FRESNEL EQUATION RECIPROCAL POLARIZATION METHOD

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Abstract

The Hyperspectral *H V* Polarization Inverse Correlation technique incorporates Horizontal and Vertical (*H&V*) polarization hyperspectral techniques in the infrared for target discrimination. Normally polarization provides an impediment to target discrimination because of the uncertainties in polarized background illumination. Here the polarization provides a definite aid in target discrimination even if the spectrum and intensity of the target and background are the same. In that regard negative images are approximately equivalent to taking the stretched reciprocal of Fresnel coefficient terms. Note in the reflective Fresnel coefficients there is a difference numerator (e.g., A-B $\approx$ $f(\Delta n, i) \equiv \cos i - n \cos i$) instead of A+B) emissive that ends up in these two denominators if the image is negative. In the near infrared (1-5 microns) we also need an additional ROI *V* and image *H* polarization components negative image correlation because of strong surface roughness wavelength angular '*i*' dependence and the often weak wavelength dependence of *n*. These two difference denominators created in this way then have many more possibilities of zeros and higher correlation between reflective ROI and reflective target elements in the image. The main application here is in discriminating thermally thick (emissive) from thermally thin (reflective) targets *even given the same spectrum and intensity*. The technique has already been tested on ground targets and shown to work and could discriminate balloons from RVs as well since balloons are reflective and RVs emissive in the near infrared. This method allows accurate appraisal of whether such targets are thermally thick.

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Section 1.0

1.1 Nomenclature

n' = index of refraction of structure
n = index of refraction of air, n ≈1
i = angle of incidence
E_o = incident electric field
E' = reflected electric field
H = Horizontal polarization
V = Vertical polarization

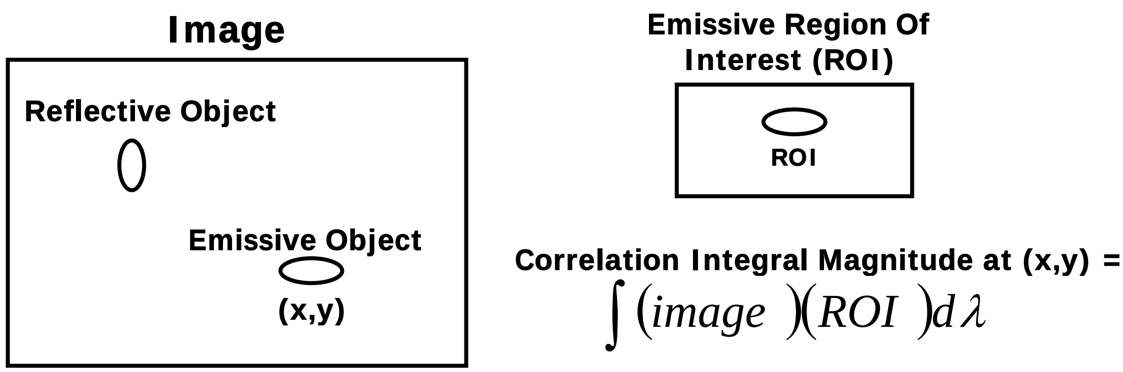
1.2 Introduction

This paper is on a new method of doing target discrimination using simultaneous hyperspectral, H and V imagery. In that regard, polarization has traditionally confused optical discrimination. But, as we show in this paper it doesn't have to. How do we make polarization work? To understand how to make polarization work we must understand a little about surface to volume ratio physics. The surface to volume ratio is small for thermally thick objects, such as tanks and RVs, in comparison to leaves and balloons (e.g., perhaps 15 cubic inches of mylar for the balloon vs 10,000 cubic inches for a RV). Thus the cooling constant is small, making tanks and RVs cool slower. In general, small volume objects radiate faster than large thermal mass objects. Thus tanks in the late afternoon or an RV a few minutes into suborbital flight are emissive objects in contrast. This is our motivation for finding a method to discriminate emissive from reflective targets in the near IR. This method of optical discrimination uses a correlation integral for inverted ROI and H and V correlation over λ: From this integral we find a (x,y) map of this integral making it then discriminate emissive from reflective. Also we must use matched filter noise abatement

Section 2.0

2.1 Correlation Integral

There is a lot of added information in a polarized image that is not in a normal natural light image. This technique finally uses this information in a way that makes polarization useful in target discrimination, instead of just adding a lot of ambiguous clutter to the image.

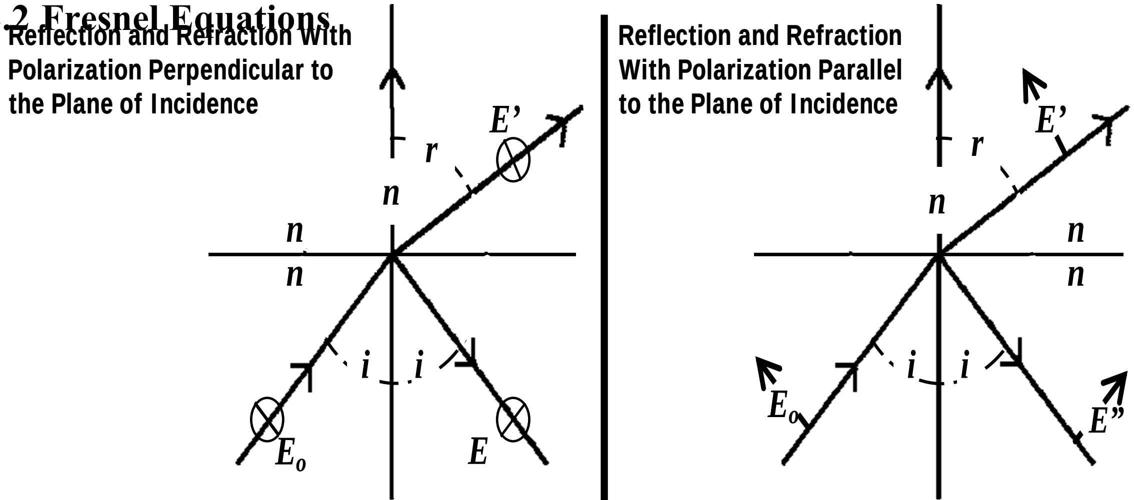


$$\int (image)(ROI)\,d\lambda$$

Figure 2-1.

What hyperspectral and/or polarization property can be used to increase the correlation integral magnitude for emissive objects in an image (thus discriminating emissive from reflective objects)? The answer is found in the properties of the Fresnel equations that can be distinguished for emissive and reflective objects. In the near infrared (1-5 microns) we also need the additional ROI *V* and image *H* polarization component negative image correlation. This is because of strong surface roughness angular '*i*' wavelength dependence and the often weak wavelength dependence of *n*.
In the near infrared emissive objects usually have relatively large thermal mass, reflective objects less thermal mass. These could be RVs vs. balloons or tanks vs. foliage for example. The map of this correlation integral is what we are after. We want a emissive ROI region to correlate well with an emissive region on the image. The map of this correlation integral will then give us a emissive object map, minus the reflective object clutter. To do this we need to find the mathematical properties of the Fresnel equations that are different for emissive and for reflective objects. This technique incorporates Horizontal and Vertical (H &V) polarization hyperspectral techniques in the infrared for target discrimination.

2.2 Fresnel Equations



	Perpendicular	Parallel
Transmission	$\frac{E'}{E_0}=\frac{2n\cos i}{n\cos i+\frac{\mu}{\mu'}\sqrt{n'^2-n^2\sin^2 i}}$	$\frac{E'}{E_0}=\frac{2nn'\cos i}{\frac{\mu}{\mu'}n'^2\cos i+n\sqrt{n'^2-n^2\sin^2 i}}$
Reflection	$\frac{E''}{E_0}=\frac{n\cos i-\frac{\mu}{\mu'}\sqrt{n'^2-n^2\sin^2 i}}{n\cos i+\frac{\mu}{\mu'}\sqrt{n'^2-n^2\sin^2 i}}$	$\frac{E''}{E_0}=\frac{\frac{\mu}{\mu'}n'^2\cos i-n\sqrt{n'^2-n^2\sin^2 i}}{\frac{\mu}{\mu'}n'^2\cos i+n\sqrt{n'^2-n^2\sin^2 i}}$
Example	Vertical *V*	Horizontal *H*

Figure 2-2.

Note the ‘difference’ math structure of the numerators of the reflective Fresnel equations. If somehow these equations could be flipped over, made reciprocal, they might also provide zeros and thus rapid changes with wavelength for example.

For $V_{ThermallyThick}$ transmitter (e.g., RV, tank) we have:

$$\frac{E'}{E_0} = \frac{2n\cos i}{n\cos i + \frac{\mu}{\mu'}\sqrt{n'^2 - n^2\sin^2 i}} \tag{2.1}$$

Where:
i is the angle of incidence
n is the index of refraction that may be wavelength dependent
n' is the vacuum index of refraction
E_O is the incident electric field perpendicular to surface
There is no difference term (e.g., A-B) in this numerator.

For $V_{thermallyThin}$ reflector (e.g., balloon, foliage, n vacuum)

$$\frac{E''}{E_0} = \frac{n\cos i - \frac{\mu}{\mu'}\sqrt{n'^2 - n^2\sin^2 i}}{n\cos i + \frac{\mu}{\mu'}\sqrt{n'^2 - n^2\sin^2 i}} \tag{2.2}$$

We note the negative sign in the numerator. How can we take advantage of the negative sign? What if the numerator and denominator were somehow interchanged? There is a difference term (e.g., A-B) in this numerator.
For $H_{ThermallyThick}$ transmitter (RV, balloon, n vacuum)

$$\frac{E'}{E_0} = \frac{2n'n\cos i}{\frac{\mu}{\mu'}n'^2\cos i + n\sqrt{n'^2 - n^2\sin^2 i}} \tag{2.3}$$

Note that there is not a difference numerator in this equation. In contrast for $H_{ThermallyThin}$ reflector (e.g., balloon, foliage, n vacuum)

$$\frac{E''}{E_0} = \frac{\frac{\mu}{\mu'}n'^2\cos i - n\sqrt{n'^2 - n^2\sin^2 i}}{\frac{\mu}{\mu'}n'^2\cos i + n\sqrt{n'^2 - n^2\sin^2 i}} \tag{2.4}$$

There is a difference numerator in this reflection Fresnel equation. For $V_{ThermallyThin}$ reflector (e.g., balloon, foliage).

$$\frac{E_0}{E_0''} = \frac{\frac{\mu}{\mu'}n'^2\cos i + n\sqrt{n'^2 - n^2\sin^2 i}}{\frac{\mu}{\mu'}n'^2\cos i - n\sqrt{n'^2 - n^2\sin^2 i}} \tag{2.5}$$

What if we could exchange the numerator and denominator? We would then have a chance for zeros in the denominator, for more sensitive correlation over n and/or incident angle i as a function of wavelength. The correlation integrals would then be far more sensitive to wavelength. One way to flip these integrals over is just to take inverse images: take white to black and black to white. To accomplish the same thing we could also correlate H polarization on the image with V polarization on the ROI. Dimness in V polarization would then correlate well with brightness in H on the image, thus having nearly the same effect as having an inverted image. If the ROI was itself an inverted image then the net effect is to correlate two inverted images. In that regard negative images are approximately equivalent to taking the stretched reciprocal of Fresnel coefficient terms. Note in the reflective Fresnel coefficients there is a difference numerator (A-B $\approx f(\Delta n,i) \equiv (\cos i - n\cos i)$, instead of A+B) emissive that ends up in these two denominators if the image is negative. The effect of inversion of the image is to take white to black, black to white. This is roughly the effect of taking a reciprocal. For reflective images this puts a difference into the denominator (A-B), enhancing the effect of changes when the two values (here A and B) are nearly the same.

2.3 Weak Wavelength Dependence of *n*

Note from examining the Sellmeir Equation we that the index of refraction curve levels out between 1 and 4 microns illustrating a weak wavelength dependence of n.

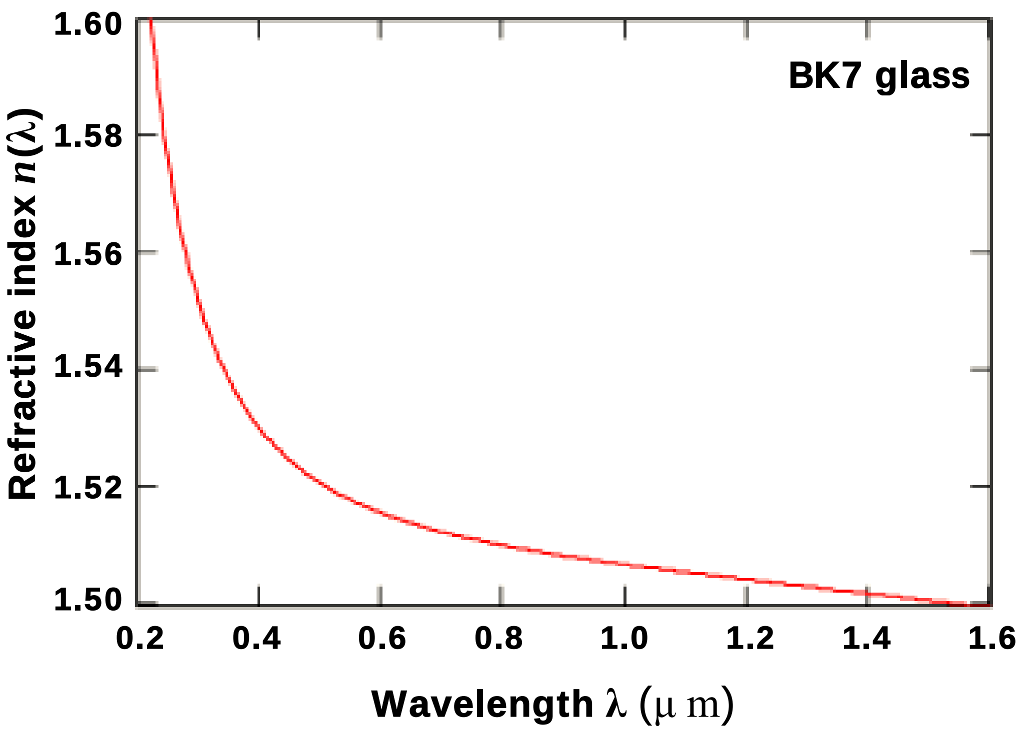


Figure 2-3.

One example of the wavelength low sensitivity of n at near IR is for BK7 glass as in figure 2-3.

In contrast H and V reflection is strongly dependent on surface roughness and wavelength. Note for a paint with 1 micron level roughness the sensitivity in angle of incidence i is high.

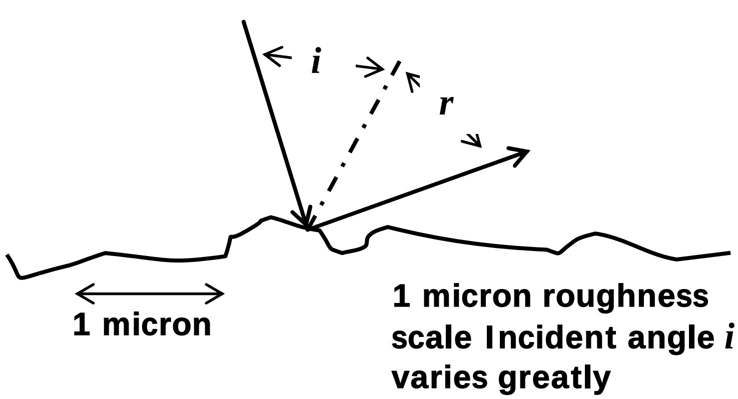


Figure 2-4.

$$\int \left(H_{ThermallyThick}\right)\left(V_{ThermallyThin}\right) d\lambda = C$$

$$\int \left(k \right)\left(\frac{k}{\lambda - \lambda_0} \right) d\lambda =$$

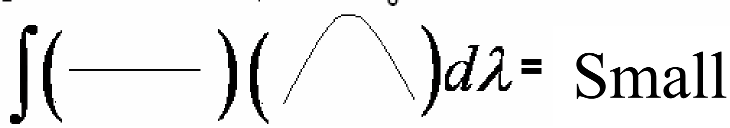


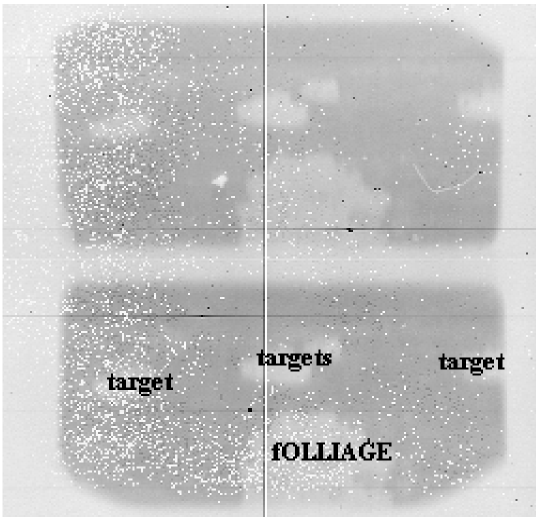
Figure 2-5.

In figure 2-5 we note that the correlation will be very sensitive to changes in the difference denominator. The correlation integral is flipped over using H and V correlation and inverted image on ROI. Note also that surface roughness spreads out the singularity hump, thus making reflecting objects correlate well in general. We then find the (x,y) map of this integral. Thus we now have a correlation over wavelength that is very sensitive to wavelength dependence of thermally thin and thermally thick materials. If the ROI is emissive then this correlation integral will represent a map of emissive regions in the image plane.

2.4 SNR from polarization and hyper-spectral dependent target discrimination.

Hyperspectral and H and V polarization splits light, thereby effectively decreasing SNR and increasing the effect of white noise. Matched filtering is needed to reduce the effect of white noise. Also this rtms sensor split the light up into 16 different wave bands and into H and V polarization. That decreases the power SNR by at least a factor of 1/30, pulling down the SNR a great deal. In that regard note the fuzziness of the images used as examples below. This has the effect of increasing the white noise. The most efficient way of lowering the effects of white noise is with a matched filter.

BEFORE



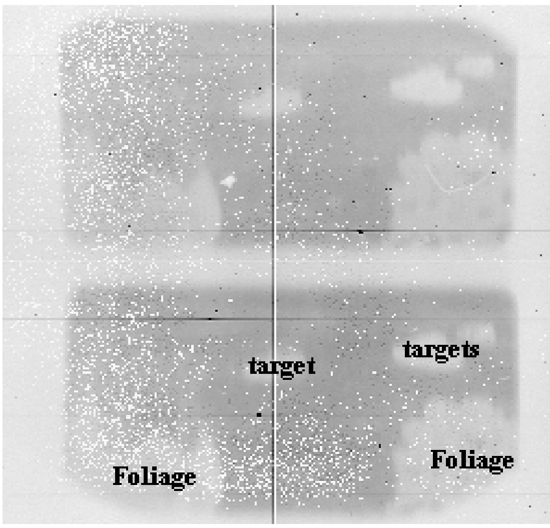
Processed H polarization

AFTER - Matched Filter, **H** polarization, ROI in V polarization

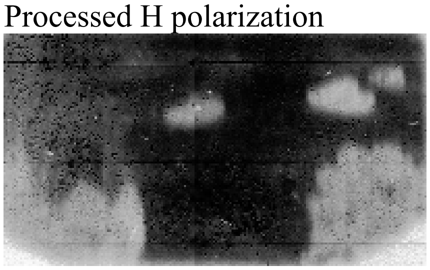
Note - NO foliage

TARGETS DISCRIMINATED
from foliage and other background

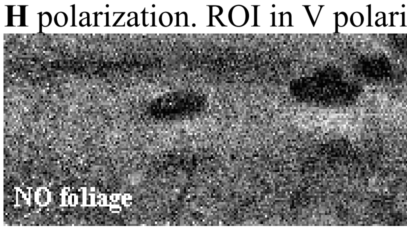
Polarization and hyperspectral dependent
Target discrimination
BEFORE



Processed H polarization

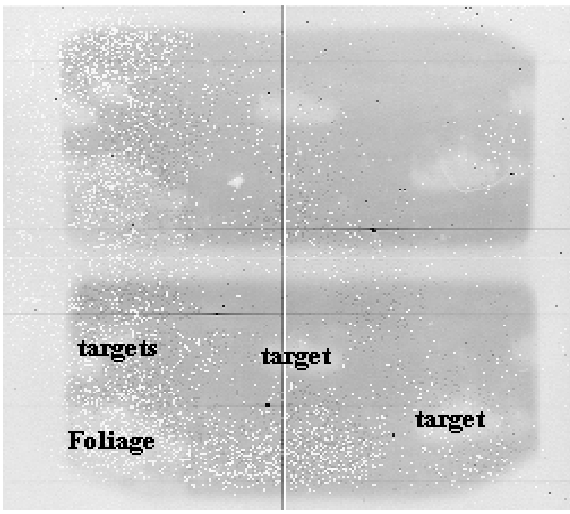


AFTER - Matched filtering
H polarization. ROI in V polarization

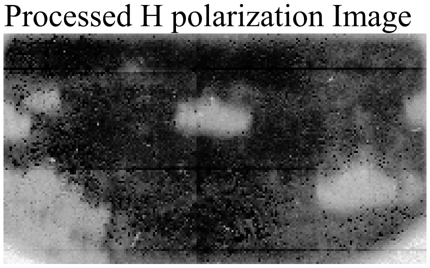


Note - NO foliage
TARGETS DISCRIMINATED from foliage and other backgrounds

BEFORE



Processed H polarization Image



AFTER - Matched filtering.
H polarization. ROI in V polarization

Note - NO foliage TARGETS DISCRIMINATED from foliage and other backgrounds

Figure 2-6

In figure 2-6 are photos taken from a 300 foot tower of armored vehicles using a rtms sensor with hyperspectral and H and V polarization. Note emissive target armored vehicles are discriminated from reflective foliage backgrounds.

Conclusion

The ability for real time discrimination of RVs from balloons, instead of requiring a dynamical history, is an important and long sought after goal. The main advantages to this technique are that there is a lot of added information in a polarized image that is not in a normal natural light image. This technique uses this information in a way that finally makes polarization useful in target discrimination, instead of just adding a lot of ambiguous clutter to the image. Even if paints are applied that make the normal spectrum look the same, this method will still discriminate in real time a emissive from a reflective object such a green painted tank from a green tree. As another example a balloon that has had a few minutes in the sunlight will mostly be a reflector and the RV will be an emitter in the near infrared and they will be discriminated in real time. Other techniques involving precessional dynamics have been proposed but they all require histories for which little time is allowed along a typical suborbital trajectory. Thus this method potentially solves the hottest problem in missile defense: that of discriminating balloons from RVs.

The disadvantages to this technique are that it needs a resolved image, the SNR is low so we must use a matched filter for white noise control, little use these days is made of simultaneous hyperspectral and H and V polarization sensors. Also a characterization of the limitations on backgrounds for a useful emissive ROI is needed.

Bibliography

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