

OIL SPILLS DETECTION BY MEANS OF UAS AND LOW-COST AIRBORNE THERMAL SENSORS

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ABSTRACT

This paper provides an overview of oil spill scenarios and the remote sensing methods used for detection and mapping the spills. It also discusses the different kinds of thermal sensors used in oil spills detection. As UAS is becoming an important player in the oil and gas industry for the low operating costs involved, this research involved working with a cheap thermal airborne sensor mounted on DJI Phantom 4 system. Data were collected in two scenarios, first scenario is collecting data in Michigan's Upper Peninsula at a petroleum company location and the second scenario was an indoor experiment simulating an offshore spill. The aim of this research is to inspect the capability of Lepton LWIR inexpensive sensor to detect the areas contaminated with oil. Data processing to create classification maps involved using ArcGIS 10.5.1, ERDAS Imagine 2015 and ENVI 5.3. Depending accuracy assessment (confusion matrices) for the classified images and comparing classified images with ground truth, results shows the Lepton thermal sensor worked well in differentiating oil from water and was not a good option when there are many objects in the area of interest. Future research recommendations and conclusions are presented.

1. INTRODUCTION

Oil spills are a major factor that affects the environment in the first place as well as its contribution to huge economic losses especially for countries who are completely depending on oil products as one of their main resources because a major oil spill could be a major loss and a big hit to the economy. Oil spills could occur in any step during oil wells drilling, treatment facilities, export pipelines and shipping. Remote sensing plays a major role in the monitoring of spills and slicks. There are different sensors that work for oil spill detection and surveillances depending on the spill conditions (onshore, offshore). Remote sensing oil detection and mapping contributes to supporting decisions for emergency response preparedness and disaster management as well as directing cleanups crews. It is vital to know where the spills and areas it covers are and knowing where are the thick layers of oil to have plans of controlling the rapid spread of oil and their directions especially in offshore scenarios. The spread of oil on land is affected by the type of soil and its moisture content as well as the type of oil (Fingas, 2005). A special case is the offshore spills because there are different factors affecting the spread of oil such as winds, tides that could make the spill spread very quickly. Knowing that it's a case by case to use remote sensing sensors depending on the conditions involved and the availability of data, Satellite imagery is not always available all the time due to its revisit times and other factors like cloud effects for example plus high-resolution satellite imagery is expensive to purchase frequently. The imagery available free of cost is of medium-low spatial resolution and it's important to mention that the unavailability of high resolution TIR and SWIR for optical imaging (Partington, 2014). Medium-low resolution imageries are good for monitoring vegetation uses for instance, however is not the best option for emergency response and disaster management purposes especially the critical impact of oil to the environment and coastal communities like anglers or touristic places. Sometimes a critical project requires an immediate response and for this, different techniques could be used to enhance the available resources, which could maximize the uses of the

available data. Unmanned aerial systems (UAS) are being widely used nowadays in oil & gas related projects for the flexibility it^{*} has to fly and having its data very quickly and process it even in the field instantly, which saves loads of money especially for routine inspection purposes and this also minimizes the danger exposure and human risks involved. UAS could have different types of sensors attached to it. The selection of sensors depends on different factors such as working during the day or night times, the weather conditions and clouds, amount of discharged oil and its relative thickness on ground for oil spills studies.

2. REMOTE SENSING METHODS FOR DETECTING OIL SPILLS AND DISASTER MANAGEMENT

Today's technology for oil spill detection using remote sensing gives much information about the location and spread behavior of oil spills and the environmental impacts associated with the spills. (Fingas, 2000) says there are many sensors that are useful for oil detection and mapping. It is not practical to use a single sensor and gain all the information required (Brown, Fingas, 2001). In the same time, there is a broad range of applications and software packages that works with data acquired from the different sensors to process and create output maps that are crucial to the disaster management and planning teams, decision makers.

Remote sensing data for oil detection and mapping come from satellite, airborne and UAS based sensors. The integration and processing of remote sensing data from different data sources in GIS creates strong tools that is very useful for decision makers. Environmental sensitivity index (ESI) or sensitive environmental mapping for instance is a GIS tool that is developed by National Oceanic and Atmospheric Administration (NOAA) and it gives free access to the U.S. shoreline data of sensitive areas to offshore oil spills like animal habitats, marshlands, beaches and parks.

Available satellite systems provide a coverage in wide range of the electromagnetic spectrum wavelengths. Another advantage of some satellite sensor platforms is their abilities of not being affected by the weather or clouds (Partington, 2014) such as

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thermal and radar sensors for instance. It is important to mention that not all the bands are useful for specifically oil detection and mapping. Even the ones that are useful, they cannot be useful at all-times because weather changes affects the suitability of some sensors if it is raining or even if it is foggy like visible, UV and infrared bands (Goodman, 1994), or the site or oil spill conditions.

Satellites sensors are being used effectively for monitoring and oil spills and their movement directions as well as the discharged oil quantities making use of satellites consistent revisit times that gives a good data availability especially if using more than one satellite platform. The atmosphere plays a major role in energy losses and influencing the spectral response patterns. These energy losses significantly differs from satellite sensors to UAS sensors. Satellite sensors are basically observing the sunlight reflectance from objects on earth's surface after the sun light makes its way through the earth's atmosphere twice (in and out). In UAS the paths travel distances are considered much shorter compared to satellites hence, UAS has a very less amount of the atmospheric scattering if comparing the signal travel path distances. In general the atmosphere affects radiance or brightness values for any given point to some extent, this also means a thermal sensor is less affected by signal scattering because it is basically recording the objects emitted energy which means there is only one travel path (Lillesand, et. al, 2014).

The deployment of airborne systems is becoming a vital technique for oil spills area identification especially for offshore operations because of its remoteness. Satellite sensors provides a good constant coverage but unfortunately, the availability of data sometimes is restricted to many factors. The major factors are: temporal resolution, weather conditions or cannot provide enough details for the calculations of oil film thickness because of the very few satellites sensors that relate to oil film thicknesses. In addition, satellites are not able to provide enough early high spatial resolution information for polluters' investigation (in offshore cases if multiple oilrigs platforms are working within the same area).

UASs are able to fly with low altitudes below clouds, which minimizes the cloud effects in imaging. If compared to manned aircrafts, this helps in providing better resolution imaging besides the cost involved in a UAS project to collect data is 1/3 of the cost if manned aircraft is being operated (Lomax, 2005).

Advanced sensors are used very often to extract useful information about oil spills film thicknesses and characterization such as laser fluorescence sensor for instance (Zielinski, 2006). The film thickness details is still a matter in research but it's very important and necessary to detect where are the thicker oil patches (Fingas, 2016). Basic sensors the most used sensors on airborne systems such as side looking radar, visible and IR/UV sensors. For offshore disaster management purposes and to identify who is the polluter there is a very recent thermal imaging technique is now being used by introducing an image intensifier equipment which could detect the labels or names of vessels or platforms even without the need to the day light which maximized the use of thermal sensors and imaging (Zielinski, 2006). UAS is now being deployed in different sectors starting with disasters, environmental management applications, law enforcement and engineering applications. UAS is currently a great addition to shoreline surveys, onshore engineering and is still limited for remote areas (Allen, Walsh, 2008). The capability of having multiple sensors mounted to UAS is what makes it a very effective tool to the oil industry nowadays.

3. OVERVIEW OF SENSORS USED FOR OIL SPILLS AND SLICKS DETECTION

3.1 Radar Sensors

Radar sensors are active sensors that transmit its own energy in the microwave region, as a coherent radiation, of the electromagnetic spectrum (Partington, 2014). These sensors are effective for oil water discrimination in offshore operations of oil slicks detection. The ocean's capillary waves reflects the radar signals, therefore, radar images of the offshore spills shows oil patches as a dark figure and the water is shown as a bright figure (Brown, Hawkins, 2003). Radar sensors cover from millimeter to decimeter range of wavelengths where the measured radiation is mostly sensitive to surface roughness. Radar systems are very useful in all weather conditions and in day or night operations but satellite radar sensors has a small swath width and they are expensive adding to it that the revisit frequency is low. Radar data interpretation is very complicated due to its surface conditions sensitivity (Partington, 2014). For offshore oil spill detection, the most common sensors are the synthetic aperture radar (SAR) as well as the side looking airborne radar (SLAR). SAR has a higher range and spatial resolution if compared to SLAR (Fingas, Brown, 1997). In the same time, SLAR is commonly used because it is less expensive than SAR systems. A major problem using radar sensor is the false detection. Wind speed has an influence on oil spill detection (Brown, Hawkins, 2003) as oil cannot be detected while high wind speeds because it will be dispersed in the water and if winds speed is low, thick and thin oil slick will not be distinguished. some films on sea surfaces produced by organic substances such as seaweeds may also results in a false detection of oil using radar data (Jones, 2001).

3.2 Laser Sensors

There are more than one kind of laser sensors used in oil detection. Laser sensors are transmitting and receiving light echoes and though they are considered active optical sensors. Laser sensors could be used in day or night operations. Laser sensors are expensive and its signals are affected by atmospheric attenuation in certain conditions like if it is a cloudy or foggy weather (Partington, 2014). Laser sensors could be used for offshore and onshore oil spills and slicks detection. So far laser sensors are considered very effective in oil detection and classification because of its ability to detect it on any surface such as in ice conditions, water, soil or even on weeds (Jha, 2009). LiDAR is a function of laser sensors in which a distance to targets can be measured according to the signal travel time and it can also provide surface elevations (Partington, 2014). Laser acoustic sensor is a specific laser sensor that is used to detect oil spills and also measure the thickness of oil layers by calculating the travel time of the ultrasonic waves in oil (Jha et al. 2008). The laser acoustic sensor detects oil depending on its mechanical properties and not according to the electromagnetic properties (Jha et al., 2008).

3.3 Ultraviolet sensors

Comparing oil to water reflectivity in the ultraviolet region of electromagnetic spectrum, even a very thin layer of oil would reflect much stronger than water knowing that the ultraviolet sensors are passive sensors and capable of detecting a thin oil sheen of 0.1 micron thickness but not more than 10 micron.

The downsides UV sensors are firstly it cannot be operated during night times because it depends on sunlight reflection and secondly many factors affect the detection using UV sensors for

example in offshore operations, wind and sun glint even sea weeds forces UV sensor to give false detection (Jha, 2009).

3.4 Visible Sensors

Since 1970, the most common sensors used in airborne remote sensing were the visible and thermal scanning systems along with aerial photography (Wadsworth, et. al 1992). Visible sensors are passive sensors and colors are used to detect oil spills and its characteristics (Partington, 2014). Visible sensors are useful in showing oil in onshore and offshore locations but still gives wrong interpretations sometimes due to the surrounding colors, for instance in offshore locations sun glint and surface currents changes due to high winds gusts may give water a shining effect or sometimes dark shorelines could be misinterpreted as oil. Also the difference in thicknesses of oil spills offshore is misleading as it is hard to visually detect thin oil sheens. Oblique angles imaging also makes it difficult to detect oil spills offshore with visible sensors (Fingas, 2000). Fingas has also explained the appearance of oil on calm water surfaces according to film thicknesses in the Table 1.

Oil Appearance	Approximate Film Thickness
Dark brown-Black	50.00 μm
Oil colors dark	10.00 μm
Brown color	2.00 μm
Red-Brown sheen	0.50 μm
Rainbow sheen	0.15 μm
Silvery Sheen	0.05 μm

Table 1. Visible oil appearance on a calm water surface (Fingas, 2000)

Although visible sensors are not an option for night operations because it basically measures sunlight reflectance from objects on earth, its broadly used in basic assessments and also creating initial standardized reporting for being inexpensive and easy to use and mount on aircrafts. American society of test materials (ASTM), 1996 and Bonn Agreement, 2004 has put together the standards for the visual appearance of oil spills on water and their relative thicknesses shown in Table 2.

The difference between the thickness measurement between ASTM standard and the Bonn agreement standard is because both didn't consider the petrol types sand relevant slick appearance and not even the solar angles (Lehr, 2010). A lot of development on sensors occurred during the past few decades and because of the continuous developments on optical sensors is hyperspectral sensors. Hyperspectral sensor have a high spectral and spatial resolution and these sensors are able to hold hundreds of spectral bands and is being used in oil spills detection and mapping as they can deliver a spectral signature and a lot of spectral information that could be used to differentiate objects (Jha, 2009).

Code	Description/appearance	Bonn, layer thickness (μm)	ASTM, layer thickness (μm)	Bonn, liters per km ²
1	Sheen (silvery/gray)	0.04 to 0.30	0.1–0.3	40 to 300
2	Rainbow	0.30 to 5.0	0.3–0.5	300 to 5000
3	Metallic	5.0 to 50	~ 3	5000 to 50,000
4	Discontinuous true oil color	50 to 200	> 50	50,000 to 200,000
5	Continuous true oil color	200 to > 200		200,000 to > 200,000

Table 2. Visible Oil Appearance, Thickness Adopted from (Bonn, 2016; Leifer et al., 2012)

3.5 Passive Microwave Sensors

These sensors works according to the emissivity of the objects (radiation). Passive microwave sensors work in the microwave region of the electromagnetic spectrum and this sensor works according to the same concepts of the thermal IR sensors but weather has very less effects on its data (Partington, 2014) as compared to thermal IR data. The passive microwave sensors are of high cost and its spatial resolution is not high but it could be used in day or night operations. These sensors are not able to provide thickness details of oil slicks offshore but they can only provide relative thickness measurement if they were calibrated (Fingas, 2000).

3.6 Infrared sensors (IR)

Infrared sensors covers the region of spectrum which is right after the visible sensing region (it covers what a human eye cannot detect) and they are passive sensors (Partington, 2014). Partington mentioned in his report the IR absorption frequencies that works in oil detection and defined them as "1.19, 1.21, 1.72, 1.73, 1.75, 1.76, 2.37, 3.3 μm " and he also mentioned that short wave IR is useful because it can penetrate through fog, thin cloud and haze.

IR sensors can detect only thick oil slicks offshore greater than 100 μm , therefore, its imaging is enhanced by fusing UV images and creating an overlay map and as a result of this, IR sensors are enhanced to detect the thinner slicks (Fingas, 2000). IR sensors are commonly used by the cleanup vessels where they usually affix the sensor on top of the ship mast and the oblique image of the IR sensor is good enough to direct the crew on where to steer for a short range and locating the thick portions (Fingas, 2000).

3.7 Thermal Infrared sensors (TIR)

Thermal IR sensors or sometimes called forward-looking IR sensors (FLIR) are passive sensors that work with emissivity and temperatures of objects. Emissivity is the ratio of radiation of an object to the radiation of a black body at the same temperature (Lillesand et al., 2014). Thermal sensors could be used in day or night times which makes it considered one of the best options for critical oil detection and disaster management projects. In an offshore scenario, the oil behavior at night is different from the daytime, oil absorbs the sun energy during the day more than water thus it looks as a hotter area if using thermal sensors but during the nighttime oil tends to show a cooler behavior than the water. Thermal IR covers the region 8-14 μm on the electromagnetic spectrum. Thermal IR sensors data is also able to indicate the oil layer thickness to some extent in offshore operations but not emulsions of oil in water because these emulsions water content in these is approximately 70% which

makes it respond to thermal sensors the same as the response of the background water (Fingas, Brown, 1997).

4. CONSIDERATIONS FOR USING THERMAL IR SENSING OF OIL SPILLS AND SLICKS

Oil spills occurs without a prior notice. It might be a desert or a jungle or even an underwater export pipeline break, export trucks or ships leaks, onshore or offshore treatment or central processing facility, well blowout (onshore or offshore). Each of the previously mentioned scenarios involves different techniques to discriminate oil from the other medians, which helps supporting the environmental protection teams and assisting decision makers to plan the cleanup processes and estimating losses and costs involved.

Oil spill detection using thermal IR sensors on different platforms (satellites, airborne and UAS) has shown a better result in offshore scenarios because of having only two medians especially in remote deep waters because sometimes near shores or shallow waters, algae blooms or seaweeds for example, affects the thermal sensors response and gives a false oil detection.

Onshore cases are more complex to use thermal IR sensors because of having multiple medians in the same area of a spillage (Road blacktop, Storage Tanks, Vegetation etc.). Each of these medians responds in its own way that is different from the oil spill depending on their physical properties, which relates to their solar radiation response of thermal sensors and this gives misleading false results especially at times when other medians are having the same temperatures as the oil is emitting.

The radiant emitted energy from objects on earth is what thermal sensors or scanners duty to detect. As previously mentioned, there are different platforms for thermal IR sensors like satellites, airborne (manned or unmanned). Some satellite platforms offer thermal IR bands that works with different parts of the electromagnetic spectrum but focuses on the region 8-14 μm because object's peak emission occurs at 9.7 μm for objects of 80° F- 27°C- 300K based on Wien's Law. Other sensors are covering the region 3-5 μm . It is important to mention that not all satellites are having a thermal sensor. Some satellites are operating for educational and research purposes and these sensors mostly gives users an open access free of cost, there are other satellites that are operating for commercial uses that provides a high end data and resolution.

5. RESEARCHES

5.1 Study Area and Experiments Details

Due to the strict environmental legislations and the quick control for oil spills in the U.S, it is very unlikely to find a random oil spill and that made it difficult to find a study area.

In order to get the study done, two approaches were taken to collect data to represent oil contaminations in different medians. For the onshore case study, The Keweenaw Petroleum Services Company (KPSC) has a location in Houghton, Michigan in which they load and unload oil tankers to serve the community in Houghton and Hancock areas.

After getting the permission from local Police department and the KPSC site manager, a Phantom DJI 4 drone system was flown to observe the very little contaminated soils, concrete floorings in the company location to study the capability of the "Lepton long wave thermal IR Sensor".

The other case study was the oil spills in waters. The experiment was done using a moderate size bucket (Figure 1) of water and manually contaminate it with used engine oil (not crude oil).

The field work at the KPSC was done when the temperature was 16 °C and the contaminated water experiment was done in a

room temperature condition 20.6° C. To have a simulation similar to real world conditions, the water bucket was exposed to an indirect heating source using two light bulbs each of 1500 Lumen for three hours and temperatures were checked after and before the heating process using a thermometer.



Figure 1. Oil water contamination experiment

The three hours heating shows a difference in water temperature of 1.8° C, as the temperature measurements were: before heating - 17.4° C; after heating - 19.2° C. In the same time temperatures were measured for the oil layer floating on a controlled area using a smaller plastic container that also had water inside it to treat the oil contamination similar to if it was floating on any part of the bigger water bucket. Oil temperature difference showed a 4.2° C. Oil temperatures were 18.8° C before heating and 23° C after the heating. This experiment showed technically how oil absorbs more thermal energy than background water if exposed to the same source and same amount of time.

5.2 Equipment Used for The Data Collection

5.2.1 Raspberry Pi, Thermal IR Sensor: Lepton® longwave infrared was the thermal sensor used in both experiments. The Lepton sensor is considered as the world's tiniest thermal camera and its capable of providing an array format of 80 X 60 progressive scan (horizontal and vertical respectively). Lepton thermal camera works in the range of -40 to +80 °C. its weight is around 0.55 grams and the pixel size is 17 μm .

The Raspberry Pi system has also a Pi NoIR camera (Karlsson Robotics, 2017) that cost around 20-30\$. Pi NoIR camera is manufactured by the Raspberry Pi foundation and its useful to collect data in the infra-red wavelength.

The cost of the Lepton LWIR sensor is currently around 260\$ and it requires some software and hardware installations and development to be able to collect data on flight. The Raspberry Pi single board computer works on a Linux platform and it was programmed to integrate the Lepton LWIR sensor and collect thermal data every 10 seconds and it also had the visible sensor integrated into the system but it was not of a good use because of the low resolution. The whole system was set in Nwazet Pi camera box that is just a little bigger than a pack of cigarettes to easily mount it on a UAS. The system required an external power inlet and for this case a mini power bank was very useful to power the system. The data was logged to an SD card fixed in the Raspberry Pi system and it could be accessed and copied to a thumb or hard drives after operating the Linux system and accessing the files. The fisheye effect in the Pi NoIR camera due to the low focal length (3.6 mm) makes it not necessary as long as a high quality visible camera is onboard the UAS. The other problem with the Pi NoIR camera is there is no shutter which

contributes to giving distorted images when the camera in movement (Aden et al., 2014).

5.2.2 DJI Phantom 4 Unmanned Aerial System: UAS used in the field experiment data collection was the DJI Phantom 4. It was flown on an altitude of 75 m above ground level (FAA regulation is 500 feet, 152.4 m) to cover the area of interest with the 12 MP camera sensor mounted on the UAS.

Attaching the Raspberry Pi box was tricky because attaching it on one side of the UAS and flying it caused some instability to the drone and it was moving towards the heavier side where the sensor was attached and it was very hard to control the drone to hover over a certain location or even landing it. To avoid this, the Raspberry Pi box needed to be in the center. A mesh wire was used to be the top of the box that has the power bank and the Raspberry Pi system for not interrupting the drone aerodynamics. Another challenge in mounting the sensor this way was when landing the UAS the camera and thermal sensors are going to touch the ground as they are in the bottom and the UAS will be sitting on it. This may scratch the lenses or even breaking the whole box if there was a big impact in landing on a hard surface as well as it leads to a landing failure, which may break the UAS itself. Some working sites like in refineries or drilling locations considers this as an incident that might be fatal due to the risks involved in these locations. Another idea is to conclude the sensor box and the power bank in a small lightweight carton box that has strong edges to be the landing platform. The Figure 2 shows the UAS and the attachment.



Figure 2. The final system used in the data collection

This explained process required having two flights instead of just one because the visible camera sensor is covered with the carton box and could not be used unless the Raspberry Pi system is unmounted but this process worked perfectly and the drone was very stable in flying and hovering except it became a little bit slower in maneuvering.

5.3 Study Results

After the images were collected using the DJI Phantom 4 drone system, and a Canon 600D for the indoor water experiment, as well as the data collection using Lepton thermal sensor, we created a classification map for every image taken before and after fusing the thermal images into the RGB images. This method was considered to see the behavior of the thermal sensor used and how this reflects on the classification results.

Unfortunately, the Lepton thermal sensor did not provide temperature values as it only produces digital numbers representing the heat variations in the resulted image. Working with the symbology in ArcMap v. 10.5.1, an ESRI software helped in differentiating nominal cool from hot areas in the

images to an extent. This leads to integrate the thermal images as a synthetic color into the RGB images of the same locations and treat the thermal images as a band to replace the red band from the RGB images for enhancing the RGB images for classification purposes. The first step was separating high quality images from lower quality ones based on image visualization for distortions and area coverage. Secondly, there was a need to clip the images to have the area of interest covered by both sensors. Before clipping images, they had to be georeferenced using *image-to-image* registration due to the unavailability of a predefined coordinates system in the drone system and not having ground control points (GCPs). Thermal images were 60 X 80 pixels whereas the RGB images were 3000 X 4000 pixels for the DJI Phantom 4 camera and 1209 X 859 for the Canon 600D camera. Images did not line up perfectly on top of each other because of the different focal lengths of lenses and the capability of area coverage as well as the sensor rotation while capturing the images. Therefore, thermal images were resized to the max (3068 X 3699) pixels and after using the extract by mask tool in ArcMap, DJI image for the area of interest (in the KPCS) size was 2227 x 2283 pixels.

The thermal image was resized to match the DJI image pixels number in order to fuse them because fusing both images without having the same pixel size and number of pixels results in an error of having a not matching spatial extent (ENVI was used to generate the fused images). The resulted ground resolution distance was approximately 27 mm by dividing a known distance by the number of pixels in the image. The width of the containers (2.44 meters standard) was used as the known distance.

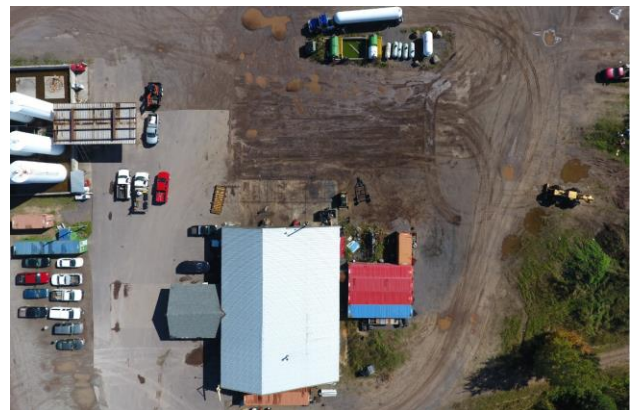


Figure 3. KPSC Location Image Captured Using DJI Phantom 4 UAS

The image to image registration using ArcMap resulted in a total RMS error of 29.07 pixels (using a 1st order polynomial method) due to the very small area covered and having a very limited features on site that could be observed in both images and this is considered a negative point for this UAS system.

As we can see in the fused image (Figure 4) the presence of the false recorded thermal data line and also the little shift in the thermal data on top of the visible image due to the image registration with no proper ground control points.

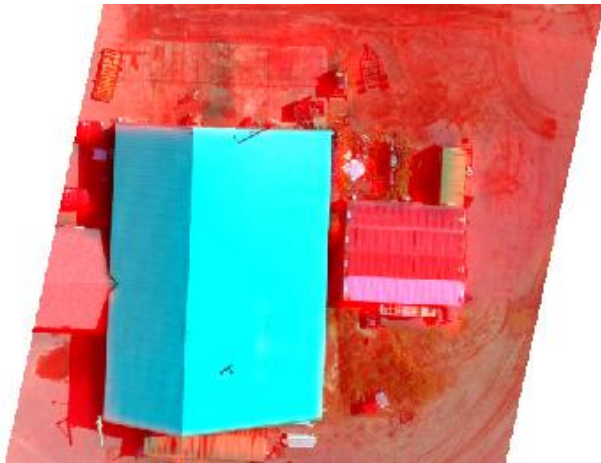


Figure 4. The fused image product (Field Experiment) (Cyan represents the cool objects and red represents hot objects)

The last step after having the fused image ready is running a supervised classification method for both the original RGB image product from the DJI phantom 4 UAS camera (Figure 5) and the fused image product (Figure 6) using a maximum likelihood parametric rule and 5 training sites for the signature file for each feature as well as 10 training sites for the oil contaminated locations.

From interpreting the previous maps, each image has misleading results and confusions that lead to generate confusion matrices (Accuracy Assessment) for both RGB classified image as well as the fused classified image.

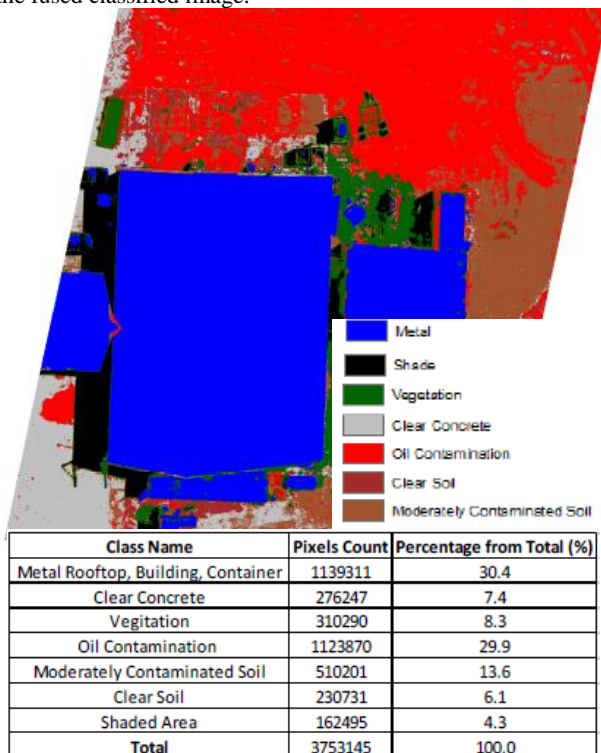


Figure 5. Classification map for the DJI phantom 4 RGB image

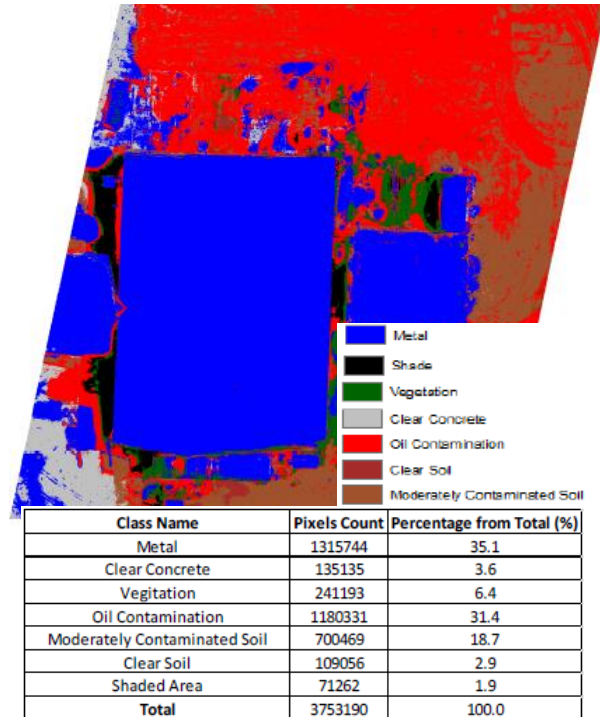


Figure 6. Classification map for the fused image

False results in the RGB image are due to the same brightness value for some objects while the false results in the fused image are due to the similar temperature values for multiple objects at that certain time of the day.

The lesson learned from this experiment is the thermal sensor is not the best option for the onshore operations where there is more than one object and there is a wide variation in temperatures around the contaminated area, this makes it nearly impossible to detect and differentiate the contaminated areas.

Class	Metal	Shade	Vegetation	Clear Concrete	Oil Contamination	Clear Soil	Mod. Cont. Soil	Ground Truth
Metal	7	1	1	0	1	0	0	10
Shade	0	10	0	0	0	0	0	10
Vegetation	0	0	10	0	0	0	0	10
Clear Concrete	0	0	0	10	0	0	0	10
Oil Contamination	0	0	0	0	8	0	2	10
Clear Soil	0	0	0	0	0	10	0	10
Mod. Cont. Soil	0	0	0	0	1	0	9	10
Total	7	11	11	10	10	10	11	70

Producer's Accuracy		User's Accuracy	
Metal	100%	Metal	70%
Shade	90.90%	Shade	100%
Vegetation	90.90%	Vegetation	100%
Clear Concrete	100%	Clear Concrete	100%
Oil Contamination	80%	Oil Contamination	80%
Clear Soil	100%	Clear Soil	100%
Mod. Cont. Soil	81.80%	Mod. Cont. Soil	90%
Overall	92%	Overall	91.40%
Omission	8%	Commission	8.60%

Table 3. Accuracy assessment for RGB classified image

Class	Metal	Shade	Vegetation	Clear Concrete	Oil Contamination	Clear Soil	Mod. Cont. Soil	Ground Truth
Metal	7	0	0	0	2	0	1	10
Shade	1	4	0	0	5	0	0	10
Vegetation	2	0	8	0	0	0	0	10
Clear Concrete	3	0	0	6	0	0	1	10
Oil Contamination	0	0	0	0	9	0	1	10
Clear Soil	0	0	0	0	0	6	4	10
Mod. Cont. Soil	2	0	0	0	1	0	7	10
Total	15	4	8	6	17	6	14	70
Producer's Accuracy				User's Accuracy				
Metal	47%			Metal	70%			
Shade	100%			Shade	40%			
Vegetation	100%			Vegetation	80%			
Clear Concrete	100%			Clear Concrete	60%			
Oil Contamination	53%			Oil Contamination	90%			
Clear Soil	100%			Clear Soil	60%			
Mod. Cont. Soil	50%			Mod. Cont. Soil	70%			
Overall	78.57%			Overall	67.14%			
Omission	21.43%			Commission	32.86%			

Table 4 Accuracy assessment for fused classified image

For this reason we conducted another experiment to see how the Lepton thermal sensor would work if there were only two mediums, water and oil.

A Canon 600D camera replaced the DJI phantom 4 UAS system for this experiment to avoid flying and crashing it indoors due to the limited space.

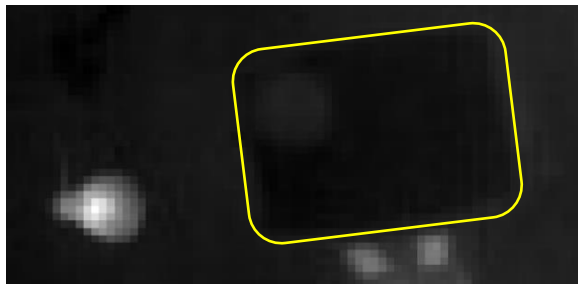


Figure 7. Lepton thermal image used in the water-oil experiment



Figure 8. Water-Oil experiment image to image registration

Image to image registration shows 8.996 pixels as the total RMS error. The corners used in the images registration were the corners of the bucket where the upper level of water reaches. This is not practical for a real world disaster because there might be no objects around the spill or there are some features not distributed on site in a way makes no use of it. Therefore, some objects should be distributed around the spill or the best scenario is using a better thermal sensor that provides better imaging than the Lepton (RGB + Thermal in one product), but costs will be higher.

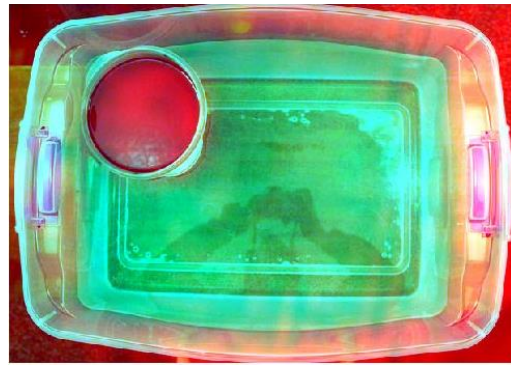


Figure 9. Fused image of the water-oil experiment

In the fused image, the reddish color represents higher temperatures and green is cooler. The oil, shown in red (Figure 9) has a reddish color as well as the plastic water container containing the oil because plastic absorbs thermal energy more than water so the areas of water looks green because its much cooler than the oil patch or the plastic.

Next step is running a supervised classification algorithm using ERDAS Imagine software for both the RGB image and the fused image to see how having the thermal image replacing the red band in the RGB image impacts the results. The images were clipped to an area of interest before running the classification process to minimize the confusion of the temperature variances of the plastic container. We used three training signatures for each class (water and oil).

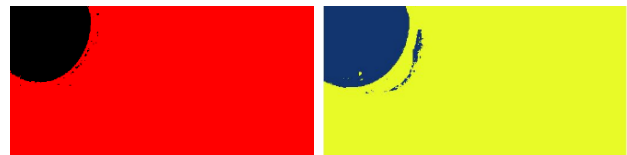


Figure 10. left) RGB image classification (red is water and black is oil); right) fused image classification (yellow is water and blue is oil)

6. CONCLUSION

The inexpensive Lepton thermal sensor used in this research showed that it is capable of being used for oil spill detection, it helps in the visualization of oil spills for disaster management purposes. Calculating oil spill surface area is feasible; however, volume is not because depth cannot be measured with thermal sensors unlike laser sensors. Lepton thermal sensor has shown great results when having only two mediums. In the second experiment, it reflected very close results to what the RGB image, given that the RGB imaging system is not practical in night operations. Therefore, Lepton thermal sensor is able to produce great results for the different temperatures of oil and water (which is a typical application scenario with oil spills) but for limited altitudes due to fisheye effect as images gets more distortions. Other thermal sensors manufacturers has provided limitations for the maximum altitudes to work with.

Working with oil slicks offshore is kind of a tricky situation for environmental treatment due to the oil spread and the movement of water due to tides or in the case of rivers, a flowing water. The environmental cleanup after an oil spill disaster in water bodies is accomplished by identifying the thickest oil patches and skimming the surface. Skimming can only be accomplished in calm water by containing the oil using collection booms. Other treatment scenarios are either burning or chemically dispersing the oil unless the spill is near shore, then only skimming is allowed. For all the previously mentioned oil spill conditions, it

is always better to start with the thick oil patches soon after the spill, clean it up before it spreads and becomes more difficult, and time consuming. In the water-oil experiment, the target was used engine oil because crude oil was unavailable. In thermal imaging offshore, oil is shown as a hotter area in the daytime and cooler than water during nighttime because oil tends to absorb the thermal energy faster than water during the daytime and cools down faster than water during nighttime, depending on oil layers thickness. Therefore, crude oil could have more temperature variances than the used engine oil. This would enable better thermal sensor detection. In addition, the sensitivity of thermal sensors is an important factor in the detection of variant temperatures.

To compare using a UAS thermal sensor to common methods using a manned aircraft, a Lepton sensor mounted on a UAS system could minimize the field exposure, risks and costs involved. However, using UAS systems depends on many factors that must be considered first such as budget, sensors and drone capability, area size needs to be covered and takeoff/landing space required.

Challenges to consider when working with Lepton thermal sensor for oil spill detection and monitoring:

- Fisheye effect if the Lepton sensor flown over a high altitude.
- Different angles of the Lepton and the drone system camera may result in misleading results if bands fusion needed.
- Field of view.
- Lepton output needed to be georeferenced to the RGB image to execute the classification. The image-to-image registration is not practical when working offshore because fixed objects are not easy to establish, and in onshore scenarios, it is not very precise.
- The need to resize the thermal images due to the smaller pixel array to match the size of RGB images if the job requires a data fusion.
- Lepton thermal sensor does not have a built-in GPS.

It is important to mention the challenge in working with thermal sensors for offshore operations: it is very challenging to tie images together in open water cases. However, it is a good option to work with it for oil spill cases in rivers or small lakes where the shorelines are seen in the images, which help in identifying control points.

A Lepton sensor can still be used for less environmental threatening jobs like smaller spills from a pipeline break onshore when there is only oil and soil for example or a small spill in a marsh or a lake.

Our recommendations for thermal sensor for oil detection is to use a one piece sensor that is capable of capturing images with visible + IR bands. It minimizes human input and the time consumed for processing in situations where time worth a lot, this way makes it much more practical to calculate areas of contamination by having one sensor mounted and GPS supported.

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