Detection of oil spill pollution on water surface using microwave remote sensing techniques

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Abstract. Oil spill pollution is a major threat to ecosystem of different water surfaces; therefore, many researches and resources are deployed and to monitor and detect oil spills on water surfaces. Many of these are still in the developing process as new researches and techniques are always presented to the subject. Ocean and river pollution monitoring, including oil spills, is mainly performed by using microwave energy due to its ability to operate during day and night and its capability to penetrate through fog and clouds. Therefore, this study is focused on the mechanism and parameters used to detect oil spills through SAR images based on backscattering microwave energy. In this study an analysis is conducted on SAR image containing oil spill with semi-automated processing to process the image and create final image with oil spill detected in it, with monitoring the oil spill fate by examining a later date image on the same area. The results are very useful to further researches on the same field. This paper is considered important in Iraq as the technology used and resources are relatively new with no previous research conducted along the same approach in Iraq.

Keywords
Oil spill, SAR images, s1 platform application, oil spill mapping

1. Introduction
Oil spill pollution is a major threat to ecosystem of different water surfaces. The increase in oil industry and demand has led to the increase in oil production and shipping around the world using sea, ocean and connected water channels as a means to transport goods including crude oil and oil products around the world. Iraq is not a different case considering its ranking as global oil exporter with heavy production and exporting in the south portal of it.

A quick glance at Iraq in terms of oil production and exporting clearly shows that this country still has a strong position among the leading rich oil countries. According to oil and gas journal, Iraq's proven oil reserves are 115 billion barrels with additional 45 to 100 billion barrels (bbls) of recoverable oil.

Basra was recognized as the economical capital city of Iraq in 2017 by the Iraqi Parliament due to its important rule in the oil industry for production and export. It has seven water ports in which two are designated as oil platform ports - they are (Al Basra Oil Terminal Known as ABOT and Khor Al Amaya...
Oil Terminal, known as KAAOT).

The main technology commonly used worldwide in the field of oil spills detection on water surface is the radar sensors through microwave energy. Besides its technical features, it is considered as the most cost-effective method, covering wide areas with ease of access that brought it to this level of popularity in this field.

Previous studies concluded many recommendations in this regard.

2. The aim of the study
Oil spills happen on frequent bases either due to operational causes or accidental causes or in some cases due to illegal discharges from oil tankers. Based on the knowledge of the author, the current processes and protocols used to detect oil spills in Iraq are based on visible observations. This study aims to study the oil spill detection on water surface using microwave energy. Despite other tools and technology that are available for the same purpose, one of the most reliable and commonly used tools is the radar satellite images which use microwave energy. This is because of its usability in all-weather types and without the need of sunlight, so it can be used during night time as well. Detection of oil spills on water surface and the distinction between the existence of oil on water surface and water can be achieved by EM waves targeting the oil-water medium as the reflection coefficient parameter can be extracted as the reflection values change based on the dielectric properties of the surface with the specific range of the EM frequencies[6]. Yuanming Shu found that the use of spatial density thresholding on the dark spots detection from SAR images is countable and productive and time effective, and can be adopted as a process for oil spills detection on water surfaces in real events [7]. This study employed one set of SAR image to extract oil spill feature using different processes like speckle filtering, oil spill detection feature and wind field estimation, finalized by geometric correction to produce accurate location of the oil spill. The final results were very promising to adopt such a process and to provide a guide for future researches and studies using Iraq crude oil properties and character in SAR images processing.

3. Oil spill behavior on water surfaces
When an oil spill is spilled into any open water surface, based on several factors like its density, compensation, water current and wind conditions, it will start to take the shape of a thin layer above the water surface. In case of high wind and currents it can spread to cover large area of the surface, for example a one ton of oil within ten minutes can form an area of 50 m radius forming a 10 mm thickness layer. If it continues it can be spread further covering an area of 12 km2 with 1 mm thickness.[1]. In general an oil spill behavior depends on several processes called “weathering “, weathering is the form of processes that will change the character and interaction of the spill with the environment that the spill took place in. It is also related directly to the environmental condition and chemical and physical properties of the oil itself. The main weathering processes can be summarized in of the following processes (Evaporation, Spreading and Movement, Dissolution Dispersion, Emulsification, Sedimentation and Sinking)., Weathering plays a significant rule in the physical-chemical foot print of an oil spill and it’s ability to be detected by radar images, mainly evaporation, emulsification and dispersion [2].

4. Oil spill detection in remote sensing
Within the different applications of remote sensing in the use of environmental studies, remote sensing in oil spill detection became essential within the development of sensors, technology and softwares to minimize costs and time. Since the 80’s a great progress have been achieved in this field. And now tools and resources are available even for free access to the aim of oil spill detection on water surfaces. Oil spill detection in remote sensing deployed different equipment and tools for that purpose including (aircrafts, visible sensors, infrared, Ultraviolet, Laser Fluor sensors and Microwave Sensors), however radar remain the main tool to be used in the application of oil spill detection on water surface, due to its
ability to cover wide areas and operational property to work all day without any dependency on sunlight or clear weather conditions [3].

Sea surface characters like color, temperature, roughness and reflectance are detected by remote sensors, two types of sensors act in this regard, passive and active. Remote sensors work by detecting sea surface properties such as color, reflectance, temperature and roughness (SEOS, Introduction 2008).

Any subject interaction with microwave energy is mainly related to the basic principle of radar and radar equation, which is related to the power received by the target, target parameters and radar parameters.

Considering that path losses are neglected. One form of radar equation can be written as:

\[ \text{Pr} = \left( \frac{P_t G_t}{4\pi R^2} \right) \times \left( \sigma_{rt} A_r / 4\pi R^2 \right) \]

Where,

- \( P_r \) received power at polarization \( r \)
- \( P_t \) transmitted power at polarization \( t \)
- \( G_t \) gain of transmitting antenna in the direction of the target at polarization \( t \)
- \( R \) distance between radar and target
- \( \sigma_{rt} \) (radar cross section), the area intercepting that amount of incident power of polarization \( t \) which, when scattered isotropically, produce an echo at polarization \( r \) equal to that observed from the target.
- The EMR at the target given by \( P_t G_t / 4\pi R^2 \)
- The expression when multiplied by \( \sigma_{rt} \) indicates the total EMR scattered by the target which can be denoted by \( P_s \).
- \( P_t, G \) and \( \lambda \) are parameters of the radar system

The equation for the received power indicates that \( P_t, G \) and \( \lambda \) are parameters of the radar system, and \( R \) is determined by the location of the radar with respect to the target. The design and operation of radar is such that these quantities normally either remain constant or are known during the use of radar. The factor that governs the average return power strength as a function of the way in which the incident EMR interact with the surface is, therefore, \( \sigma_{rt} \).

The scattering coefficient \( \sigma^o \), in general, is related to polarization, look angle, wavelength and interaction property of the target: geometric, dielectric and conductive. As transmitted power, antenna, wavelength and polarization are fixed by the design of the system, only the average return power strength changes with \( \sigma^o \).

Radar return from a target depends on the strength of transmit energy and the reflecting or scattering capability of the target. The targets of radar tend to scatter with different strengths and directions. And their scattering characteristics may be conveniently described in terms of their scattering, or reradation, patterns (plots of signal strength versus angle). The backscattering pattern is of particular interest to radar, it shows the return-signal strength in the opposite direction of the incident radiation.
Every material has a relative complex dielectric constant, $\varepsilon$, consisting of real part, $\varepsilon'$, and imagery part $\varepsilon''$. By relative, we mean that $\varepsilon$ is the dielectric constant of a material, normalized to the permittivity of free space, $\varepsilon^\circ$. Often, $\varepsilon'$ is referred to as the relative permittivity and $\varepsilon''$ is referred to as the loss factor [5].

Radar return from water is expressed in terms of the average radar scattering cross-section per unit area (NRCS), or referred to as the scattering coefficient $\sigma^\circ$, which is normally presented in terms of decibels as a function of the incidence angle for each associated wavelength and polarization condition [5].

5. Methodology

The methodology in this study is based on a case study of an oil spill that occurred on 5th August 2018 captured by S1 radar image. After the downloading of forty images, two images have been selected to be the focus of the study. The first image was once captured on 5th August 2018 where it blanketed the area of the south of Iraq and the water surfaces of the Arab gulf to about 86 km to the south as in discern x. The vv polarization band was selected amongst the different bands due to the reality that it’s the most desired band in oil spill detection. The photo was once sensed by using sentinel 1A mission with a radar frequency of 5.4 Ghz., the other image was selected covering the same area but with a later date to demonstrate the fate of the oil spill, the later image date was 17th August 17 2018.

The ESA (Europe Space Agency) developed the Sentinel Application Platform (SNAP). SNAP application represents a resourceful tool box to process, analyse and produce final products using earth observation satellite images and radar images. Along with that application ESA offered to the globe a free access to its hub called “Copernicus”.

The Program is coordinated and managed by the European Commission. It is implemented in partnership with the Member States, the European Space Agency (ESA) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Ocean.

Oil spills that appear on water surfaces are detected by imaging radars since they damp the short surface waves that are in charge of the radar back scattering. Oil spills show up as dark objects on radar images. Also radar cross section (NRCS or $\sigma^\circ$), which represents the level of power of the back scattered radar signal is also responsible for the grey level formed in the radar image [4]. This is a general behavior of oil spills interaction with microwave sensors on radar images. However, other phenomena can act as the same to the oil spill interaction and cause what is known as the ‘look-alike spill’ like fresh water slicks, high wind effects on water currents, shadow of topographic objects on water, seaweeds beds, biogenic oil and life forms on sea. But despite that oil spill detection by radar images proved to be reliable due to its ability to operate during day and night and through all weather conditions and its ability to cover wide areas with revisit times can reach up to 4 hours per day [3].

In this study a raw s1 radar image was captured and downloaded from Copernicus and processed with SNAP application.

On 5th August 2018, at 5:08 am, an oil spill occurred on the south boarder of Basra international water,
approximate 25 km south of Faw city. Figure [1] shows the raw image before processing, where through eye observation we can see the capillary wave effect and the oil spill pointed by the arrow and the oval shape figure [2]. The image was processed through SNAP to detect and classify the oil spill shape and character. Image processing can be different from application to others based on the developer, algorithms and focus on the application purpose. However, the recent application of SNAP brought an already built-in feature to run a series of processes to the purpose of oil spill detection. Nevertheless basic operations need to be implemented before applying the oil spill detection feature.

The following workflow chart represents the standard process of oil spill detection on radar image.

![Figure 3. Oil spill detection flow chart.](image)

As seen from figure 3, there are few processes that need to be implemented before reaching the final result. Those processes are:

- Image subset
Subsisting the image will allow us to concentrate on the target area and thus, will decrease processing time and efforts for the follow up processes as illustrated in figure [5].

- **Speckle Filtering**
  As it is known, every radar image has some level of noise, which is referred to as salt/pepper noise. It is basically the mixing between black and white pixels in the image, SNAP offers a great feature to run speckle filtering using predefined algorithms, the most effective one to use is Sigma Lee filter. A Lee Sigma filter with a window size 7*7 and target window size 3*3 applied to this image, the result of speckle filtering is demonstrated in figure [6].

- **Profile Plot**
  The profile plot is an essential tool that helps to visualize the effect of oil spill reflectance on the SAR Sigma. And we can get the profile of the Sigma Naught \(\sigma_0\).

- **Oil Spill mapping**
  After getting the Sigma Naught, we can have better understanding on the maximum and minimum values of Sigma Naught, which will help in setting the threshold for the oil spill detection algorithm. Also it's important to notice that the tool will work on the water surface only so it's built in with another feature called Inland Mask Out which is to remove any land from the final product. The oil spill detection tool includes two preprocessing steps: mask out the inland areas and radiometric calibration so that pixel values truly represent the radar backscatter of the reflecting surface illustrated in figure [7].

  After those preprocessing steps, dark spots are detected using an adaptive threshold algorithm where the local mean backscatter level is estimated using pixels in a large window. Then, a threshold is set to ‘k’ decibel below the local mean calculated before. Pixels within the window with values lower than the threshold are detected as dark spot. Finally, the detected pixels are clustered into a single cluster and those with sizes smaller than a predefined size selected by the user are eliminated.

- **Wind field estimation**
  As the wind blows across the ocean surface, it generates surface roughness generally aligned with the wind direction. Consequently, the radar backscatter from this roughened surface is related to the wind speed and direction. Wind can affect the fate and movement of oil spills therefore it’s used in this study to show an estimation of the wind direction and speed from C-band SAR imagery as shown in figures [8] [9].
Figure 6. The SAR subset image after applying lee sigma speckle filter.

Figure 7. The SAR image profile plot for oil spill mapping.

Figure 8. Wind field estimation of speed and direction.

Figure 9. Wind speed and direction effecting the oil spill movement.

Figure 10. The final product after applying geometric correction UTM/WGS84.

Figure 11. Another SAR image taken on 17 August 2018 shows the fate of the remaining oil spill.
6. Results

Figure [10] represent the final product of the oil spill detection by using SAR images processed through sentinel 1 application platform, the oil spill detection tool in SNAP were able to classify suspected oil spill, however some of them are defiantly look alike even from visible eye interpretation of the image as it can be seen in figure [10] the red classified by the shore is related to look-alike debris and accumulated oil moved by the tidal wave towards the shorelines, thus both a technical knowledge with image interoperation and SNAP technology we can reach a good percentage of oil spill detection up to 85%, based on the efforts and abilities of SNAP, oil spill detection can be time saving and cost free using free access resources.

To increase the efficiency and extract exact values of NRCS from the oil spill to determine approximate oil density, pixel values were extract from specific locations on the image where pins were placed on selected targets that is classified as oil spill and the values were placed on a table referred to table [1] representing the pins values. As shown in figure [12].

![Figure 12. Pins location on the image of the spills.](image)

The following table represent the pins value in terms of location, pixel coordination and RCS (σ°).

| CoordID | Name   | Latitude | Longitude | PixelX | PixelY | Date/yyyy-MM-dd | SigmaQ_VL_db | incident_angle | elevation_angle |
|---------|--------|----------|-----------|--------|--------|-----------------|---------------|----------------|-----------------|
| 1       | pin_1  | 39.65524 | 48.66975  | 645.5  | 1044.5 | 05/06/2018     | -24.0568732  | 34.9003199     | 12.0448730     |
| 2       | pin_2  | 29.85712 | 48.68594  | 727.5  | 886.5  | 05/06/2018     | -25.05863882 | 34.96331384    | 31.08902388    |
| 3       | pin_3  | 29.83640 | 48.63894  | 794.5  | 1029.5 | 05/06/2018     | -25.53285408 | 34.98090744    | 31.10922461    |
| 4       | pin_4  | 29.66901 | 48.514858 | 1093.5 | 1008.5 | 05/06/2018     | -25.15904089 | 35.20159531    | 31.29548877    |
| 5       | pin_5  | 29.88038 | 48.813568 | 1158.5 | 887.5  | 05/06/2018     | -25.02707649 | 35.24534717    | 31.5819684     |
| 6       | pin_6  | 29.88359 | 48.622473 | 1256.5 | 803.5  | 05/06/2018     | -25.97493444 | 35.24200435    | 31.39921556    |
| 7       | pin_7  | 29.87881 | 48.615329 | 1213.5 | 870.5  | 05/06/2018     | -25.8665589  | 35.2790303    | 31.5019956     |
| 8       | pin_8  | 29.87628 | 48.810838 | 1253.5 | 897.5  | 05/06/2018     | -26.41146318 | 35.50415728    | 31.88572351    |
| 9       | pin_9  | 29.85011 | 48.606861 | 1293.5 | 1198.5 | 05/06/2018     | -25.22020721 | 35.32323931    | 31.40802811    |
| 10      | pin_10 | 29.34413 | 48.669027 | 633.5  | 1143.5 | 05/06/2018     | -23.15255130 | 34.90959988    | 31.03678331    |
| 11      | pin_11 | 29.54512 | 48.600753 | 1302.5 | 1154.5 | 05/06/2018     | -23.50513275 | 35.26681252    | 31.43186573    |
| 12      | pin_12 | 29.80594 | 48.610304 | 1113.5 | 1300.5 | 05/06/2018     | -26.0923481  | 35.24645539    | 31.30667877    |
| 13      | pin_13 | 29.83094 | 48.619992 | 1121.5 | 1158.5 | 05/06/2018     | -25.57462425 | 35.21694441    | 31.33120211    |

7. Conclusions

SAR images processed with sentinel 1 application platform produced final results with high classification of oil spills, given the fact that the images and tools to process the images are free to access
brought a great importance to this technology, also in Iraq no further researches were made to explore the potentials of this technology, thus the study purpose to explore and work with this technology to detect oil spill was successful.

Conclusions can be summarized in the following points:

1- Oil spill detection on water surfaces using microwave energy is the most reliable, cost effective, time saver and advantage technology to be used in that purpose.

2- The validation of the use of SNAP as a free reliable software to the aim of oil spill detection on water surfaces showed great results, therefor it’s recommended to further explore this technology as a tool in oil spill detection in Iraq for future researches and projects.

3- The use of a combination of visible image interpretation with image processing can achieve highly accurate results in the determination of oil spills on water surface with a 85% percentage of success. And it’s able to present monitoring and initial disaster state estimation on oil spillevents.

4- Feature extraction represented by the radar cross section values obtained from the image processing can be used by future researches to examine Iraqi crude oil dielectric properties and compared with a field samples to form a validation reference.

5- It’s advised to conduct further studies and researches on this topic since the use of the technology is now available for public access offered by ESA, furthermore the technology can be used to identify illegal oil exporting through coastlines, ships detection and monitoring and other applications as well.

6- The processes used in this study can be concluded as a reference to related government agencies, local organizations and other entities whom are interested in environmental work related to oil spills events.

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