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A STATISTICAL EXPLANATION OF THE EFFECT OF LUMINANCE ON PHOTOPIC VISUAL ACUITY OF SPECKLED IMAGES

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Une explication statistique de l'effet de la luminance sur l'acuité visuelle dans les images avec granularité laser (speckle)

SUMMARY : The intensity of a polarized speckle pattern obeys a negative exponential probability density function. This probability distribution implies a signal-to-noise ratio, *S/N*, unity since the standard deviation equals the mean intensity. However, when the logarithmic response of the retinal photoreceptors is considered, the first-order statistics of the pattern is transformed in such a way that *S/N* ratio becomes a function of the mean intensity.

This theory is closely connected with the masking effect of speckle in experiments of vision. In particular, it contributes to explain why in photopic vision of speckled images the resolving power of the visual system decreases as the mean luminance increases.

RÉSUMÉ : L'intensité d'une figure de speckle (granularité laser) polarisé obéit à une fonction de densité de probabilité exponentielle. Cette distribution de probabilité implique une raison signal-bruit *S/N*, égal à l'unité puisque la déviation standard égale l'intensité moyenne. Néanmoins, considérant la réponse des unités réceptrices de la rétine comme une transformation logarithmique, la statistique de premier ordre est transformée de façon que la raison *S/N* devient une fonction de l'intensité moyenne.

La théorie développée ici a du rapport à l'effet de masquer le produit par le speckle en des expériences de vision.

En particulier, il aide à expliquer pourquoi, en la vision photopique des images avec speckle, le pouvoir séparateur du système visuel amoindrit quand la luminance moyenne augmente.

INTRODUCTION

The effect of luminance on photopic visual acuity in the presence of laser speckle was investigated by J. M. Artigas and A. Felipe [1]. Whilst in incoherent illumination acuity increases slighly as luminance does [1, 2], they found that visual resolving power decreased from 33 to 26 c/deg when the mean luminance of the speckle grating target varied from 3 to 400 cd/m^2.

The dependence with luminance of the masking effect of speckle was explained by the authors taking into consideration the spread suffered by a point source of diameter less than 1′ as luminance increases. This phenomenon causes the apparent size of the point to seem larger [3, 4]. Moreover, the existence of points in the speckle pattern with an intensity higher than the mean, accounts for the prevalence of speckle masking effect over unmasked resolution acuity due to spreading of the grating target itself.

In what follows another contribution to the masking effect of speckle will be presented. It arises from assume the logarithmic response of the retinal photoreceptors.

THEORETICAL BASIS AND RESULTS

It is well established that the intensity of a polarized speckle pattern obeys a probability density function of the form [5].

$$P_I(I) = \begin{cases} \{1/\langle I\rangle\} \exp(-I/\langle I\rangle) & I \geq 0 \\ 0 & \text{otherwise}, \end{cases} \quad (1)$$

where $\langle I\rangle$ is the mean value. An important propertie of the negative exponential distribution is that the standard deviation equals the mean value. Thus, the signal-to-noise ratio, *S/N*, is always unity. However, when visual logarithmic transformation is taken into account, this is no longer valid.

Let us consider a speckle pattern submitted to the transformation $D = \ln(I)$, where the intensity, I, has been appropriately normalized to vary between 0 and 1.

The probability distribution (1) is then transformed into

$$P_D(D) = \exp(D - D_0)\exp\{-\exp(D - D_0)\}$$

$$D \leq 0 \quad (2)$$

where $D_0 = \ln\langle I\rangle$. An equivalent expression was obtained by H. H. Arsenault and G. April [6]. If $D_0 = 0$.

$$P_D(D) = \exp\{D - \exp(D)\} \quad (3)$$

which is the Fischer-Tippett probability distribution [7] with the change of variable $D \to -D$.

After some lengthly mathematics, the mean value is found to be

$$\langle D\rangle = D_0 - \gamma \quad (4)$$

where $\gamma = 0.577...$ is the Euler's constant. It can be noted that the logarithmic transformation causes a distortion of the signal : the mean density is not the logarithm of the mean intensity.

Similarly, it can be proved that the variance is

$$\sigma_D^2 = \pi^2/6\,. \quad (5)$$

From (4) and (5) the *S/N* ratio of a logarithmically transformed speckle pattern is found to be

$$|S/N| = \frac{\sqrt{6}}{\pi}(\gamma - D_0) \quad (6)$$

which clearly depends on the mean intensity. *Figure 1* shows the dependence with $\langle I\rangle$ of the *S/N* ratio. It can be seen that an increase in $\langle I\rangle$ implies a decrease in the *S/N* ratio and thus, the perception of the signal in the noisy background is worse as luminance increases, strengthening the masking effect of speckle.

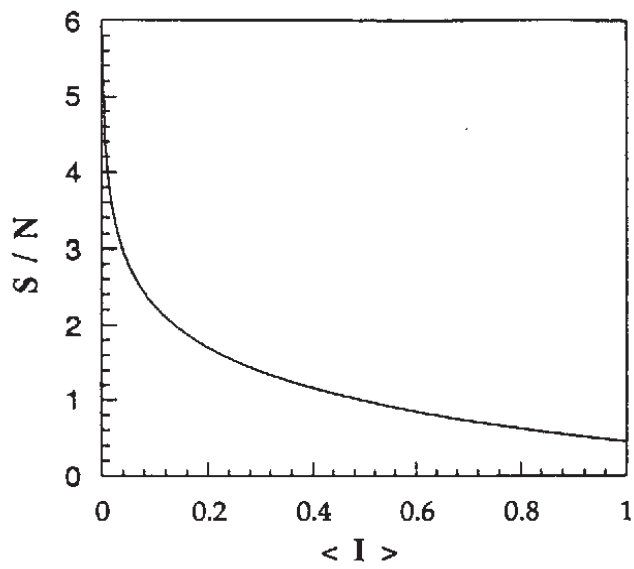

FIG. 1. — *S/N versus* $\langle I\rangle$ *of a logarithmically transformed speckle pattern.*

Thus, both theory exposed in this paper and experiment described elsewhere [1] point out that when we are involved with vision of speckled images, statistics concerned is no longer the negative exponential distribution but effects of visual logarithmic transformation must be incorporated.

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