars}_p$, μ_i is points mean of set_p which is similar to squared pairwise deviations in same cluster.

$$\arg_{set} \text{ minimum } \sum_{p=1}^c \frac{1}{2|set_p|} \sum_{a,y \in set_p} ||x - y||^2$$

similar features can be deleted by using formula $\sum_{a \in set_i} ||a - \mu_p||^2 = \sum_{a \neq y \in set_p} (a - \mu_p)(\mu_p - y)$, which shows number of total variance is constant between points in cluster.

Let as consider k mean initial set $n_1^{(1)}, \dots, n_k^{(1)}$, with assign observation in cluster, where mean has Euclidean distance

$set_p^{(i)} = \{a_p ||a_p - n_p^{(t)}||^2 \leq ||a_p - n_j^{(t)}||^2 \forall j, 1 \leq j \leq c\}$, where a_p assigned one's and $s^{(t)}$ can be assigned to three or more cluster. In update step it calculates and observed new mean to be centroid in the new cluster.

F. Active contour

Active contour describe boundary and shape in SAR images. it is also known as snakes. It solves problems based on boundary and its shape. It is deformable model, so active contour help to monitor image noise and motion tracking. It also helps to find Illusory contours in the data by information of missing boundary. Active contour works on adaptive and autonomous search, Gaussian smoothing in image, track object dynamically.

Let us consider point's m_i with set of s where $x = 0, 1, 2, \dots, n-1$, ' $B_{external}$ ' external energy edge based help to control fitting in image, external energy is a force combination to image itself and ' $B_{internal}$ ' internal energy based energy help to control deformation in image. The sum of external and internal energy sources form energy function in the input image.

$$A_{active \text{ contour}} = \int_0^1 A_{contour}(v(s)) ds = \int_0^1 (A_{inter}(v(s)) + A_{img}(V(s)) + E_{exter}(v(s))) ds$$

To find out boundary in image it work under intensity, $A_{Line} = I(p, q)$, line attracted towards in darker and lighter lines in the images. Image smoothing and noise deletion can be done using formula.

$$A_{Line} = filter(I(p, q)),$$

$$A_{internal} = A_{contour} + A_{curve}$$

$A_{contour}, A_{curve}$ It defines corresponds continuity and curvature terms.

G. Histogram based method

Histogram based analysis required one pass through pixel in satellite image. Histogram is computed according to all pixel and help to locate cluster in images. To measure image it can considered intensity and colour for input data. It helps in multiple frame adaptations in satellite image. Consider histogram based on pixel values H_0, H_1, \dots, H_N , here H_k define number of pixel with gray scale 'n' and 'k' which is maximum value of pixel. In first step guess has to be made

$$\sum_{i=0}^K H_k \geq \frac{n^2}{2} > \sum_{i=0}^{k-1} H_k, \quad n^2 \text{ is number of pixels in } n \times n \text{ Images}$$

In each category calculate pixel value of mean which is equal to or less than k.

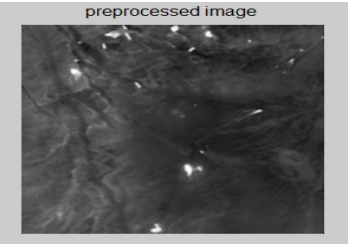

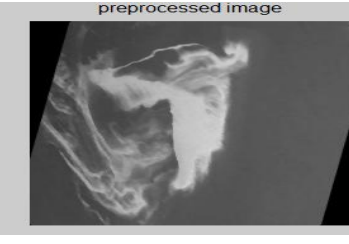
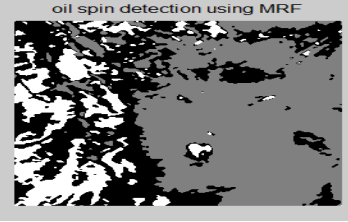
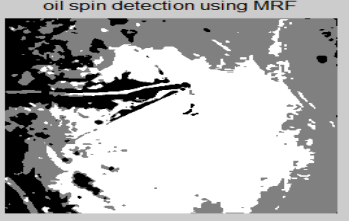
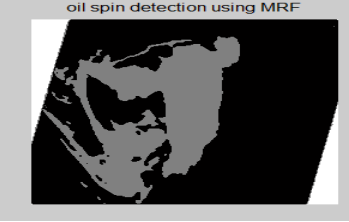
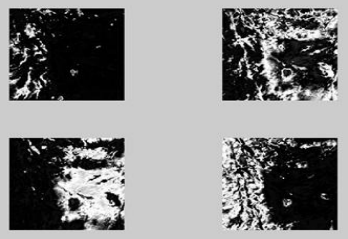
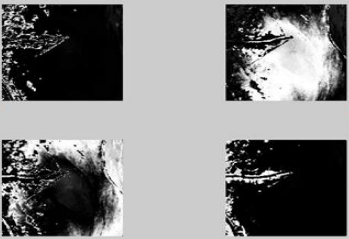

$$\text{Value less then and equal to denoted by } \mu_1 = \frac{\sum_{i=0}^k i H_i}{\sum_{i=0}^k H_i}, \text{ if greater than 'k' it is given as } \mu_2 = \frac{\sum_{i=k+1}^N i H_i}{\sum_{i=k+1}^N H_i}$$







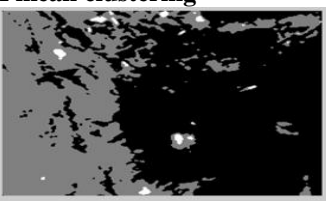
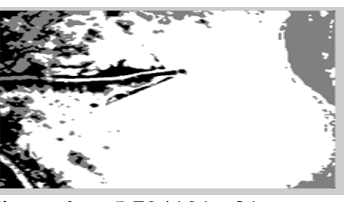


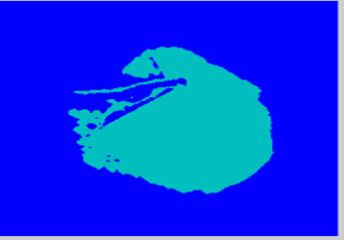

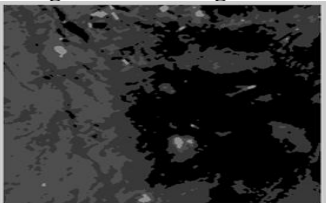
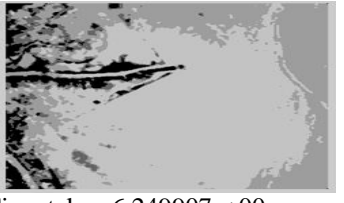

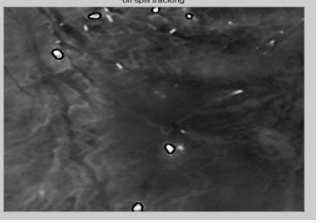
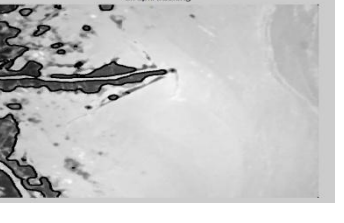
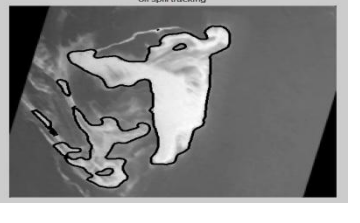
Re-assign k between two mean as half way: $k = \frac{\mu_1 + \mu_2}{2}$, Repeat above steps until k stop changing values

RESULTS AND DISCUSSION

In this approach, seven different techniques were used which helps to regular monitoring and detection of oil spills in the ocean. This research work is carried out using SAR RADARSAT-2 image. This technique examined SAR image to find structure of the oil spill with levels of gray corresponding to less damp / most damped area of sea surface roughness. Radar images confirmed grey level mask containing structure of the slick in Gulf of Mexico. Oil spill happened on 27 April 2010 where crude oil spread in 49,500 km² across 19,112 square miles in Gulf of Mexico. As we know oil spill is one of the biggest issue in marine environment. Here seven algorithms are applied to find out pattern, dark patches and tracking of oil spill with low time complexity in the given ENVISAT ASAR images. In this research different days images has been taken for regular monitor and observe occurrence of oil spill in ocean. For detection of oil spill incidence angle with HH polarization is suitable for research. According to HH polarization and incidence angles it helps to reduce noise which is created during bad weather conditions. For detection of spill ASAR width increase to 300km- 350km. Advance synthetic aperture radar provide high level of sensor images. Figure-3 indicates spills with patterns, dark patches, oil spill tracking and surrounding area of the images. To determine positive and negative pattern it compared with neighborhood pixels. In this paper after comparing seven algorithms, it define morphological closing techniques is more convenient and good for oil spill detection because in ASAR images it slowly varies gray level point based on image location and positions which help to monitor and detect oil spill region in fast way with low time complexity based on different weather condition. Here table2. represents experimental results for oil spill detection with area coverage.

Figure3. Oil spill Detection Results

 <p>preprocessed image</p>	 <p>preprocessed image</p>	 <p>preprocessed image</p>
<p>Markov random field</p>  <p>oil spin detection using MRF</p> <p>Time taken for MRF 1.932765e+00 secs</p>	 <p>oil spin detection using MRF</p> <p>Time taken for MRF 1.764280e+00 secs</p>	 <p>oil spin detection using MRF</p> <p>Time taken for MRF 1.710396e+00 secs</p>
<p>Fuzzy c-mean clustering</p>  <p>Time taken for fuzzy c means 5.373666e+01 secs</p>	 <p>Time taken for fuzzy c means 5.373666e+01 secs</p>	 <p>Time taken for fuzzy c means 5.529804e+01 secs</p>
<p>Adaptive Thresholding</p>		

		
Time taken for 2.264546e-01 secs	Time taken 2.226974e-01 secs	Time taken 2.470920e-01 secs
Morphological closing 		
Time taken 2.799448e-01 secs	Time taken 2.790913e-01 secs	Time taken 2.470920e-01 secs
K mean clustering 		
Time taken 5.442832e-01 secs	Time taken 5.794191e-01 secs	Time taken 5.312782e-01 secs
Active contour 		
Time taken 6.175917e+00 secs	Time taken 5.955170e+00 secs	Time taken 6.372601e+00 secs
Histogram based Segmentation 		
Time taken 6.324111e+00 secs	Time taken 6.249907e+00 secs	Time taken 6.292125e+00 secs
Oil Spill tracking 		
Oil spill Pattern		

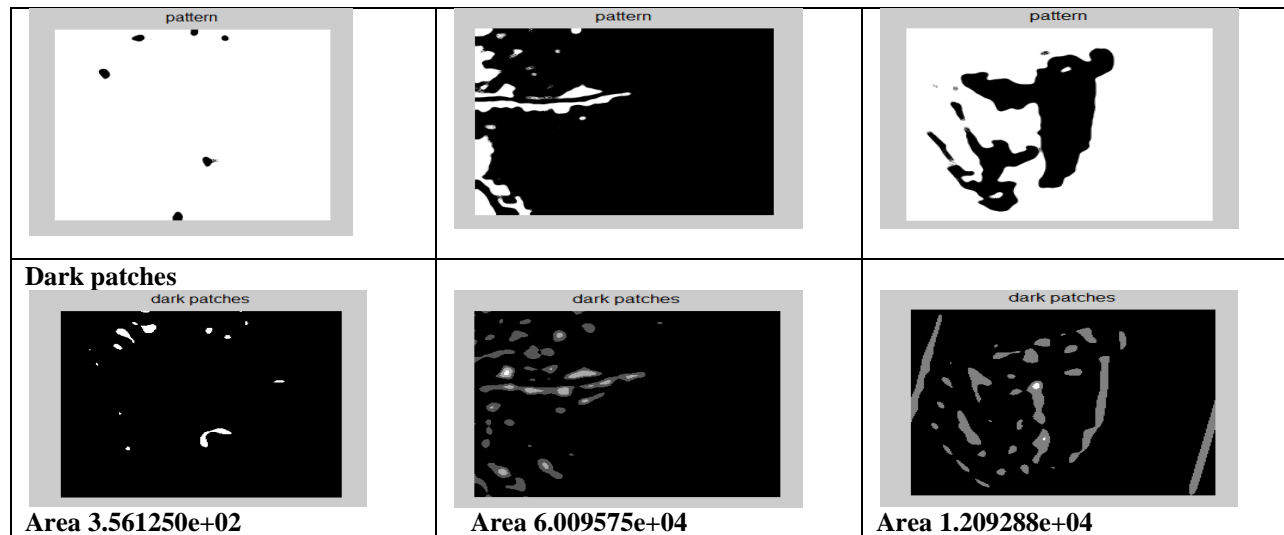


Table2. Experimental Results for oil spill Detection Time

Techniques used	Image 1	Image 2	Image 3
Markov Random Field	1.932765e+00secs	1.764280e+00secs	1.710396e+00secs
Fuzzy c means	5.373666e+01secs	5.390935e+01secs	5.529804e+01secs
Adaptive thresholding	2.799448e-01secs	2.790913e-01secs	2.815672e-01secs
Morphological closing	2.264546e-01secs	2.226974e-01secs	2.470920e-01secs
K means clustering	5.442832e-01secs	5.794191e-01secs	5.312782e-01secs
Active Contour	6.175917e+00secs	5.955170e+00secs	6.372601e+00secs
Histogram based Segmentation	6.324111e+00secs	6.249907e+00secs	6.292125e+00secs
Coverage Area (m²)	3.561250e+02	6.009575e+04	1.209288e+04

IV. CONCLUSION

In this research work oil spill detection techniques were used using Advance synthetic aperture radar images in Gulf of Mexico region. As we know oil spills become bigger issue in ocean water which effect marine species and animal's life. We know oil and sea water does not mix because oil is less dense than water and density of water depends on temperature and salinity. Ocean water density is about 1027 kg/m³. Main objective of doing this research is to compare algorithms to determine dark patches, bands and tracking of oil spills in given input radar images with less time consuming. This research work helps to regular monitor oil spill area and region which help agencies for further process. After comparing algorithms morphological closing techniques act as good tools for oil spill detection and monitoring. Advance synthetic aperture radar image serves as a good sensor for surveying of oil spill. In conclusion, after comparing seven algorithms, morphological technique serves as excellent method for detection of oil spill with low time complexity.

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