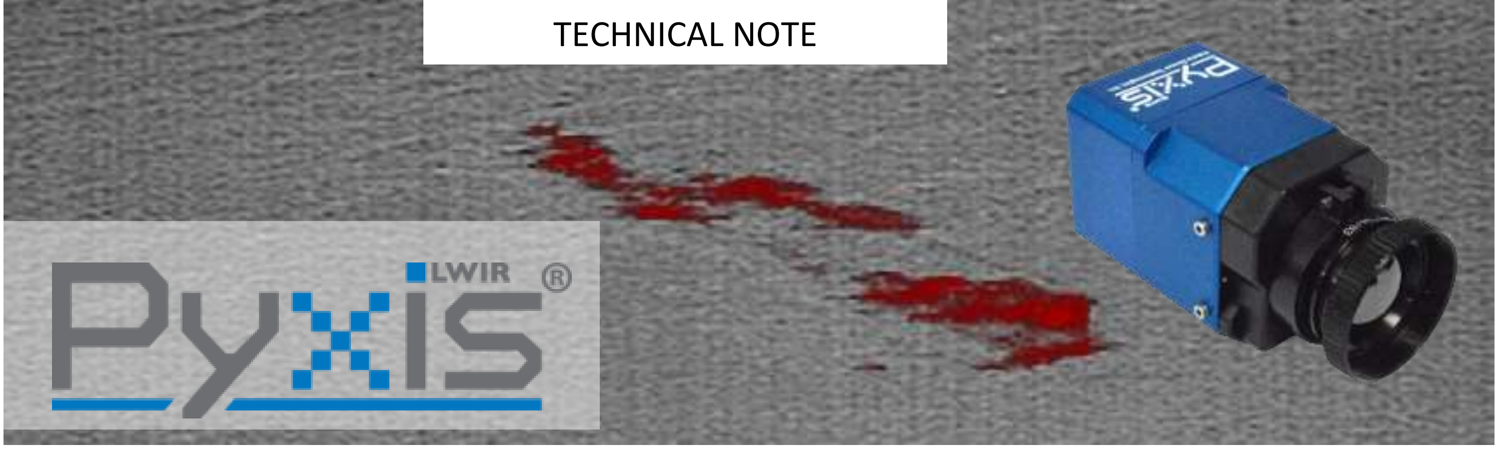


# Why is Pyxis® Better than Thermal Alone?

When assessing options for sensors and comparing the Pyxis to thermal cameras, one might wonder why one would choose the Pyxis. After all, thermal cameras have been around for a long time and are marketed as an oil spill detection sensor. The short answer is that the polarization sensing capability in Pyxis detects oil significantly better in a wider range of situations for a larger variety of spill conditions. Importantly, Pyxis adds this capability to thermal sensing and doesn't take away that capability. In this Technical Note, we'll describe how the Pyxis gives better contrast of oil on water, how this impacts detection, and show the improvement over thermal alone.

**Overview of Pyxis, How it Works and What it Measures**

The technology underlying the Pyxis sensor exploits the polarization of light in our environment, a fact that we use every day with our polarized sunglasses to reduce glare off the car in front of us in traffic. When ambient illumination is reflected off of an object, the reflected light becomes polarized. Likewise in the thermal infrared, light becomes polarized as it is emitted from the water and oil in an amount that depends on the material properties. The key factor here is that the amount of polarized light *does not depend on temperature* and thus the water and the oil can be the same temperature and have different levels of polarization. Pyxis measures the polarization and hence performs detection more effectively in a greater variety of conditions. These conditions will be described in greater detail below.

The Pyxis camera itself uses a modified uncooled microbolometer camera core with the addition of a pixelated or checkboard patterned polarization filter. This approach enables real-time, simultaneous acquisition and calculation of the polarized *and* thermal video in a package that is compact and low power, and is light enough to be integrated onto small unmanned aerial systems (UAS) or drones. A range of standard lenses enables a selection of magnifications and fields of view.

**Pyxis Detection of Oil vs. IR**

Pyxis discriminates oil from water due to the optical property material differences between oil and water. A thermal or infrared (IR) camera only senses temperature differences. When oil is in contact with water for any length of time, it tends to be the same temperature of the water that it is floating on. For large, very thick oil slicks, sunlight heats up the oil and the oil develops a strong heat signature. However, when the sun is not shining (such as at night) then thermal imagery just isn't as effective. One of the first tests on Pyxis was conducted overnight at the Ohmsett Oil Spill Response facility operated by the Bureau of Safety and Environmental Enforcement (BSEE) and examined thick and thin oil floating on water. **Figure 1** shows the experimental setup and the results. The red lines show the contrast of the thermal measurement of the oil relative to the water and the blue lines show the contrast of the polarization measurement relative to water. You can see that in the 15:27 thermal image, the thin bin thermal image is nearly indistinguishable from the surrounding water background. In the 17:17 image, the thermal contrast is better, due to heating by sun late in the day, but it is still not as good as the polarization image for both times. Polarization remains strong even at night, as visualized by the imagery for 21:27. Finally in the morning hours, the thermal image of the thick oil bin gets quite bright but this is the only time the thermal performs better. The time lapse video that shows all images and the complete plot over this time frame can be found in the video "Clean Gulf 2017" starting at the 1:10 mark on Polaris' YouTube channel at https://youtu.be/T_neM6jmj7c.

This same video shows several examples of crude oil and diesel in both very smooth water (a difficult scenario for oil detection radars) and in smooth and breaking waves. These video sequences, a snapshot of which is shown in

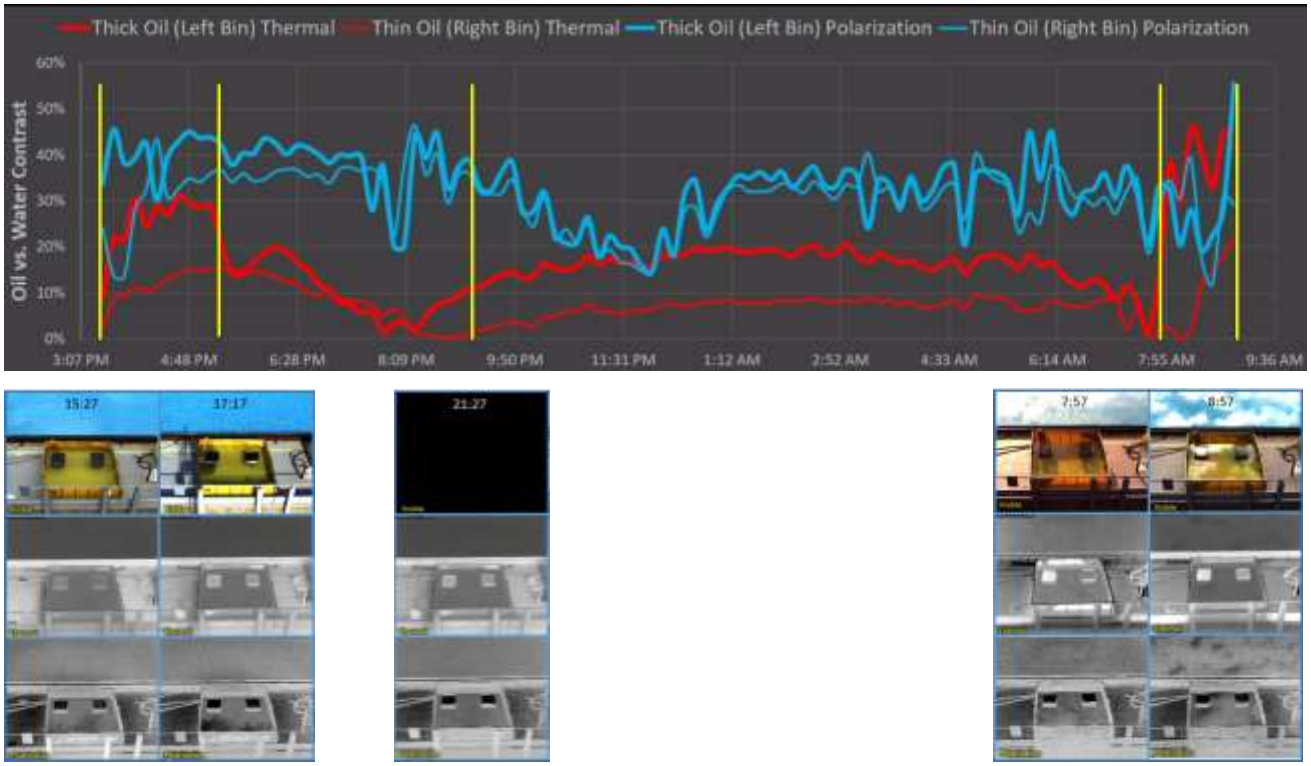


**Figure 1**. The plot shows Contrast computed for thermal (red) and polarization (blue) data products. Polarization performs better 92% of the time. The bottom imagery shows visible, thermal, and polarization imagery of the 5 mm thick (left bin, thick line in the plot) and 0.5 mm thick (right bin, thin line) oil samples at the times marked by yellow lines.

**Figure 2**, show the visible image in the upper left, the thermal image in the upper right, the polarization image in the lower left, and an "eTherm" or enhanced thermal image in the lower right. The eTherm® imagery combines both the thermal and the polarization into a fused image containing both data products that retains the thermal information in gray scale but highlights the detections through polarization using color.

Other tests were conducted at the BSEE Ohmsett facility with oil thicknesses ranging from 10 $\mu$m (rainbow sheen) to 100 $\mu$m (metallic) to 5 mm thick. Further tests included measurements of emulsified oil and oil in the presence of dispersant. The emulsified oil was aged and subjected to ultraviolet and wave action to produce an emulsification with 80% water content. The oil being dispersed was visible right up to the moment when the oil left the surface and entered the water column. In every case, polarization showed better contrast and detectivity than thermal

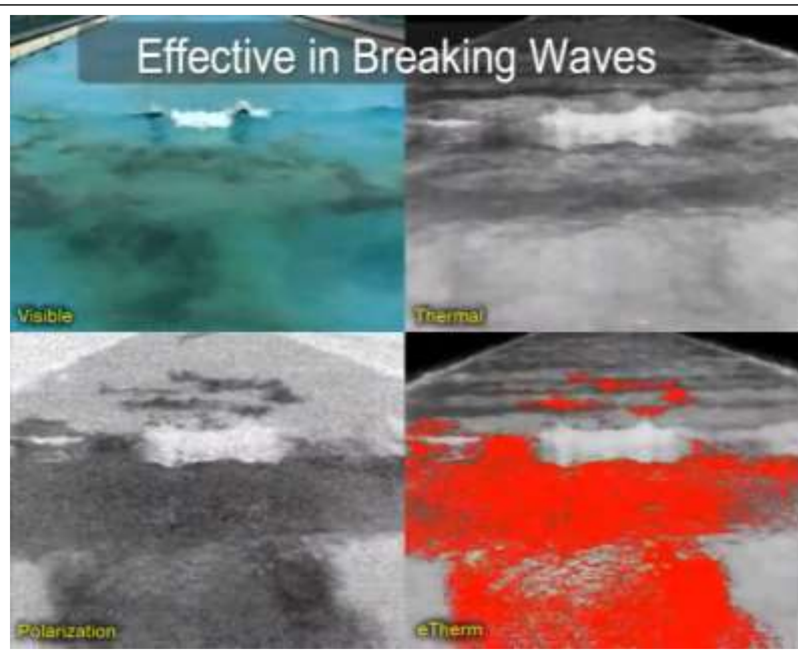


**Figure 2**. Visible, thermal, polarization, and eTherm imagery of crude oil on water in breaking waves. Oil is essentially undetectable in the thermal imagery.


**Figure 3**. Oil spill detection off the coast of California. The Pyxis eTherm image shows the detection in red whereas the thermal and visible imagery show confusing clutter.

alone, either due to better contrast, or through the reduction of thermal clutter due to wave action. This is extremely helpful during cleanup efforts by determining areas that are clean and those are that are still affected.

Several opportunities to demonstrate the superior detection performance of Pyxis in the environment have also shown the benefit of polarization detection. Pyxis was deployed to Santa Barbara at the time of a pipeline spill where it was operated as a handheld camera from a manned helicopter. **Figure 3** shows visible imagery of the scene and the eTherm image. In this scene there are several features that produce clutter in the scene in both the visible and the thermal imagery including a kelp forest, sun glint, and surface wellings. The oil sheen is observable in the visible image if you know where to look but is confounded by the other surface features. The eTherm image clearly highlights the thickest part of the sheen and through the filtering provided the polarization, the confounding clutter is suppressed.

Other deployments to the Gulf of Mexico and in a recovery operation for a marina fire have shown similar detection capabilities and superior performance over thermal cameras. Specifically, in the marina fire response, the Pyxis imagery was solely responsible for finding the location of a sunken vessel due to detection of leaking oil.

Finally, initial studies in looking at oil pooling on sand or earth has shown significant capability of detection through polarization sensing over that of thermal. The thermal clutter resulting from the environment of a pipeline or beach is too great to reliably detect oil. In polarization however, pooling oil is readily found even if it is diluted by water or waves.

**Pyxis Detection of Oil vs. radar**

Detection of floating oil using radar relies on the effect that the oil has on the fine wave structure on the surface, and not on the material differences between water and oil like polarized IR. Oil-dampened waves have lower backscatter than waves without oil. Hence, radar does not work at winds speeds less than 2 m/s (4.5 mph). Other effects can cause false alarms such as natural surface films produced by plankton or fish, cold upwelling water which changes the stability of the air-sea interface, divergent flow regimes, e.g., with internal waves, tidal flow over underwater sand banks, and oceanic eddies, dry-fallen sand banks during ebb tide, or floating macro-algae including sargassum and kelp. In all these cases, Pyxis does not detect these as false alarms.

**Summary**

The Pyxis polarized thermal camera combines the advantages of thermal and polarization-based sensing. The polarization capability significantly enhances detection of floating oil over that of thermal in a variety of conditions including:

| | |
|---|---|
| Breaking waves and smooth waves | Emulsified or aged oils |
| Smooth water | Diesel, kerosene (or jet fuel), mineral oil |
| Crude and refined oil refined | Day and night |
| Oils interacting with dispersant | Does not detect biologicals |

It is important to note that Pyxis is a remote sensing technique that detects oil floating on water (and other petroleum products) and not subsurface oil, or oil entrained in the water column. It is a remote sensing surface measurement that covers a wide area in a single snapshot.

Polaris is currently developing a prototype Pyxis Oil Detection System or PODS, a system for autonomously monitoring a site with minimal human intervention. We also have available a Software Contact Polaris for details.

**Pyxis Specifications**

| Pyxis® LWIR 640-G | |
|---|---|
| Resolution (H x V) | 640 x 512 pixels |
| Field of View w/ Standard Lens | 30.4° x 24.6° |
| Camera Frame Rate | 30Hz or 7.5Hz |
| Input Voltage | 5 VDC or POE |
| Steady State Power @ 70°F | 4 – 6 Watts |
| Operating Temperature | 0°C - 70°C |
| Size w/ standard lens | 88 x 46.5 x 46.5 mm |
| Weight w/ standard lens | 184 g |

**Export**

The Pyxis thermal polarimetric camera comes in two versions, a 30 Hz frame rate and a 7.5 Hz frame rate. The fast version is governed by Department of Commerce EAR export regulations with an ECCN of 6A003 which requires a license for export to many countries. The slow version is covered under ECCN 6A993 and does not require a license for export to most countries. Please contact Polaris regarding export regulations requirements.

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