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Comparison of directly measured to derived polarization imagery using an adaptive signature detection algorithm

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Abstract

Directly measured linear polarization images are shown to be more effective in target detection compared with derived imagery using a constant false alarm rate (CFAR) detection algorithm. The CFAR algorithm is derived from a maximum likelihood ratio test and is used to compare two pairs of inputs. One pair is directly measured imagery: an image with reflectivity/emissivity and a linear polarization and another with reflectivity/emissivity and a linear polarization perpendicular to the first image. The other pair is the first two Stokes images (S_0, S_1): a linear polarization image and a reflectivity/emissivity image. Detection using the directly measured pair is shown to be consistent with detection using the derived pair. Furthermore, using the directly measured pair is computationally simpler, and for target detection on natural backgrounds, does not increase the false alarm rate.

Keywords: Polarization; ATR; Maximum Likelihood Test; CFAR

1. Introduction

Small low-contrast target detection is at the forefront of remote sensing application research. Electro-optical sensors can provide distinction in four areas: spectral, spatial, temporal, and polarimetric [1]. Spatial and spectral contrast has been utilized extensively in automatic target recognition. Temporal information is important for dynamic scene analysis and moving object detection. Recently, polarization is becoming more utilized as a distinguishing factor between natural and manmade objects.

Spectral-based discrimination is an effective tool for revealing manmade targets surrounded by natural environments [2]. In many cases, the interesting objects are small and designed to spectrally match their surroundings. Land mines are a particular instance of these hard to detect targets. In such a critical area as landmine detection, detection requirements are very high and false alarm allowances are very low [3]. Temporal discrimination is often not applicable since mines are not typically dynamic in image analysis.

The principal drawback to spatial-spectral detection is that highly variable backgrounds produce many spectral anomalies which often lead to false alarms. Sensing polarization properties in addition to spatial-spectral differences can reduce the number of false alarms [4].

Light reflected by manmade objects tends to exhibit different polarization states than that reflected by naturally occurring backgrounds. In general, the smoother the surface of an object, the more polarized the return. This holds true in thermal emissions as well as visible reflectivity. Manmade objects tend to have smoother surfaces than naturally occurring objects. Most paints and metals tend to be smooth [1]. In addition to the polarization differences exhibited by manmade and natural objects, polarization can be useful in the detection of disturbed soil. Disturbed soil is a phenomenon often associated with recently buried mines. Burying a mine disrupts the natural particle size layering caused by weathering. Smaller particles that are normally washed down or blown away are brought to the surface. These smaller particles, along with a more uneven

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surface produce a multiply scattered return. A multiply scattered return is more unpolarized than that of a singly scattered return [5].

The amount and type of polarization depends on surface properties, the angle between the surface normal and the line of sight, and the polarization of the incident illumination. Polarization can be completely described with the four Stokes parameters. They are commonly used since their elements are simply constructed from measurable components. These components are collected to form polarimetric images. The polarimetric images can be combined, not only to characterize polarization, but also reflectivity/emissivity.

System designers must often justify inclusion of different discriminants. The advantages of using polarization are often demonstrated by applying a detection algorithm to two sets of images. One set contains no polarization information; the other set is the same as the first set with the addition of an image that only contains polarization contrast. The image with only polarization contrast is can be a degree-of-polarization (DOP) image. A direct comparison can then be done between the two results. Rather than use all of the polarization information, it is common in remote sensing to use only linear components [6–8]. The sum and difference of linear components can be used for reflectivity/emissivity and limited polarization contrast, respectively.

Intuitively, the information contained in the sum and difference of the linear polarimetric images is available in the individual linear polarization images. It is therefore reasoned that effective detection is possible using these separate images. Reducing or eliminating the calculations should preserve the information content that is lost through numerical errors. Furthermore, the total processing time dedicated to preprocessing is decreased.

This paper will show that combining two linear polarimetric images directly into a detection algorithm provides effective, efficient, and more robust detection capabilities when detecting objects on a non-polarizing background than a sum and difference of the polarimetric images. Section 2 reviews the Stokes parameters in terms of the directly measured components that can be used in their derivation. These directly measured components are referenced as polarimetric images within this paper.

A maximum likelihood detector that serves as a metric for judging detection is briefly reviewed in Section 3. It is a constant false alarm rate (CFAR) detection algorithm that was developed for use in multi-band imagery. While it is often difficult to predict the spectral signatures of targets, the shape of the target may be known. This detector exploits geometric target features and contrast differences between targets and their surrounding areas. The detection algorithm is derived from a general statistical model of the data with the greatest emphasis on the background.

The comparison between the two approaches regarding target detection is given in Section 4. Theoretically, the detection approaches are shown to be consistent. That is, that detection in either case leads to detection in the other case. Further, using the linear polarimetric images results in a lower or equal false alarm rate compared to using the derived linear polarization and reflectivity/emissivity images.

Section 5 presents the results of processing visible spectral data. The imagery is of spectrally high and low-contrast man-made objects on a natural background. These examples demonstrate a lower false alarm rate when using directly measured imagery as compared to derived imagery, as was theoretically predicted in Section 4.

2. Stokes parameters

A light wave traveling forward can vibrate in a plane perpendicular to its direction of propagation. This vibration can be vertical, horizontal, or in an intermediate direction. Ordinarily a ray of light consists of a mixture of waves vibrating in all the directions perpendicular to its line of propagation. If the vibration remains constant in one direction, the light is said to be polarized.

Polarization can be completely described with the four Stokes parameters. They are commonly used since their elements are simply constructed from measurable components. The first parameter is the total intensity of the light and contains no polarization information. The second is a difference of linear polarizations measured at 0° and 90°. The third parameter is contains polarization information for orientations measured at either a 45° or −45° angle. The forth is a measure of circular polarization.

The Stokes parameters may be written as a vector:

$$\mathbf{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix}. \tag{1}$$

The Stokes parameters may be constructed by collecting four polarimetric images, each measuring light intensity, I, through a differently oriented polarizer or retarder. The images are: $I(0°,0)$, which is an image collected using a linear polarizer oriented at 0°; $I(90°,0)$ an image collected using a linear polarizer oriented at 90°; $I(45°,0)$, an image collected using a linear polarizer oriented at 45°; and $I(45°,\pi/2)$, an image collected using a linear polarizer oriented at 45° along with a 1/4 wave-plate retarder.

The Stokes parameters are related to these measurements by

$$\begin{aligned} S_0 &= I(0°,0) + I(90°,0) \\ S_1 &= I(0°,0) - I(90°,0) \\ S_2 &= 2I(45°,0) - s_0 \\ S_3 &= S_0 - 2I(45°,\pi/2). \end{aligned} \tag{2}$$

The degree of polarization is a measure of the portion of polarized light relative to the total intensity. In terms of the Stokes parameters, the degree of polarization is