Chapter

Computational Techniques of Oil Spill Detection in Synthetic Aperture Radar Data: Review Cases

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Abstract

In this chapter, a major role of environmental assessment is an oil spill identifies or detected from the coastal region surfaces or marine surroundings. Normally, the oil spills on the coastal regions impact their characteristics of environmental activities. However, these activities are monitoring through several radar satellites and sensor. For those achievable activities detecting or identifying, many researchers developed several approaches. Particularly, this chapter discusses about the detection of oil spill current operational effects on coastal region surfaces. In addition, the current research operations of oil spill characterizations and quality of its impacts, effects of current environmental bio-systems, their control measurement strategies, and its surveillance operations are discussed. Finally, the oil spill detection is done through the SAR image region classification based on its feature extraction. This could be monitored from the image dark region selection through remote sensing techniques.

Keywords: remote sensing, oil spill detection, coastal monitoring, pollution control, SAR images

1. Introduction

The coastal region monitoring is very important to protect marine environment from oil spill pollution, which is caused due to oil transportation, storage, tanker accident, or intentional drainage of oil into sea water. Day by day the percentage of pollution-affected coastal or ocean region due to fuel is getting increased and thus, it becomes increasingly important to protect ocean regions and lives of marine regions [1, 2]. The spilled oil of ships or tankers spread over the sea surface forms dark regions and causes marine pollution. It could affect the lives of the coastal regions to greater extent. Thus, a suitable mechanism is required to detect and remove those oil spills from coastal regions at the earliest. The above-said task could be accomplished only through remote sensing technique, which is defined as a coherent technique through which any regions or objects in the earth surface could be located at a far distance and monitored. In remote sensing process, information about earth's object is collected either using space-borne satellite or using airborne aircraft [3]. At the initial stage, space-borne satellites could be used for locating the region but further analysis would be carried out with the help of airborne aircrafts. In order to detect and remove spilled oils on sea surface, space-borne satellites such as ERS, ENVISAT, RADARSAT are predominantly used. In general, there two kinds of RADAR are in use, they are Synthetic Aperture Radar (SAR) and Real Aperture Radar (RAR). The Synthetic Aperture Radar (SAR) uses microwave sensors for data collection in the form of 2-D images [4, 5]. These Synthetic Aperture Radars are mounted on satellites and used for earth observations. The microwave sensors reflect the image visual perception of any earth objects and their attributes. Thus, it could be used for monitoring ocean regions during day and night under all weather conditions for detection of spilled oil. Norwegian water pollution authorities are using space-borne satellites for monitoring oil pollution [6].

In this chapter, extensive study on oil spill detection using both manual and semi-automated approaches is carried and presented. The objective of this study is to determine various approaches currently being used for oil spill detection and its accuracy in ocean monitoring for environmental protection. Though the research has been started in 1994, the automatic detection of oil spill is still in infant stage as it is considered as a very complex task. Since oil spill on sea surface resembles look-alike, it is very difficult to differentiate them automatically from it. In general, look-alikes of oil spill are biological film, grease ice, front eddies, rain cells, internal waves, and upwelling zones [7, 8]. In most of the cases, even the trained operator cannot differentiate oil spill from look-alikes, for example, it has been carried out manually at TSS by assigning attributes such as low, medium, and high value to various oil slicks based on its existence with attributes. Once it is characterized as oil spill, this information could be further analyzed through aircraft surveillance system used by Norwegian Pollution Control Authority (NPCA) [9, 10]. Thus, it is very difficult to design an automatic oil spill detection system.

In Section 2, the problems of oil spills in coastal regions were discussed. In Section 3, characteristics of Spilled oil and its impacts in coastal regions are presented in detail. Section 4 discusses about various sensors and satellites employed for ocean monitoring. Section 5 presents existing methodologies till date and Section 6 presents various classifications approaches using features of Oil Slicks. In Section 7, current operational efforts on oil spill monitoring is discussed elaborately. Section 8 briefs case studies in relevant area. Section 9 concludes the work.

2. Oil spill problems

In this section, the major problem in coastal region monitoring is oil spill detection. The spills are more predominantly considered during marine ecosystem pollution control. However, the marine oil spill term considers—where oil is released into costal or ocean waters and spills may also occur on land.

From these circumstances, the oil spills are very harmful to marine birds, sea turtles, and mammals, and also can harm fish and shellfish. In general, the oil spills are destroying the insulating ability of fur-bearing mammals, such as sea otters, and the water-repelling abilities of a bird's feathers, exposing them to the harsh elements. Many birds and animals also swallow oil and are poisoned when they try to clean themselves or when eating oiled prey [11].

This can be considered to monitor and detect the oils pills on coastal surface areas. To protect the coastal environments, this could be considered to monitor the ocean regions and also surfaces of oceans.

Finally, many techniques are reviewed to carry such type of problems in marine regions. All these techniques/methodologies/approaches are discussed in subsequent sections.

3. Characteristics of spilled oil and its impacts

In this section, characteristics of spilled oil on coastal region and its impacts are discussed in detail. The spilled oil can spread over sea water, on sea shore, land area, and glaciers. It is highly dangerous as wind, waves, and currents could scatter large oil spill over a wide area within a short period of time [12]. The spilled oil quickly spreads to form a thin layer on the water surface, which is called as oil slick. As time progresses, the oil slick becomes thinner, forming a layer called as a "sheen," which has a rainbow-like appearance with a multiple color. The light weigh oil is highly toxic but it gets evaporated quickly, whereas heavy weigh oil is less toxic but persists in the environment for a longer time. The heavy weigh oil can get mixed with pebbles and sandy beaches where they may remain for many years [13].

It is required to measure the spread of spilled oil over the sea surface called "slick measurement." It is achieved through the wavelength of backscattering of capillary waves that are generated only on the very dark region of sea surface. The measurement of slick regions also depends upon the polarization of RADARs and its incidence angle, nature of spilled oil, and metrological ocean conditions [14].

The coastal region monitoring depends on the capability of radar satellite sensors to be used to detect the oil spill on the sea surface. The multi-temporal imaging technology is used to obtain data captured by sensors as it is very important to model the oil spill. Satellite remote sensing sensors can provide the following information for oil spill contingency planning of large area location and oil spill spread, thickness of the oil spill quantity estimation, the classification of the oil spills from the environmental activities and finally assist the information that provides a cleanup valuable operation [15].

The oil spill in water may severely affect the marine environment and causes damage to plankton and other aquatic organisms. The livelihood of many coastal people is severely impacted by oil spill, particularly those who are depending upon fishing and tourism as their livelihood [16].

The movement of oil on land surface depends on various factors such as oil type, soil type, and moisture content of the soil. Oil spilled on agricultural land can impact on soil fertility and pollute ground water resources as well. Oil companies and shipping operators are responsible for controlling spilled oil and cleaning polluted areas. In the event of oil spill, information about the size and extent of it is very critical and it is required to assist the government and industry in oil spill contingency planning to describe the guidelines for estimating oil thickness using visual appearance as shown in **Table 1** [17]. It also explains the appearance of oil varies from silvery-sheen to dark brown with its approximate thickness in micrometer.

Oil spill appearance	Approximate film thickness (μm)
Silver sheen	0.05
Rainbow sheen	0.15
Reddish-brown sheen	0.50
Brownish	2.00
Dark	10.00
Dark Brown	50.00

Table 1.
Appearance of oil on water surface.

3.1 Impacts of spilled oil

In **Table 2** nature of oil spill, environment, and its impacts are presented in detail [18]. This is clearly explained about the present impacts of oil spills in environments. Each step gives the nature of present impact of spilled oil in two types of regions: one is called, Aqueous Region and another called, Land Surface. The first, Aqueous Region explains an impact of the current spilled oil on the ocean water surface and its affecting on the environments from the chemical organs. Second, Land Surface gives the current role of spilled oil about the groundwater bodies and its effects on earth surface nature.

However, in the physical and bio-degradable components of environmental persistence are accumulative processes on the normality for minimizing the oil parameters

Nature of spilled oil	Spilled environment	Impact of spilled oil
Lighter oil less dense than water	Aqueous region	Spilled oil spreads over surface of sea water and it affects the livelihood of aquatic organisms
	Land surface	Spilled oil penetrates the earth surface and moves down due to gravity and reaches groundwater bodies and contaminates it.
Mixture of volatile compounds (hydrocarbons)	Aqueous region	Spilled oil started vanishing when in contact with air and pollutes it. It happens once it reaches top point of water surface.
	Land surface	Volatilization may happen likewise from a spill amassed on top of shallow groundwater. Once vanished, the unstable vaporous mixes with air and pollute environment.
Mixture of compounds with different water solubility	Aqueous region	In spite of the fact that oil is little water solvent and collects on top of water, some oil mixes may break down to some degree in water. The broke down mixes turn out to be more portable and spread bit speedier with water and more bioavailable to be taken by marine life.
	Land surface	Oil is less leachable by precipitation water and may continue in subsurface situations, including on top of groundwater for a considerable length of time.
Sheens or Oil Slicks	Aqueous region	Since oil and water are not miscible, it forms shapes on water surface. This expands the resistance of oil to characteristic constriction procedures and makes it steadier in the earth.
	Land surface	Oil is less leachable by precipitation water and may continue in subsurface situations, including on top of groundwater for quite a long time.

Nature of spilled oil	Spilled environment	Impact of spilled oil
Oil physical state (liquid) and biodegradable components	Aqueous region Land surface	Some normal constriction procedures may lessen the measure of dirtied oil even without human intercession. This is because of a blend of vanishing, disintegration, and biodegradation of oil slick. In marine or stream situations, such characteristic lessening procedures are quicker than those in subsurface situations, ashore or in groundwater.
Oil composition involving the presence of individual components with environmental persistence and bio-accumulative potentials	Aqueous region Land surface	Some oil segments (e.g., PAHs) may continue longer in environment, collecting in dregs, marine life, fishes, and natural life when all is said in done.

Table 2.
Impacts of spilled oil in environment.

without the human interaction. Because of the coastal condition, the marine environment properties are minimizing the procedures as well as surface situations or ground water conditions.

3.1.1 Impact of freshwater habits

Oil spills occurring in freshwater bodies are less publicized than spills into the ocean even though freshwater oil spills are more frequent and often more destructive to the environment. Freshwater bodies are important for human health and the environment, but unfortunately, it is highly sensitive to oil spills [19]. They are often used for drinking water and frequently serve as nesting grounds and food sources for various freshwater organisms. All types of freshwater organisms are susceptible to the deadly effects of spilled oil, including mammals, aquatic birds, fish, insects, microorganisms, and vegetation. In addition, the effects of spilled oil on freshwater microorganisms, invertebrates, and algae tend to move up the food chain and affect other species [20].

3.1.2 Impact of marine environmental bio-system

The major spills of crude oil and its products in the sea occur during their transport by oil tankers, loading and unloading operations, blowouts, etc. Due to spillage of oil in the marine environment, it undergoes a variety of transformation involving physical, chemical, and biological processes. The physical and chemical processes include evaporation, spreading, emu1sification, dissolution, sea-air exchange, and sedimentation. Chemical oxidation of some of the components of petroleum is also induced in the presence of sunlight. The degraded products of these processes include floating tar lumps, dissolved and particulate hydrocarbon materials in the water column, and materials deposited on the bed [21].

Biological processes, though very slow, also act simultaneously with physical and chemical processes. The important biological processes include degradation by microorganisms to carbon dioxide or organic material in intermediate oxidation stages, uptake by large organisms, and subsequent metabolism, storage, and discharge [22].

3.1.3 Impact on marine habitats

The marine environment is made up of complex inter-relations between plant and animal species and their physical environment. Harm to the physical environment will often lead to harm for one or more species in a food chain, which may lead to damage for other species further up the chain. Where an organism spends most of its time—in open water, near coastal areas, or on the shoreline—will determine the effects of an oil spill is likely to have on that organism [23].

In open water, marine organisms such as fish and whales have the ability to swim away from a spill by going deeper in the water or further out to sea, reducing the likelihood that they will be harmed by even a major spill [24]. Marine animals that generally live closer to shore, such as turtles, seals, and dolphins, risk contamination by oil that washes onto beaches or by consuming oil-contaminated prey. In shallow waters, oil may harm sea grasses and kelp beds that are used for food, shelter, and nesting sites by many different species.

4. Sensors and satellites

In coastal region monitoring, oil spill detection and its removal play an important role in protecting the environment and reducing economic loss. It could be achieved through remote sensing technique that uses space-borne satellites and airborne aircrafts. The space-borne satellites use mounted RADAR in it which comprises sensors. It is also observed that the selection of particular sensor plays an important role in detecting oil spills. At the initial level, space-borne satellites are most suitable for oil spill detection but further analysis could be carried out using aircraft sensors [6]. In ocean monitoring, microwave sensors are preferred to optical sensors due to its excellent performance under all weather conditions. The role of different sensors in oil spill detection is presented in the subsequent section.

At the initial stage oil slicks have been identified and processed using images of ERS, ENVISAT ASAR, and RADARSAT-1. Recently, many radar satellites with a potential for oil slick location have been propelled, specifically, RADARSAT-2, Terra-SAR-X, and COSMO SkyMed. A general exchange of the suitability of RADARSAT-2 for beach-front applications is found in [17]. These satellite radars use new imaging modes that open some new potential outcomes for enhanced imaging of oil slicks.

However, the ERS-1 is currently being used by the Norwegian Space Center (NSC) on behalf of pollution control board in the coastal region for oil spill detection. In ERS-1, radar frequency range is located accurately and it is used for processing radar signal-by-signal projections. It is the technique used to capture images of resolution 30 m X 30 m. In ERS-1 SAR raw data processing, large geographical area can be covered by adjusting physical length of the ERS-1radar antenna. In specific, for oil spill detection, the ERS-1 radar produces variety of images at various levels based on wind speed by covering large area. These images need to be processed to identify oil slicks. At present, ENVISAT RADAR is predominantly used for oil spill detection due to its wide area coverage with a spatial resolution of 150 m and a pixel spacing of 75 m. Similarly, the RADARSAT, ScanSAR covers 60–400 km swath width with a spatial determination of 50 m and a pixel dispersing of 25 m [25].

Even though the ENVISAT higher-frequency radar, spatial data determination is accessible from the remote sensing medium determination, the spatial data information takes care a sensible bargain permitting covering the vast territories and as yet recognizing significantly littler oil slicks from the SAR image regions [26].

The other is named as COSMO-SkyMed satellite with a group four, which permits the great scope of feature analysis in significant time periods. The COSMO-SkyMed SAR fragment was dispatched in November 5th, 2010 at 1920 L and it has been utilized for the water/deep-water horizon oil slick studies. As indicated in [27], it ought to have greater capability in detecting oil slick localities with double polarimetry SAR images that are captured by COSMO-SkyMed satellite sensors.

Terra-SAR-X has the capability of capturing images in different directions while monitoring the specified area of coastal region. It uses larger value of standard deviation for differentiating oil slick or look-alike. In addition, it uses double polarimetric SAR technique, in discriminating the spilled oil from look-alike. The RADARSAT-2 has a few polarization alternatives—for example, single-polarization SAR modes with one of the accompanying polarizations such as HH or HV or VH or VV [28]. It also offers dual polarization SAR modes with appropriate polarizations such as HH + HV or VV + VH. A quad-pol alternative is likewise feasible for fine and standard modes.

Adamo et al. have proposed a model for oil spill examination by considering normal number of accessible MODIS, MERIS, and ASAR images. These images need to be captured within observing time periods without cloud images in sunglint conditions. However, the MODIS/MERIS is ensured if the smoothness of radar data as image is situated in oceanography regions inside as well as outside. Similarly, they noticed a wavelength from reliance oil/non-oil class distinctness with expanded execution at

Satellite name	Agency	Sensor name	Spatial resolution	Spectral resolution	Year of launch
RORSAT	NOSS	EORSAT	Low	X-band	1967
Seasat	NASA	SMMR	High	L-band HH polarization	1978
GeoSat	ESA	GRA	Medium	Ku-band	1985
ERS-1	ESA	GOME SAR	Low	C-band VV or Sun-Syn pol	1991
ERS-2	ESA	GOME, ATSR-2	High	C-band VV or Sun-Syn pol	1995
RADARSAT-1	CSA	SCN	Medium	C-band HH	1995
GFO	ESA	GFO-RA	High	Ku-band	1998
JERS-1	JAEA/NASDA	OPS	High	L-band HH polarization	1998
Quickscat	NASA	SeaWinds	High	Ku-band	1999
ALOS	NASDA	AVNIR-2	Low	L-band HH	2001
ENVISAT	ESA	MODIS, MERIS (P) and ASAR WSM	Low/ medium/ high	7 bands, Q 15 bands, P and C-band VV or HH	2002
ALOS	NASDA	PALSAR	Fine resolution	L-band HH polarization	2006

Satellite name	Agency	Sensor name	Spatial resolution	Spectral resolution	Year of launch
SAR Lupe	ESA	XSAR	High	X-band	2006
Metop – A	ESA	ASCAT	High	C-band	2006
RADARSAT-2	CSA	SCN/QP	Medium/ high	C-band HH or VV or Quad pol	2007
TerraSAR-X	CSA	TSX-SAR	High	X-band Single or dual pol	2007
COSMO-Skymed	ISA	Multi-SAR	High	X-band Single or dual pol	2007
Cloudsat	SDSC	CPR	High	X-band	2008
RISAT-2	SDSC (ISRO&IAI)	XSAR	High	X-band	2009
TanDEM-X	ESA	GSCDA	High	X-band	2010
RISAT-1	SDSC (ISRO)	ScanSAR	Medium	C-band	2012
Metop – B	ESA	IASI	High	X-band	2012

Note–P: 350–1050 nm, Q: 610–2155 nm.

Table 3.
Different space-borne satellites with its specifications for remote sensing.

the more NIR band wavelengths of MODIS and MERIS [27–29]. Their recreations for a range in the Mediterranean appeared that by and large 150 images every year would be suitable if an aggregate cloud list of under 2/10 was required. Occasional varieties further demonstrated that the period between spring and pre-winter was the most suitable for sunglint conditions. MERIS and MODIS symbolism is routinely used to make water quality maps and checking algal sprouts [30]. Indeed, without sunglint conditions, algal blossom maps can be utilized in the mix with SAR pictures to lessen the quantity of false cautions because of green growth. Radar satellites are most suitable for quick detection and monitoring of large areas. At present, most of the remote sensors can detect oil spills.

Table 3 shows various satellite-based sensors for oil spill monitoring. From these satellites, sensors are using various spectral bands (i.e., X, L, C, and Ku-band) for monitoring the coastal region surfaces. Finally, the remote sensing manner transmits the data from one location to another location, while observing the ocean surfaces for change detection of costal activities.

Band type	Frequency range (GHz)	Wavelength range (cm)
C-band	4–8	60–30
L-band	0.5–1.5	30–15
Ku-band	10.7–12.75	2.5–1.67
X-band	8–12	3.75–2.5

Table 4.
Different band and its wavelength with its frequency range.

In **Table 4**, different bands used by different satellites are shown below with its frequency range and its wavelength. It can be considered as for the satellite band type as well as the frequency and wavelength ranges. The corresponding radar satellite only uses these appropriate band models. And also, most of the radar satellites are using a C or X-band for the coastal region monitoring.

5. Existing methodologies

A review of literature survey on various methodologies used to detect oil spill for ocean monitoring has been carried out and presented subsequently in detail.

In 1999, Solberg et al. [31] have proposed an algorithm for automatic detection of oil spill using rule-based approach combined with statistical modeling (i.e., Gaussian density). It also uses prior knowledge about oil slick for classification of it. In this algorithm, authors have used 11 features of oil slick that include distance to point source, number of detected spots in the scene, number of neighboring spots, Homogeneity, Slick Complexity, Slick width, slick area, first invariant planar, local area contrast, border gradient, power-to-mean ratio. The accuracy attained by rule-based classification approach is 95%. But the observed limitation of this approach is it requires prior knowledge about oil slicks. The proposed algorithm could be considered as semi-automatic algorithm as it uses prior knowledge.

In 2000, Fabio Del Frate et al. have proposed a neural network algorithm for classification of oil spill from look-alike in [1]. The proposed algorithm uses the rule-based Bayesian statistical decision approach. The performance of classification algorithm has been evaluated on a dataset containing oil spill and look-alike. The proposed algorithm uses some of the features that describe both physical and geometrical properties of oil spill. Those features are used as candidate features for classification. The accuracy attained by proposed algorithm is 70%. However, the observed limitation of this approach is that it is required to develop the classification rules for the complex datasets. Hence, this algorithm could be considered as neural network algorithm as it uses statistical-based classification decisions.

In 2004, Maged Marghany [32] has proposed an approach for oil slick detection and oil slick trajectory model. The proposed approach uses two sub-models. The first model uses texture analysis for oil slick detection. The second model uses the oil slick trajectory forecasting model. The oil slick trajectory model contains the integration between Doppler frequency shift model and Lagrangian model. Both models have used a classical Fay's algorithm, to simulate the oil slick trajectory movement. In this proposed algorithm, authors have used features such as entropy, surface current changes, energy, slick homogeneity, and slick direction. The results of this approach are not accurate, which is a primary limitation. The proposed approach could be considered as an automatic algorithm as it uses slick trajectory models of classical Fay's algorithm.

In 2004, Frederic Galland et al. [33] have proposed an approach for monitoring pollutant of major environmental hazards at ocean surface and minimizing it. The proposed approach consists of two parts. In first part of the proposed algorithm, homogeneous regions are partitioned that should be applied with polygonal active grid. In second part of the proposed algorithm, classification is carried out and it should be applied with an automatic minimum description length (MDL) thresholding technique. In this work, feature considered includes size, shape, distance of object from coastal region, intensity, and texture. The results of accuracy of oil spill regions are obtained for larger areas with appropriate coastlines. In this proposed method, observed limitation of MDL application is that noise is not removed fully from SAR images.

In 2005, Iphigenia et al. [34] have proposed computational intelligence-based approach for oil spill detection on satellite images. In this approach, smoothing is performed through Gaussian filtering followed by thresholding is applied. The image enhancement technique is applied to enhance dark regions and then, objects are grouped together using segmentation method. Finally, fuzzy classification approach is applied to classify oil spill or look-alike. In this approach, authors have used three features: region eccentricity, land distance and the probability of oil spill. The proposed algorithm has been tested with 26 images and attained 88% of accuracy in detecting oil spill regions.

In 2005, Fanny Girard-Ardhuin et al. [35] have proposed semi-automatic approach for detecting spilled oil regions, characterization of region properties, and classification of oil spill or look-alike. For semi-automatic detection of dark regions median filtering is applied to remove noise followed by Sobel operator for thresholding and segmentation. The filtered regions are characterized using features such as size and shape. In this algorithm authors have used some of the features about the oil spill formation of wavelength, spill polarization of sea surface areas, satellite projection of incidence angles with radar projection view, the slick nature and changes of the sea surface conditions. While applying this algorithm, the image dark region parameters are not properly detected and its complexity is not determined accurately.

In 2006, Gregoire Mercier et al. [36] have proposed a semi-supervised approach for oil spill detection using wavelet decomposition. This proposed method is implemented in complex sea surface and features used are sea surface wavelength, spill polarization of image region, the radar different views of oil spill projection. The obtained results of oil spill are shown as very effective and accurate in detecting oil slicks from the specified image region. This proposed approach is applicable for large ENVISAT images with complex formatting. It is considered as limitation of this algorithm.

In 2007, Topouzlis et al. [37] have proposed a neural network-based approach for detecting and classifying oil spill. The proposed approach detects the dark formation areas and classifies it into oil spill or look-alike. In this proposed algorithm, features such as oil spill perimeter, shape factor of the region, the object complexity estimation, standard deviation, and power-to-mean ratio are used. The obtained results show that the algorithm detects dark formation with 94% accuracy and discriminate it as oil spill with 89% accuracy. The limitation of this proposed algorithm is that it is not suitable for high dynamic data environments.

In 2007, Solberg et al. [38] and Maurizio Migliaccio et al. [39] have proposed a three-step algorithm for detection of oil spill using the RADARSAT and ENVISAT SAR images. The first step is used to detect the dark spot and the second step is used to extract the dark spot features, and finally, it classifies the dark spot as oil spill or look-alike. In this proposed algorithm, authors used features such as the complexity, width, area, and slick moment; contrast of dark region about local contrast, border gradient and smoothness of the spill region; homogeneity of spill region about the power-to-mean ratio; the spill surroundings about the detection of dark spots, spot region, and distance from the coastline. The result of this algorithm is reported for 59 images of RADARSAT and ENVISAT about oil spill or look-alike. The observed limitation is classification approach not carried automatically.

In 2008, Lena Chang et al. [40] have proposed an approach for ocean monitoring with minimized computational complexity. In this proposal, image segmentation is carried out using split and merge technique. The conventional detection theory called centralized look-alikes ratio test (GLRT) is used to detect oil spill using simple variance and statistical properties with the help of decision-making rules. The proposed algorithm determines oil spill effectively on ERS-2 SAR images. The similar pixels are not shown on the specified image region, while applying the GLRT method using ERS-2 SAR images.

In 2008, Camilla Brekke et al. [41] have proposed improved classification algorithm using a multivariate Gaussian classifier for reducing low-confidence levels. In this work, authors have used features such as slick complexity, power-to-mean ratio of slick, slick border, slick local contrast, slick width, slick region, slick smoothing contrast estimation, and slick variance. The observed limitation of this algorithm is that the manual operation could not be performed on selected region. In Ivanov et al.'s work [42] image processing methods are proposed for detecting oil spill. In this proposal, study is carried out on East China Sea for oil spill detection using SAR images. Authors have selected features such as shape, slick size or length, location, orientation, type of edge on oil slick, and database contrast. The result and analysis show small oil patches are uniformly distributed along the ship tracking. From the results, detection of oil spills on image region is not accurate. Kontantinos N. Topouzelis [43] have proposed a classification with fuzzy logic technique. In this proposal, authors have used nearly 25 features of oil spill includes object's area, perimeter, perimeter-to-area ratio, complexity, shape factor I, shape factor II, mean value, standard deviation, 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, local area contrast ratio, mean border gradient, standard deviation border gradient, max border gradient, mean difference to neighbors, spectral texture, shape texture, and mean Horlicks texture. Authors have claimed that the obtained accuracy is reported as 99% in detection of oil spill. But this algorithm observed some limitations that are the imbalanced training datasets, data selection validity, and high dynamic environment selection of dataset. In Chuanmin, Hu et al.'s [44] works use slick region statistical parameters like mean, standard deviation, and minimum and maximum distance of the slick from the region. The results show an annual seapage rates in the northwestern Gulf of Mexico and also the slick time series variation recording. But the observed limitation is that it could be performed only on medium resolution of MODIS data under tropical and sub-tropical.

In 2010, Konstantinos Topouzelis et al. [45] have proposed an algorithm for feature selection and classification. In this algorithm, classification method uses the statistical decision tree rules and features considered are area, perimeter, complexity, shape, mean, power-to-mean ratio, texture, and contrast of oil spill region. The result shows that the obtained classification accuracy rate is 84.4% in detecting oil spill. This proposed method suffers from problem of classification of 70 trees and it performs only sequential selection operation.

In 2011, Biao Zhang et al. [46] have used an unsupervised classification approach for distinguishing oil slicks from sea surfaces. It uses very simple and effective mapping techniques. In this proposal, quad polarization SAR images of lower wind condition are mapped with normal condition by considering features such as slick entropy and slick region. But the observed limitation is the selected smaller dark regions on images could be processed only under moderate wind conditions on sea surface regions.

In 2012, Chanudhuri et al. [47] have proposed four step algorithms for automatic detection of ocean disturbance. This proposed approach first enhances SAR images to emphasize the dark regions. The second step then segments dark regions using iterative method. After this, the graph theory-based method uses to remove the unwanted false alarms. Finally, a link-based algorithm is applied for detecting the disturbance features using statistical approaches. In this algorithm, the used features enhance the image, segmentation of the image regions, hole filling, region removal of slick enhancement, segment link of the same regions, and spur removal of specified region. The result shows that synthetic test images with different noise levels and real images from a variety of satellites such as ERS-2, SEASAT, ENVISAT, RADARSAT for sea disturbance features. But this algorithm observed one limitation to compute the data models in a single way only. Bhogle et al. [48] have proposed algorithm for automatic detection of oil spills. This algorithm consists of three steps for protecting the water life and reduces environmental damages from oil spills. In this algorithm, the first step detects the dark spot on image regions. The next step is feature's extraction of each dark spot. The final step is classification of dark spot is oil spill or look-alike. After these steps, then the texture entropy is used for discrimination of oil spill area and Mahalanobis classifier is estimation of the oil spill identification. In this algorithm, authors used three features of oil spill such as the distance from coastline, mean of spill on specified region, and the co-variance of image region pixels. The reported result shows different algorithm for an automatic detection with accurate and efficient manner. And also computing the texture entropy features 94% of accuracy with help of Mahalanobis classifier. But this algorithm observed some limitations are texture entropy might complex process and less flexible using the Mahalanobis classifier is not effectively remove the speckle noise for data analysis. This proposed algorithm classifies the texture variations of spill detection on image regions.

In 2012, Michele Vespe et al. [49] have proposed approach for quality issues of satellite images related to marine applications. This algorithm is to assess the quality and indicators for vessel and oil spill detection. This algorithm used some features including global quality aspects of radiometric sensitivity, radiometric resolution, radiometric accuracy, region stability and error to detecting, spatial resolution, geolocation accuracy about the local-quality aspects with peak-to-side-lobe ratio, the integrated sidelobe ratio, ambiguity of slick detection, interference of artifacts, structured data, missing data, and SAR processing errors. The result is reported based on current issues of marine applications from oil spill detections. But the observed algorithm limitation to generalize the quality levels should be encountered based on the data representation.

In 2014, Alireza Taravat et al. [50] have proposed neural networks algorithm for fully automatic detection of darkspots. In this algorithm, two methods use non-adaptive identification of oil spill on image region. First method called Weibull Multiplicative Model (WMM) is applied for filtering in each sub-image. Second method called Pulse-Coupled Neural Networks (PCNN) is used for segment and removing the false targets. In this algorithm, authors used features as well-defined slick region identified, linear well-defined, massive well-defined, not well-defined, linear not well-defined, massive not well-defined, linear dark spot, and massive dark spot. The results tested 60 ENVISAT and ERS-2 images and reported 93.66% accuracy of overall dataset. But algorithm-observed limitation shows a fewer effective result.

In 2014, Yu Li et al. [51] have proposed a statistical quad-pol reconstruction method for SAR quad-polarization data. This method improves a compact polarimetric SAR data for reconstruction using statistical methods. This proposed method refines the scatter behavior of SAR signal relationship for iterative quad-pol reconstruction data. In this algorithm, authors used only one feature that is slick region iteration and the reconstruction of quad-pol data. The result shown is to improve compact polarimetric SAR data using the quad-pol reconstruction model accurately. But the algorithm observed one limitation is to perform only for low-accuracy quad-pol reconstruction model. This proposed algorithm has been used to improve the data performance and data accessing model for reconstruction using SAR polarimetric techniques.

In 2014, Salberg et al. [5] have proposed algorithm that uses hybrid polarimetric SAR technique for slick classification. This proposed algorithm is used only to improve hybrid-polarimetric SAR data and its feature extraction. In this algorithm, authors used five features that include oil spill detection on image dark regions, correlation co-efficiency, standard deviation, slick decomposition of region, conformity index of the slick with polarimetric SAR data, and coherence measurement of slick region separation. The result shows the features of hybrid polarimetric SAR data and then classifies each detected slick on the specified region. But algorithm observed one limitation that performs only limited testing images from the hybrid polarimetric SAR data. This proposed technique identifies slick feature and its measuring capabilities of hybrid polarimetric SAR data.

In 2014, Giacomo De Carolis et al. [52] have proposed an approach for measuring the slick thickness in medium-resolution imaging spectrometer instrument (MERIS) and moderate-resolution imaging spectro-radiometer (MODIS) images. This proposed approach estimates the thickness of oil slick from marine surface. In this proposed approach, authors used one feature for estimation of slick thickness from the detected region. The result shown is reported from the June to August 2006 under Lebanon oil spills occurred in MERIS and MODIS gathered data. But this approach not shows the perfect values of gathered data samples as a limitation.

In 2015, Collins et al. [53] have proposed approach as a compact polarimetric SAR technique for coherent dual-pol SAR images. This approach uses simulated airborne compact SAR data for characterizing oil-water mixing of deep-water horizon oil spill. On the other hand, this SAR is used to perform the great potential for maritime surveillance application on oil spill characterization. In this approach, author used single feature as reconstructing the errors for sea water. This result shows quad-pol data features and pseudo-quad data and their differences. But this approach is observed only for variations of different compact polarimetric SAR images.

In 2016, Saeed Chehresa et al. [54] have proposed an algorithm to detect the oil spills and lookalikes based on the selection of optimum features in a given SAR data set('s). This algorithm is evaluated based on classification of SAR image dark spots. This algorithm of 93.19% accurate is classified with optimum set of features from the dataset. Also, eight different evolutionary algorithms are considered to classify the desired feature subsets. Giacomo Capizzi et al. [55] have proposed an automate cluster-based system developed for oil spill detection in satellite remote sensing. This system interactively working with several characteristics about the availability and adaptability of the different classes of objects and SAR images are considered based on application areas. This proposed algorithm uses a back-propagation neural network algorithm to obtain the outcomes as identify objects such as ships with spills/sliks on SAR images.

In 2017, M. Konik and K. Bradtke [56] have proposed an object-oriented approach to detect oil spills on ENVISAT ASAR (Advanced Synthetic Aperture Radar) images. This proposed methodology improves the classification at the scale of entire water bodies, focusing on its repeatability. Also, this approach analysis enhances the optimized filters to multilevel hierarchical segmentation. This proposed system recorded 96.15% of accurately identified spills and 4% of dark spots extracted from the given dataset.

In 2018, Majidi Nezhad et al. [57] carried case study on sentinel 2 satellite images for oil spill detection analysis. In this analysis part, exploit areas of oil spills and oil loading ports are often used by the governance of tankers and ship. With ENVI tool, this analysis is carried out to discuss oil spill detection in Persian Gulf by using multi-sensor images data.

In 2019, Jiao et al. [58] proposed a deep learning approach to detect the oil spills in an unmanned aerial vehicle. This proposed approach having three main steps, first step used with CNN model to detect oil spills in image. Second step is used for filtering the detected results of first step with help of Otsu algorithm. Third step is used to detect detail manner in a region-based detection with oil spills. So, this proposed approach is effectively solved to reduce the cost of oil spill detection by 57.2% compared with the traditional inspection process.

In 2020, Yekeen et al. [59] proposed a novel deep learning algorithm to detect the oil spills. This process can be achieved by the similar visuals of oil slicks and look-alike, which affects the reliable SAR images for the marine oil spill detection. But, this can be used for minimal detection and discrimination of oil spills with help of traditional deep learning models with limited accuracy. Moreover, the proposed novel deep learning algorithm detects the oil spills using computer vision instance segmentation mask region based on CNN model to detect maximum oil spill on ocean regions.

In 2021, Syedi et al. [60] have proposed multiscale multidimensional residual kernel convolution neural network. This proposed method is used for overall accuracy of oil spill detection in Gulf of Mexico regions. Also, this study investigates a proposed model with OSD algorithms had shown better performance.

6. Classification using features of oil slick

In general, oil spill detection could be carried out either by manual process using trained personnel or by an automated system. As per literature review, existing systems uses either manual approach or semi-automated system. The numbers of SAR images to be analyzed are getting increased annually. If oil spill detection is carried out manually in a wide swath image with appropriate resolution, it is a very time-consuming process. Thus, it is required to design an automated system for improving results. In certain cases, as outlined in [31], it is observed that manual detection is preferred.

The manual oil spill detection approach at KSAT is described in [61]. About the wind speed Automatic Information System (AIS) ship tracking of sea and their outer surface information, location of oil rigs, pipeline, national territory borders, and coastlines are available to the operator. Possible oil spills are assigned confidence levels based on their contrast to the surroundings, wind speed, identification of possible sources, natural slicks or low-wind areas nearby, and edge and shape characteristics of the slick. Various algorithms for oil spill detection based on single-polarization SAR images are reviewed in [62–64]. Several of the papers describe a methodology consisting of identifying dark spots followed by computing features describing the shape, contrast, surroundings, and homogeneity of the spots. The main challenge is not to segment out dark areas in the SAR image, but to identify a set of good features that can be used to discriminate between oil slicks and look-alikes, and then to use the features in a reliable classifier.

Some of the algorithms for oil spill detection based on SAR polarization images were reviewed from a single direction. Discernibly, the huge uniqueness spill and sea

Sl. no.	Features
1.	Dark area (A)
2.	Dark area border (B)
3.	Ratio (A/B)
4.	Spill complexity
5.	Spill region shape
6.	Spill width
7.	Standard deviation of dark region
8.	Standard deviation of background
9.	Max dissimilarity between dark region and background
10.	Max dark area border gradient
11.	Mean dissimilarity between dark region and background
12.	Mean dark area border gradient
13.	Gradient standard deviation
14.	Local region contrast ratio
15.	Spill power-to-mean ratio
16.	Average of inside dark area
17.	Average of outside dark area
18.	Number of detected spots in the SAR image
19	Number of neighboring spots
20.	Gradient of dark area border

Table 5.
SAR image single-polarization features.

surface territories are checking of extensive regions for oil detection. The dissimilarity decreases about the generality of wind levels. But the main complicating thing is the low wind dark area with very high dissimilarity common in low-wind conditions. Most important features are, if possible, spills from the selected region can be seen on SAR image. Polarimetric SAR image features can be extended to a certain region and availability of SAR-limited data.

The existing system feature extraction for the oil spill detection is given in [63]. Most commonly used features are shown in **Table 5** for single-polarization SAR oil-spill detection and **Table 3** features are used for polarimetric SAR oil spill detection [64]. The most of polarimetric SAR features are listed in **Table 6**. These are not used for automatic algorithms. But some automatic methods are to be used for detection of oil spill with polarimetric SAR data. The main comparison between the accuracy with single SAR polarimetric and polarimetric SAR data is not yet processed for large datasets.

The existing system experimental results are tried to get the rank features according to their importance. The objective was to select and use only those features characterized by strong discriminative capacity. It appears that combinations of features with high discriminative capacity were not giving satisfying results as combinations of features having lower discrimination capabilities. For example, if we have 10 cases, three of which can be discriminated by feature X, the question is how many of the remaining seven cases can be discriminated by another feature, for example, feature

Sl. no.	Feature
1.	Entropy
2.	Mean scatters
3.	Standard deviation of CDP
4.	Coherent circular polarization
5.	Combined features
6.	Correlation coefficient

Table 6.
Polarimetric features used for oil spill detection.

Y. If features X and Y contribute only in discriminating the same three cases, then the combination is not good and another feature (e.g., feature Z) has to be used.

7. Current operational efforts in oil spill monitoring

The use of satellite imagery for regular oil spill monitoring worldwide is increasing. Pedersen et al. [65] describe the Canadian oil spill monitoring efforts. They currently acquire and analyze 5000 SAR images over Canadian waters annually. From 2006 to 2007, 360 images were analyzed, 12 anomalies were detected, and three of them were verified. An overview of long-term oil spill monitoring efforts in Europe is described. The Baltic Sea is an area where oil spill monitoring has been performed for many years already. Oil spill statistics are computed annually. According to the number of detected and verified oil spills correlates well with the shipping density. The European Maritime Safety Agency (EMSA) is responsible for providing vessel traffic monitoring services to the European Union Member States. EMSA manages maritime shipping systems: SafeSeaNet, CleanSeaNet, and LRIT. SafeSeaNet is a ship, vessel monitoring system based on AIS and LRIT track vessels outside the range of AIS coastal networks [66]. Thus, the CleanSeaNet offers near-real-time oil-spill detection from [67].

The EMSA CleanSeaNet satellite monitoring service provides annual statistics of potential oil slicks. In 2008, 3196 potential slicks were reported, while this was reduced to 2107 in 2009 and 1981 in 2010. In 2009, 751 of the reported slicks were checked by the national authorities and 194 verified (for verifying oil spills weekly) [68]. Although it is impossible to quantify the exact volume of oil involved in these spills, it is believed that deliberate discharges account for a progressively greater proportion of pollution than the accidental events. CleanSeaNet uses SAR images from ENVISAT, RADARSAT-1, and RADARSAT-2. The service is supposed to be extended [69], to include optical images (MODIS Aqua) in 2011. Operators assess the SAR images together with meteorological, oceanographic, and ancillary information to detect the presence of oil on the sea surface. Detection results are reported to the affected country less than 30 min after satellite image acquisition.

In case of a major accidental spill, European Union Member States and/or the European Commission will normally activate the International Charter for Space and Major Disasters [68]. EMSA can assist in analyzing satellite imagery to help coordinate

Figure 1.
This is an example of discharging oil from the ship.

Figure 2.
The Texas City accident on U.S. coast in March 22nd, 2014 © Houston Ship Channel.

and order all possible satellite imageries to continuously monitor the evolution of an accidental spill as well as to assist in applying forecasting computer models (**Figure 1**).

In the current operational scenario based on monitoring, the pollution control phenomena as aircraft and ship surveillance under the traditional techniques have many drawbacks: time delay, weather conditions, airborne surveillance, and SAR data evidence rules. These drawbacks are frequently reported by oil spills and their detection capabilities very low of the remote sensing monitoring. The Side-Looking Airborne Radar (SLAR) aircrafts observing is to detect pollution under different conditions about the wider areas of the coastal region surface [70]. However, the National Pollution Control Authorities Center for environmental protection detects the spoils from the oil spill damages: early warning, legal prosecution, and provision of pollution statistics (**Figure 2**).

8. Case studies

Outline of Oil Spill Detecting in Remote Sensing—The study of the major remote sensing gives major information about oil spills in marine surroundings or sea surface areas after accidents. Normally, the oil spills are caused by enormous accidents and their size of the oil area is covered from discharge region. After happening accidents, the huge regions can be covered by oil. The oil spill detection of accidents compared with smaller discharges will be different as the expected area of the oil spill will be different as the expected area of the oil spill will variation of the expected area of the oil spills in two different cases. The case of an accident is major assessment and the tracking is possible for oil trajectory models. gCaptain [63] shows a coast Guard photo from U.S. National Transporation Safety Board (NTSB) accident docket investigation on March 22nd, 2014 in the Houston Ship Channel (HUC).

The HUS is involving a cargo ship and a tank barge being measured by a Kirby tugboat. Its abound cargo ship MV Summer Wind collided with two-barge tow being led by the Kirby 27,706 tank barge and also pushed by the Kirby inland tow-boat Miss Susan at approximately 12:35 pm. In this case, most of the oil not immediately reaches the coastlines. The resulting collision is release of approximately 4000 barrels (168,000 gallons) of fuel oil into the waterway from a breach in the double hull of the Kirby 27,706 [71]. However, docket contains more than 4000 pages and it includes a summary of the oil incidents, transcripts from both vessels and witnesses aboard nearby vessels, and their factual report investigation. In 2002, many studies should be describing remote sensing of the Reputation accident; see the examples of [72]. The different satellites are such as ERS-2, ENVISAT, ASAR, RADARSAT-1, TerraSAR-X, and ALOS PALSAR data after oil spill incident on coastal. So, they associated the theoretical checking ratio from given frequency and its ratio estimated wind speed measurement. Normally, the sea surface conditions were not well appropriate to regularly detect surface oil out layer. But this could be covering a lack of sunglint the oil was difficult to show on visible band spectrum.

9. Conclusion

Oil slicks on the ocean surface are watched generally regularly. Contamination because of either mischances or think slick releases from boats speaks to a genuine danger on the marine environment. The effect of the spills relies on the sort and measure of oil, area, season, sea profundity, and meteorological and maritime conditions. Spaceborne remote detecting sensors can recognize spills before they cause broad harm. If there should be an occurrence of bigger mishaps, remote detecting symbolism gives simple reviews of the degree of the oil slicks. A mix of airborne and satellite-based remote detecting is at present utilized for operational oil slick checking around the world. Spaceborne SAR gives a diagram of substantial sea regions, and reconnaissance flying machine can be coordinated to check conceivable oil slick areas to confirm the spill and catch the polluter. Oil slick identification is most adequately performed on a substantial scale utilizing SAR pictures because of its every single climate capability [73] (given wind speeds in the reach 2–14 m/s) and great scope. The SAR scope relies on upon scope and is great in northern districts, where the climate conditions seriously restrain the functional utilization of optical sensors.

The most genuine downside with oil slick observing taking into account SAR pictures is that occasionally in low-wind conditions oil slicks cannot be dependably isolated from clones. In the course of the most recent years, a few new remote-detecting satellites with great oil slick location capacities have been propelled. Notwithstanding giving better scope as the quantity of operational satellite sensors expands, late research demonstrates that they additionally can give better separation between oil slicks and biogenic movies or carbon copies. Lately, various polarimetric measures valuable for oil slick discovery have been proposed. These incorporate both quad-pol elements such as polarimetric entropy and anisotropy, mean diffusing edge, polarimetric compass, congruity coefficient, and also the double pol components, for example, standard deviation of the co-energized stage distinction and the co-captivated relationship coefficient. By utilizing, the polarimetric SAR as accessible on RADARSAT-2 and TerraSAR-X, it appears that oil slicks can be recognized from biogenic movies. Optical sensors with great scope, as ENVISAT MERIS and Terra/Aqua MODIS, can give a decent supplement at geological areas where the likelihood of a without cloud scene with sunglint conditions is genuinely high.

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