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Detection in polarimetric images in the presence of additive noise and non-uniform illumination

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Abstract. Active polarimetric imaging systems yield information about the intensity contrast and the Orthogonal State Contrast (OSC) in the scene. However, in real systems, the illumination is often spatially or temporally non uniform which creates artificial intensity contrasts that can lead to false alarms. We derive the Generalized Likelihood Ratio Test (GLRT) detectors when intensity information is taken into account or not. These results are used to determine in which cases considering intensity information in addition to polarimetric information is relevant or not.

A simple configuration consists in illuminating the scene with a totally polarized beam (whose state of polarization is located anywhere on the Poincaré sphere) and in acquiring two images: the first one X is formed with the fraction of the light having the same state of polarization as the illumination and Y is formed with the fraction of the light in the orthogonal state. We consider homogeneous sub-samples X_i and Y_i, $i \in [1, N]$ of the images, that may be spatial or temporal. The average number of photo-electrons under unitary and uniform illumination, denoted m_X and m_Y, are identical for all pixels. The intensities for the two polarization directions at each pixel $i \in [1, N]$ can be written as:

$$X_i \quad = \quad F_i \, m_X + n_i^x \quad \text{and} \quad Y_i = F_i \; m_Y + n_i^y, \tag{1}$$

where $\mathbf{F}$ denotes the spatial fluctuations of the illumination intensity. In other words, F_i represents the intensity of the incoming light and m_X (m_Y) represent the reflectivity of the observed material with respect to each polarization. One can use another parametrization where $I = m_X + m_Y$ is the intensity and $P = (m_X - m_Y)/(m_X + m_Y)$ the Orthogonal State Contrast (OSC). Each measure are perturbed by additive white Gaussian noises n_i^x and n_i^y with zero mean value and variance σ^2, which are assumed statistically independent.

To address detection, we will use the formalism explained in detail in Ref.[1]. The sample is divided into two parts $\Omega_a = [1, N_a]$ and $\Omega_b = [N_a + 1, N]$ so that $N_a + N_b = N$. The region a corresponds to an homogenous part of the image and so does region b. The first part of the subsample $\chi_a = \{X_i, Y_i, i \in \Omega_a\}$ is defined by parameters (I_a, P_a). The second part of the subsample $\chi_b = \{X_i, Y_i, i \in \Omega_b\}$ is defined by the parameters (I_b, P_b). We denote $\mathbf{F_a} = [F_i]_{i \in \Omega_a}$ and $\mathbf{F_b} = [F_i]_{i \in \Omega_b}$. Our objective is to know whether regions a and b have different polarimetric properties or not.

For that purpose, we have derived the optimal detection algorithm which is the generalized likelihood ratio test [2]. We first assume that the illumination pattern $\mathbf{F}$ is non uniform and unknown. After a simple but cumbersome computation we obtain:

$$\mathcal{R}_{Funknown} = \frac{1}{4\sigma^2}\left\{\sqrt{D_a^2+W_a^2}+\sqrt{D_b^2+W_b^2}-\sqrt{(D_a+D_b)^2+(W_a+W_b)^2}\right\}, \quad (2)$$

where $D_v = \sum_{i\in\Omega_v}(X_i^2 - Y_i^2)$ and $W_v = 2\sum_{i\in\Omega_v} X_i Y_i$ with $v = a, b$. It can be shown that this detector is only sensitive to OSC contrast.

In order to take into account the intensity contrast, one may use the detector adapted to uniform illumination ($F_i = F_0, \forall i \in [1, N]$) whose expression is easily computed:

$$\mathcal{R}_{uni} = \frac{1}{2\sigma^2}\frac{N_a N_b}{N_a+N_b}\left[\left(\sum_{i\in\Omega_a}\frac{X_i}{N_a}-\sum_{i\in\Omega_b}\frac{X_i}{N_b}\right)^2+\left(\sum_{i\in\Omega_a}\frac{Y_i}{N_a}-\sum_{i\in\Omega_b}\frac{Y_i}{N_b}\right)^2\right]. \quad (3)$$

We applied detectors $\mathcal{R}_{uni}$ and $\mathcal{R}_{Funknown}$ on experimental images of a metalic object on a diffusive background (see Fig.1). We present successively the intensity image, the OSC image, the results of $\mathcal{R}_{uni}$ and $\mathcal{R}_{Funknown}$ detection. This series of images are realized for three different values of correlation length of the spatial variations. The correlation length l_c, is defined as the half width at half maximum (HWHM) of the autocorrelation function of the illumination pattern.

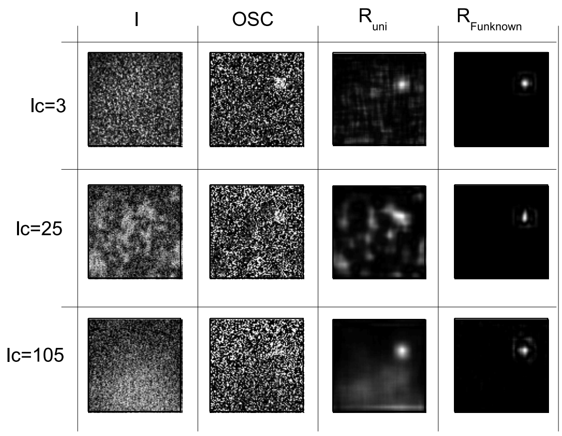

Figure 1. Detection in scenario corresponding to OSC contrast only. Horizontally: intensity image, OSCI, the results of $\mathcal{R}_{uni}$ and $\mathcal{R}_{Funknown}$ detection. Vertically: those images are realized with illumination pattern with different coherence length: $l_c = 3$, $l_c = 25$ and $l_c = 105$.

We observe that, on the one hand, detector $\mathcal{R}_{Funknown}$ shows really good performance and is able to detect the target under all different illuminations. On the other hand, the detector $\mathcal{R}_{uni}$ is less efficient than $\mathcal{R}_{Funknown}$ for all l_c and is significantly affected by the type of illumination. Let us linger on the case $l_c = 25$, which correspond to an illumination pattern whose correlation length approximatively matches the size of the target. In this case we potentially observe $\mathbf{F_a} \neq \mathbf{F_b}$, which leads to high probability of false alarm. The detector actually consider the variations of the illumination as a contrast in intensity. When $l_c = 3$ or $l_c = 105$, the illumination variations are either smaller or larger than the size of the targets which implies $\mathbf{F_a} \approx \mathbf{F_b}$. This explains why, in these cases, $\mathcal{R}_{uni}$ has better performances than when $l_c = 25$.

To conclude, we demonstrated that the spatial distribution of the illumination, and the existing contrats in the scene must be taken into account to decide between both detectors. An interesting perspective will consist in integrating, in the model, the photon noise, and to generalize the approach to other image processing tasks such as segmentation for instance.

References

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