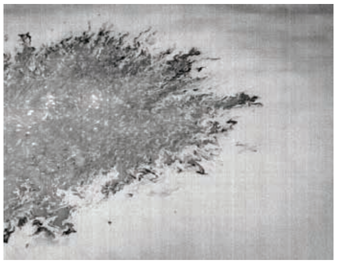
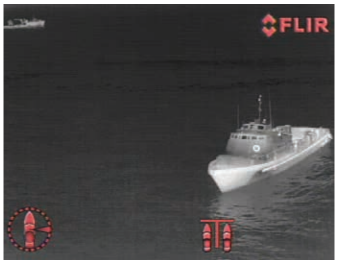
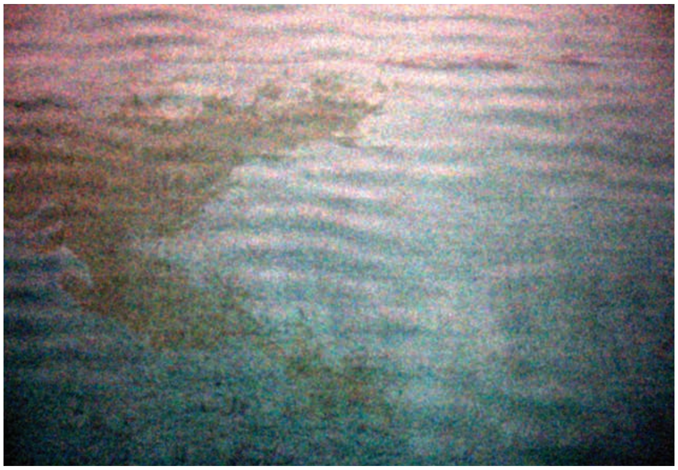
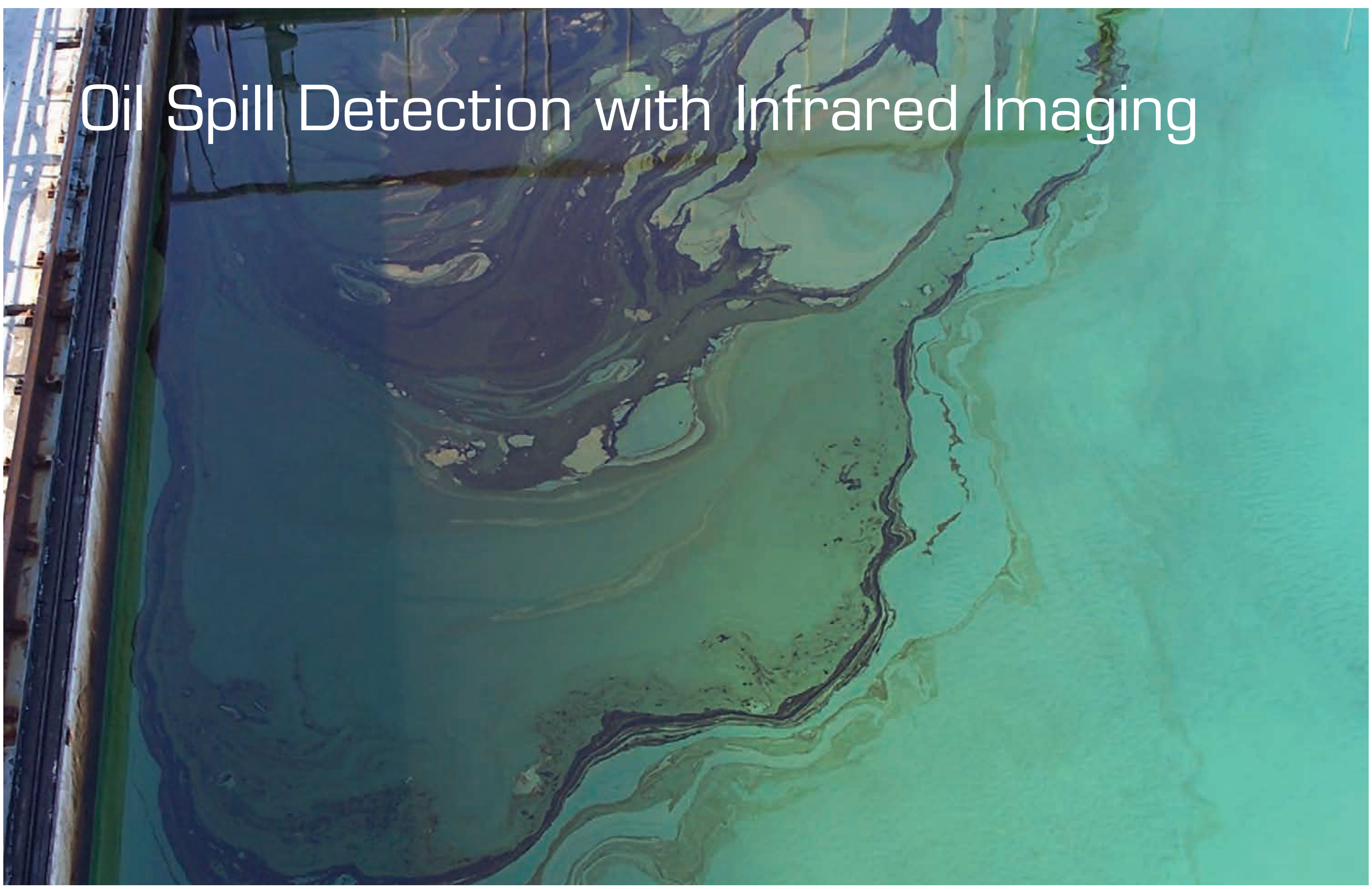
Technical Note







Oil Spill Detection with Infrared Imaging



Oil Spill Detection with Infrared Imaging

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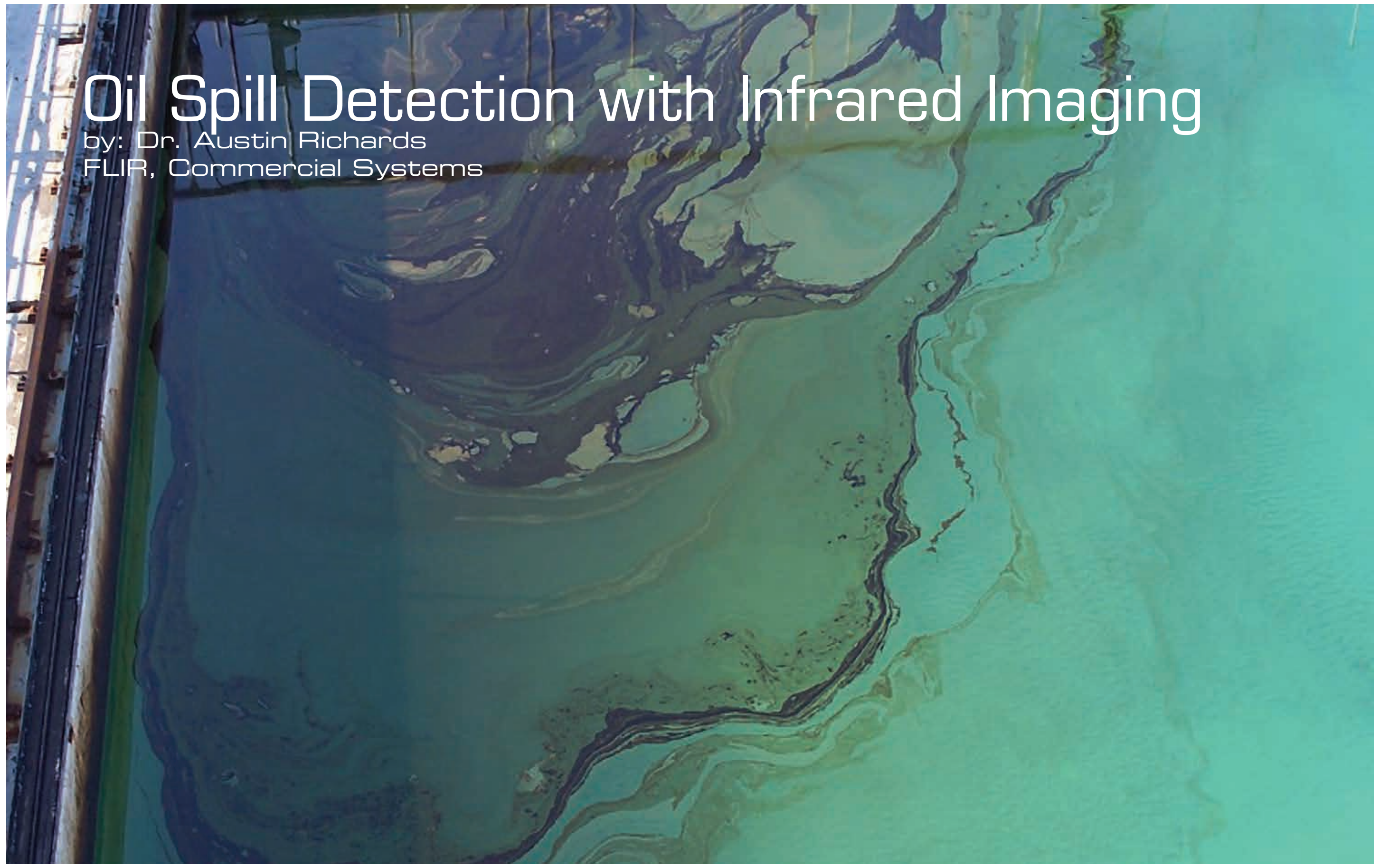

Introduction

Oil spills in water present a special challenge for imaging-based detection methods. In the visible-light waveband (VIS for short), ocean water is often murky and appears dark when looking straight down. At high angles, ocean water reflects the sun, horizon or sky and can appear very bright. Against this highly variable surface brightness, any thin film of liquid floating on the surface can be hard to see with the naked eye or with a color video camera.

Crude oil or diesel spills typically rise to the surface and float there for awhile because of their lower density. Although spills can form well-defined films, especially in still waters, there is often not a strong visual contrast between the film and the water surface, at least to the unaided eye. Particularly at low incidence angles, both the water and the oil film tend to look dark. Detecting the oil becomes even more difficult in choppy or wavy water since the undulating water surface alternately appears dark or light depending on how it reflects the sky or the sun above it, masking the low contrast oil-film areas to an even greater extent.

But visible light is just one method of imaging. Alternative wavebands of the spectrum hold out the promise of increased contrast between petrochemicals and water in a variety of different sea states and lighting conditions. Recent investigations by FLIR engineers have determined that there are at least three fundamental reasons why longwave infrared imaging is a powerful tool for spill detection in field conditions.

1: Variability of Visible Light Levels

Oil spill detection systems should ideally be continuously operational at any time of the day, irrespective of cloud cover. However, the natural illumination of an ocean surface scene is highly variable in the visible band. Visible light levels can vary by as much as a factor of 100 million between a bright sunny day and an overcast night with no moon or artificial light sources.

The thermal infrared part of the spectrum, however, especially the longwave IR band, is very uniform with light levels changing by a factor of two at the most. Thermal IR scenes are always intrinsically lit by IR emission from the scene itself, do not require illumination at night, and have an appearance that changes very little between day and night.

2: Variability Created by Reflection in Visible Light Spectrum

The surfaces of natural bodies of water are often very non-uniform reflectors in the visible band, especially when there are waves, surface chop, or windy conditions. Surface waves can act like alternating convex and concave mirrors, changing the apparent brightness of the water surface rapidly and easily hiding surface features like floating oil.

Solar interference can also be a huge problem for visible-light camera systems – a camera can easily be blinded from sunlight reflecting off the water surface, especially at sunrise or sunset if the camera is looking towards the sun. Thermal IR cameras are much less sensitive to the sun's rays relative to visible-light cameras. The sun is peaked in the visible part of the EM spectrum, around 500nm in wavelength, so there is plenty of interference when trying to see oil on the water surface. Solar radiation in the longwave IR band that is diffusely reflected from the water surface is orders of magnitude weaker and is hardly noticeable near normal incidence.

Even on a cloudy day where the visible light illumination is much more uniform, the degree of variability of the water surface brightness in the visible band can change rapidly due to the variable reflectivity of the water surface. Since most of the thermal infrared radiation one sees with a longwave IR camera is emitted by the water surface itself rather than being reflected, the surface looks much more uniform. This brightness uniformity found in the thermal IR wavebands sets the stage for practical detection of oil spills by imaging.

3: Ability to Render a Clear, High-Contrast Image

Oil or diesel film on the surface of water tends to look quite different from the water itself in the thermal IR bands, giving floating films of oil a distinct appearance. In the visible band, oil films can be very hard to see unless the lighting and viewing angles are just right, or the film is dirty crude oil and thick. Thermal IR images of oil films are much less sensitive to these factors, especially in the longwave IR band where reflections of sunlight off water are negligible.

By experiment, we have found that thin oil and diesel surface films tend to look darker than water in the longwave IR band and lighter than water in the midwave IR band. The reasons for this variability in appearance are due to a complex mix of phenomena, involving the refractive indices of water and oil, interference effects that one sees in transmissive thin films, and the emissivities of oil and water in the thermal IR wavebands.

For example, an optically thick film of oil will be more reflective than water in the thermal IR bands because of oil's higher bulk index of refraction. Oil films that are optically thick and in thermal equilibrium (at the same temperature) with the water surface will always emit less IR light than the water, and hence always appear darker than the water. These optically thick films will also reflect the cold sky above into the camera lens, further adding to their dark appearance relative to water.

Experimentally-observed oil films appear optically thick in the longwave IR band almost right up to their edge, because longwave IR light is highly absorbed in the very top layer of molecules in the oil. These same oil films are less absorbing to midwave IR light, and therefore can have a much more varied appearance because the films are no longer optically thick; i.e. there is transmission of MWIR light through the thin film, which allows reflections off both the air-oil interface and oil-water interface, leading to thin-film interference effects. These are the same effects that make a spill of gasoline in a puddle appear as rainbow-colored swirls. The result of these optical effects is that in the MWIR band, oil films on water will tend to have a mottled appearance. They can look alternately light and dark in complex patterns with less well defined boundaries to the overall film. There is always less contrast between petrochemical films and sea water in the MWIR band relative to the LWIR band.

Experimental Results:

Recent experiments conducted by FLIR personnel at the Ohmsett test facility in coastal New Jersey confirm that longwave IR cameras image petrochemical spills on the sea water surface better than either visible-light imaging or midwave IR imaging. **Figure 1** shows three simultaneous views of approximately 100mL of Doba/Chad crude oil dumped on a sea water surface with a calm sea state. The viewing angle is 45 degrees from normal incidence.

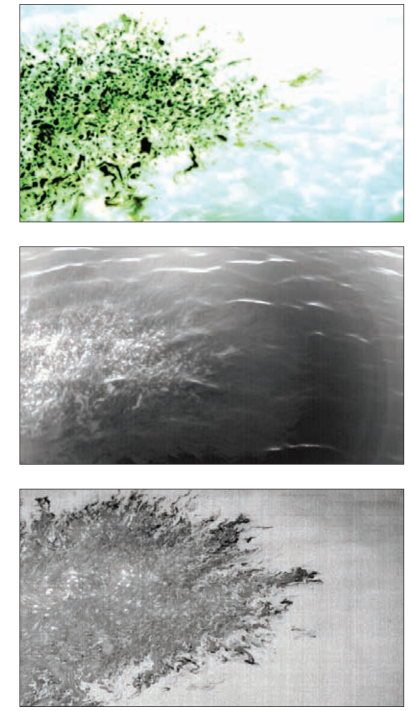

Figure 1. Doba/Chad crude oil spill, calm sea state.

Top – VIS, Middle – MWIR, Bottom – LWIR

During the Gulf Oil Spill, FLIR cameras allowed spill response crews to work around the clock, and even recover oil in total darkness.

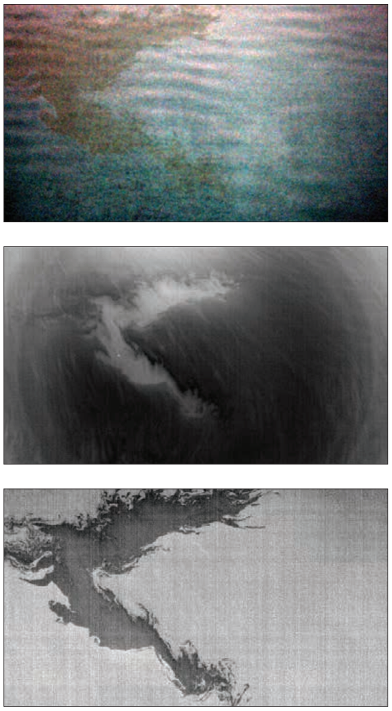

Figure 2. Diesel fuel spill on water imaged at dusk.

Top – VIS, Middle – MWIR, Bottom – LWIR

The oil film looks like a high-contrast dark patch on the water surface in the longwave IR image because, as stated earlier, the oil film has a lower bulk emissivity and therefore a higher reflectivity relative to the water. The oil film reflects the cold sky above it into the camera. The midwave IR image of the same oil film shows a bright central area surrounded by a fainter looking ring where the oil film is thinner. The change in reflectivity is caused by interference effects that result from the oil film's partial transparency to midwave IR light. This phenomenon reduces the contrast between water and an oil film, and makes MWIR a less effective way to visualize oil films on water. There is also some evidence of sunlight reflecting off the ripples – solar interference is a problem for MWIR imaging systems. The visible-light image shows strong contrast between the oil and the water, but as the oil spreads, it becomes harder to see. The oil looks quite dark in the visible band where it has formed thick blobs. The oil itself is fairly transparent to visible light – we are seeing the carbon particles and other impurities suspended in the film. Note that the overall water surface scene is highly cluttered by time-varying and spatially-varying reflections of ambient light off the moving water surface, making the oil much more difficult to see in the visible band, except for the black blobs.

Figure 2 shows the results of an experiment where a patch of diesel fuel was poured on the water. The fuel is faintly apparent in the visible-light image. This picture was taken at dusk when the ambient light was greatly reduced and contrast was poor. The MWIR image shows the spill as light in color, while the LWIR image of the spill is dark. Note how the thermal IR images are unaffected by the lack of sunlight.

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