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Development of Crude Oil Spill Imaging Database for Effective Quick Spill Detection and Remediation Procedures

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Abstract

Crude oil spills need to be detected as quickly as possible in order to prevent damage to the environment, aquatic and land animals, humans and financial losses. Visible sensors which are passive sensors operating in the visible region of the light, are still widely used in oil spill remote sensing despite many shortcomings, including the fact that there are no established methods to ensure the positive detection of an oil spill in visible sensor images. There is a need for a publicly available database of ground truth crude oil spill visible images for researchers to develop effective automated spill detection algorithms for images in the visible spectrum. This paper presents the design and development of the first Crude Oil Spill Imaging Database available to the Oil and Gas Industry to assist in equipping and training them in swift and automated crude oil spill detection, estimation, classification, and recommendation of the appropriate clean-up and remediation procedure for each type of spill encountered, ensuring full remediation of our environment and protecting our health. The database currently contains 104 images of simulated ground truth visible crude oil spill images. Future work includes increasing the number of visible crude oil spill images to 500, and the inclusion of spill images taken with infrared sensors, optical, laser fluourosensors, synthetic aperture radar (SAR) sensors and thermal-infrared sensors.

Keywords: Crude oil spill, imaging and detection, estimation, classification, remediation

1. Introduction

Crude oil spills have significant negative effects on the health, economy, environment, and society in which they occur and this has been documented extensively (Chang, et at., 2014a,b,c; Ahmed and Egbodion, 2013; Iwejingi, 2013; Adelana et al., 2011; Osuagwu and Olaifa, 2018; Frank and Biosa, 2018; Agunobi, et al., 2014; Laffon et al., 2016; Oshienemen, 2018; Kadafa, 2012; Zabbey, et al., 2013; Fentiman and Zabbey, 2015; Enegide and Chukwuma, 2019; Bruederle and Holder, 2019; Oyebamiji and Mba, 2013; Okunrobo, 2014; Mogborukor, 2014; Isaac, 2013; Osuagwu, 2014). Several methods have been employed for spill detection, including real-time remote surveillance by flying aircrafts with surveillance teams. Other methods employ various sensors such as visible sensors, infrared sensors, ultraviolet sensors, radar sensors, and laser fluorosensors. Visible sensors (passive sensors operating in the visible region of the light) are still widely used in oil spill remote sensing despite many shortcomings, including the fact that there are no established methods to ensure the positive detection of an oil spill in visible sensor images. Visible sensors are widely available and can be easily mounted on aircraft. Video cameras possess a lower resolution than still cameras but are still in widespread use for oil spill remote sensing (Maya et al., 2008), as they are less costly and easy to use. The visible light spectrum still remains a research area as it is an economical method for monitoring oil spills, particularly on countermeasures support operations (Fingas and Brown, 2019).

Nigeria's leading energy giant, The Shell Petroleum Development Company of Nigeria Limited (SPDC), has deployed state-of-the-art high definition cameras for quick detection of and response to crude oil spills from its facilities (SPDC, 2018). SPDC Nigeria regularly captures visible light images of all land crude oil spills detected by the company and utilizes this in data gathering for spill response, clean-up and remediation measures (SPDC, n.d). Automated oil spill surveillance systems, such as the Ground Robotic Oil Spill Surveillance (GROSS) system (Ejofodomi and Ofualagba, 2017; Ejofodomi and Ofualagba, 2020) and, the Aerial Spill Surveillance System (Ejofodomi and Ofualagba, 2017), and the Underwater Oil Spill Surveillance (UROSS) System (O. Ejofodomi and G. Ofualagba, 2018) and employ the use of visible light sensors when reporting the parameters of a detected crude oil spill (Ejofodomi and Ofualagba, 2019).

While video cameras are being used extensively in the oil industry for spill detection, little research has been done in image analysis to detect and characterize crude oil spills in visible light images (Ejofodomi and Ofualagba, 2017). In order to facilitate the positive detection and characterization of crude oil spills in the images acquired by video cameras, a publicly available database of ground truth oil spill images needs to be made available for researchers to develop effective crude oil spill detection algorithms for visible light images. To date, there is no database of crude oil spill imaging devoted and dedicated to equipping its users understand and master the art and essential technique of crude oil spill detection from video camera images using remote sensing devices and equipment. This paper presents the development of the first Crude Oil Spill Imaging Database for the Oil and Gas Industry. The initial design of the Database contains 104 crude oil spill images using state-of-the-art-cameras but will be increased to 500 crude spills in future. For each ground truth crude oil spill image in the database, the following factors were varied: time of day of image capture, presence/absence of crude oil pipeline in image, volume of crude oil present, exposed surface area of the oil spill, shape of the crude oil spill, and image content. This was done to give spill detection algorithm developers full assortments of images to enable them develop and test algorithms capable of positive spill detection, estimation, and classification.

Automated Detection of crude oil spill in visible sensor images is a novel research area yet to be developed. The few algorithms that have been developed in this area relied on crude oil spill images obtained by Shell Petroleum Development Company (SPDC, n.d, Ejofodomi and Ofualagba, 2017, Ofualagba and Onyishi, 2020). However, the authors were unable to properly assess the efficiency of their algorithm as the volume of the crude oil spill in each image used was unknown. As such, spill estimation, classification, and remediation recommendations could not be derived from these images. While the spill images from SPDC are publicly available, the intended use was not for spill detection. As a result, these images lack the required parameters needed for effective algorithm development (including spill volume, spill surface area, spill shape, and image resolution).

It is therefore necessary that a publicly available database of visible crude oil spill images with the required parameters mentioned above be provided for analysts and researchers to develop and test effective algorithms for spill detection, estimation, classification, and remediation. If researchers have access to the same set of characterized crude oil spill images, then the algorithms they develop can be easily and rigorously compared, tested, and refined until automated detection of crude oil spills in visible light images is effectively accomplished.

2. 90Materials and Methods

Samples of crude oil obtained from verified legal sources are utilized to simulate oil spills at the Federal University of Petroleum Resources (FUPRE). The crude oil was poured over disposable transparent polythene bags spread over the desired ground surface area. A sample of a 0.0 litre simulated crude oil spill is shown in Figure 1. The polythene bags used for the database images are transparent to ensure minimal effect on the detection algorithms to be developed using these images. Because the crude oil was spread on the polythene bags, it was easy to collect the crude oil after obtaining high resolution camera, without incurring any environmental pollution in the test area.

The volume of crude oil spread over the polythene bag, the shape, as well as the surface area of the simulated spill, was measured and controlled and has been made available for each image to be used in developing rigorous algorithms for spill detection.

Figure 1: Simulated Crude Oil Spill – Volume: 1 litre, shape: circular

Selected volumes in litres for the spill images in the database are approximately 0.01 , 0.1, 0.2 , 0.4, 0.5, 1, 2, 3, 10 , 20, 50, and 100 The selected surface areas in cm^2 of the crude oil spills are 40, 100, 500, 1,000, 3,000, 5,000, 10,000 and 20,000 respectively. However, the actual surface area for each captured spill image is provided for each image in the database. The volume of the crude oil spill may be an important aspect in judging the effectiveness of a spill detection algorithm. The area of the crude oil spill exposed to the surface may also have an impact on spill detection, estimation and classification. The shape of the simulated oil spills were designed to be approximately circular, rectangular, star-shaped, or irregular.

The time of image capture was varied from day to night for algorithm developers to fully explore the effect of sun glitter on their spill detection algorithms (Maya et al., 2008). The content of the crude oil image was also varied to contain one or more of the following: land, vegetation or sky. Samples of documented crude oil images with varied image content are shown in Figure 2. The contents of the crude oil spill image often determine the complexity of the spill detection algorithm necessary to extract the crude oil spill from the image, estimate, and classify it. Some spill images contain the crude oil pipeline from which the crude oil spill emanated or erupted (see Figure 2f), while others simply contain the crude oil spill without the pipeline. The effect of the presence of a crude oil pipeline on spill detection, estimation, and classification depends on the dexterity and efficiency of the algorithm and can be easily explored using the images provided in the database.

(a) (b) (c)

(d) **(e)** **(f)**

Figure 2. Crude Oil Spill Images with Varied Content [25] (a) Spill with Land. (b) Spill Image with Vegetation. (c) Spill Image with Land and Vegetation. (d) Spill Image with Sky and Land. (e) Spill Image with Sky, Vegetation, and Land. (f) Spill Image with Crude oil pipeline.

3. Results and Discussion

3.1 Results Presentation

The schematic diagram of the Crude Oil Imaging Database is shown in Figure 3. An image was classified as a day image if its time of capture fell between 6:00 a.m. and 6:00 p.m. An image was classified as a night time image if its time of capture fell between 6:00 p.m. and 6:00 a.m. Each Day or Night image was further characterized by five defining features: They are shown in table 1. Some images of the ground truth visible crude oil images currently in the Database are shown in Figure 4.

Table 1: Five defining features used to characterize day or night image

Image Content	Volume in Litres	Surface Area in cm^2	Shape	Pipeline
Land	0.01	40	Circular	Absent
Vegetation	0.1	100	Rectangular	Present
Land and Vegetation	0.2	500	Star	
Sky and Land	0.4	1,000	Irregular	
Sky, Vegetation and Land	0.5	3,000		
	1	5,000		
	2	10,000		
	3			
	10			
	20			
	50			
	100			

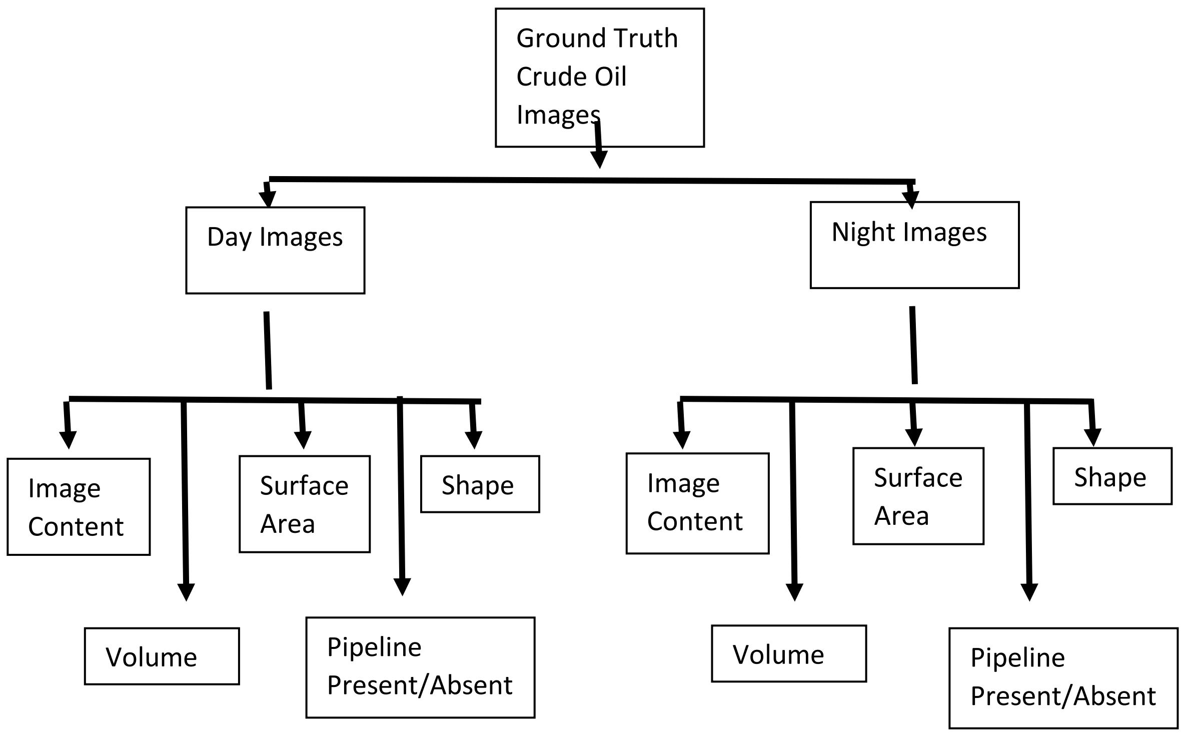

Figure 3: Schematic Layout for the Crude Oil Spill Imaging Database

Table 2: Quantitative Breakdown of Image Data in the Crude Oil Imaging Database based on Image Feature Characteristics.

		No. of Images
Day Images		400
Night Images		100
	TOTAL	**500**
Image Content:	Land	100
	Vegetation	50
	Land and Vegetation	100
	Sky and Land	50
	Sky, Vegetation and Land	200
	TOTAL	**500**
Volume (litres)	0.01	21
	0.1	3
	0.2	3
	0.4	3
	0.5	16

	1	25
	2	16
	3	17
	10	100
	20	100
	50	100
	100	96
	TOTAL	**500**
Surface Area (cm^2)	40	30
	100	20
	500	20
	1,000	50
	3,000	80
	5,000	100
	10,000	200
	TOTAL	**500**
Shape	Circular	200
	Rectangular	60
	Star	40
	Irregular	200
	TOTAL	**500**
Pipeline	Present	150
	Absent	350
	TOTAL	**500**

(a) (b) (c)

(d) (e) (f)

(g) (h)

Figure 4: Ground Truth Crude Oil Visible Images from the Crude Oil Spill Imaging Database. (a) Image_0102: Day Image, Volume: 0.5 L, Surface Area: 43 cm x 37 cm (b) Image_0021: Day Image, Volume: 1 L, Surface Area: 40 x 32 cm (c) Image_0012: Day Image, Volume: 1 L, Surface Area: 49 x 48 cm (d) Image_0029: Day Image, Volume: 0.5 L, Surface Area: 22 x 22 cm (e)Image_0088: Day Image, Volume: 1 L, Surface Area: 23 cm x 27 cm (f) Image_0083: Day Image, Volume: 2 L, Surface Area: 31 cm x 38 cm (g) Image_0078: Day Image, Volume: 3 L, Shape: Circular, Diameter: 55 cm (h) Image_0063: Day Image, Volume: 3 L, Surface Area: 49 cm x 35 cm (i) Image_0039: Day Image, Volume: 0.01 L, Surface Area: 6 cm x 6 cm

3.2 Discussion of Findings

The Crude Oil Imaging Database design contains 350 images taken during daylight hours (6:00 a.m. – 6:00 p.m.) and 150 images taken during night-time hours (6:00 p.m. – 6:00 a.m.). This is necessary in studying the difficulty in detecting crude oil spills in dark times, as some spills do occur during night-time. Delay in detecting such spills until daylight results in larger environmental damage and financial losses associated with crude oil spills. The surface area, shapes, and volumes of the crude oil spills are varied (see Table 2), and are physically designed and constructed by the authors. There are no established methods to ensure the positive detection of an oil spill in visible sensor images (N.J. Maya, L. Jason and G. Yang, 2008), and so far, very little research has been done in image analysis to detect and characterize crude oil spills in visible light images (Ejofodomi and Ofualagba, 2017). Research conducted in this field has indicated that image content (land, vegetation, sky, and water) has a great effect on an algorithm's ability to detect crude oil (Ejofodomi and Ofualagba, 2017). Presence of the crude oil pipeline in the image also needs to be taken into consideration in detection algorithms so it does not affect the crude oil spill detection. Vegetation typically reduces the estimated size of the detected crude oil spill, because the inhomogeneity introduced by the vegetation affects detection (Ejofodomi and Ofualagba, 2017). The size of the surface area of the crude oil spill exposed to the surface has an important role in the efficiency of the spill detection algorithm. Prior research show that if the surface area is too small, spills go undetected and this is unacceptable. The volume of the crude oil spilled certainly affects crude oil spill detection algorithms. The larger the volume, the higher the possibility of detection of the oil spill. However, we want to detect spills as soon as they commence to prevent and limit environmental pollution. This is why images containing crude oil spills as small as 0.01 L are included in the Crude Oil Spill Imaging Database for image analysts to be able to develop crude oil spill detection algorithms capable of identifying spills with volumes as small as 0.01 L.

Currently, the Crude Oil Spill Imaging Database contains 104 Day Images and these images are already publicly available to researchers for crude oil spill algorithm development and refinement (www.cosid.com.ng, 2020). Of the 104 ground truth spill images already publicly available, 21 images have a spill volume of 0.01 L, 3 images have a spill volume of 0.1 L, 3 images have a spill volume of 0.2 L, 3 images have a spill volume of 0.4 L, 16 images have a spill volume of 0.5 L, 25 images have a spill volume of 1 L, 16 images have a spill volume of 2 L, and 17 images have a spill volume of 17 L. The spill shapes currently available are irregular and circular (www.cosid.com.ng, 2020). The surface area for the ground truth oil spill images currently ranges from 36 cm^2 to 9,503 cm^2, and the ground truth location of the spill within each image is made available in the database for effective algorithm evaluation.

Efficient spill detection devices such as GROSS, AROSS, and UROSS are able to detect 1 L volume spills (Ejofodomi and Ofualagba, 2016; Ejofodomi and Ofualagba, 2017; Ejofodomi and Ofualagba, 2018; Ejofodomi and Ofualagba, 2019; Ejofodomi and Ofualagba, 2020), but other devices may not be as efficient and the spill volume may exceed 50 L or 100 L before the spill is detected. The Oil and Gas Industry requires spill detection devices with as little spill volume detection threshold as possible. The database provides a wide range of spill volumes to assist and aid in the development of different spill detection devices. Automated spill detection algorithms for these devices can be improved by developing and refining them on ground truth images in which the actual spill volume is well known and documented, such as those contained with the Crude Oil Spill Imaging Database (www.cosid.com.ng, 2020). Once a spill is accurately assessed, prime recovery of the environment can be achieved if the appropriate remediation process and clean-up procedure is taken. The Crude Oil Spill Imaging Database is currently publicly available to researchers and image analysts at www.cosid.com.ng.

The focus of the database is to ensure that users are equipped to detect crude oil spills within minutes of onset, regardless of time of occurrence, automatically estimate and classify spills and state the appropriate clean-up and remediation procedure for that particular crude oil spill. Subsequent work involves increasing the number of publicly available ground truth crude oil spill images in the database from 104 images to 500 images. The ground truth oil spill images in the database are crude oil spills from land crude oil pipelines. As these images are simulated, they do not affect the environment negatively, the actual location, total volume and extent of the spill is known and can be used in developing rigorous algorithms for earliest and highly effective crude oil spill detection by all remote sensing devices and equipment (preferably automated). There will be simulated crude oil spills from subsea crude oil pipelines added subsequently. Future improvements to the database will include the addition of more images of laser fluourosensors spill images, infrared spill images, thermal infrared spill images, and SAR spill images.

Conclusion

Crude oil spills need to be detected as quickly as possible in order to prevent damage to the environment, aquatic and land animals, humans and financial losses. Visible sensors are widely used, although there are no established methods to ensure the positive detection of an oil spill in visible sensor images. This paper presents the design and development of a Crude Oil Imaging Database containing 500 ground truth oil spill images with the following factors varied: time of day of image capture, presence/absence of crude oil pipeline in image, volume of crude oil present, exposed surface area of the oil spill, shape of the crude oil spill, and image content. The Crude Oil Spill Imaging Database currently contains 104 ground truth crude oil spill images and is publicly available at www.cosid.com.ng to the Oil and Gas Industry to assist in equipping and training in swift and automated crude oil spill detection, estimation, classification, and recommendation of the appropriate clean-up and remediation procedure for each type of spill encountered, ensuring full remediation of our environment and protecting our health.

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