Constructive role of sensors nonlinearities in the acquisition of partially polarized speckle images

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Abstract. We study the impact of the level of the speckle noise on data acquisition in a partially polarized coherent imaging system with the presence of a nonlinearity in the imaging sensor characteristic. In perfectly linear acquisition conditions, due to the essentially multiplicative action of the speckle, the image contrast is unchanged as the speckle noise level increases, and so it has no impact on the quality of the acquired images. On the contrary, in nonlinear conditions the acquisition is affected by the speckle noise level. However, this effect of the speckle is not always detrimental. We show that, in definite nonlinear conditions, there is usually an optimal level of the speckle noise that leads to a maximum quality of the acquired images. We theoretically analyze such nonlinear regimes with partially polarized speckled images. We specifically exhibit the existence of an optimal speckle noise level in the interesting case of images realized only by a depolarization contrast. Illustrations are given with a simple 1-bit hard limiter and binary images. Then, we propose and discuss as perspectives an experimental optical setup to confront theory and experiment.

The present study is connected to the field of stochastic resonance and improvement by noise in nonlinear information processing, and it considers possible extensions and applications to optical signals and imaging. In this framework, we have recently [2, 3, 5, 4] demonstrated the possibility of coherent imaging situations where nonlinearities (threshold [2, 3], saturation [5]) in the sensor response, cooperating with noise, can give way to an improvement of the acquired image in comparison with the image produced by a perfectly linear sensor. The images considered in [2, 3, 5, 4] are strongly affected by speckle noise and characterized by their statistical properties. The image acquisition is shown to be improved when the speckle noise is tuned up to a level which is large enough to force the sensor to operate in the nonlinear parts of its response. Such possibilities of exploiting the speckle noise in order to draw benefit from sensor nonlinearities are illustrated with images of calibrated transparencies with multiple [2] or binary [3, 5, 4] distributed gray levels. The model of speckle in [2, 3, 5, 4] was a simple model of fully developed and polarized speckle. Here, we propose to extend the work from [2, 3, 5, 4] to partially polarized speckle noise [1, 9].

Results are illustrated in Fig. 1 where the input image is a binary image constituted by two regions occupying identical surfaces and presenting a contrast of optical properties in terms of transparency and depolarization. In Fig. 1, the input image is then corrupted by a multiplicative speckle noise and the output image is delivered by a sensor with input–output characteristic taken as a hard limiter with threshold equal to 1.Fig. 1 gives an illustration of the impact of the speckle noise level for various contrast in transparency and depolarization on the input–output image transmission assessed by a similarity measure chosen as the input–output mean square error. We observe in Fig. 1 a nonmonotonic evolution of the mean square error which can be improved when the level of the speckle noise increases. As visible in Fig. 1, the input–ouput mean square error reaches its minimum value when the level of the speckle noise is tuned at an optimal nonzero value. A specifically interesting feature in Fig. 1 is that the nonmonotonic evolution of the mean square error as a function of the speckle amplitude is preserved even for images with a contrast in polarization and no contrast in transparency (case of $I_1 = I_0 = 1$).

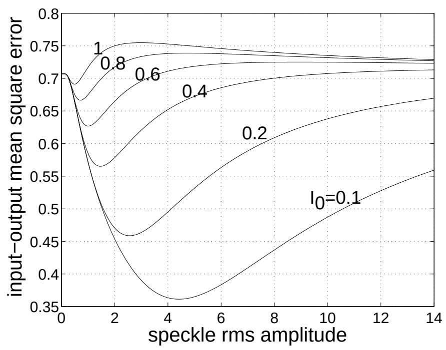

Figure 1. Mean square error as a function of the speckle noise rms amplitude for various transparencies I_0 and $I_1 = 1$ in a binary input image.

As a perspective, it would now be interesting to confront, as done in [3, 5], experiment and theoretical modeling. It would be an easy task to build a binary input image with a maximal contrast in depolarization properties. For example [1], one can think of a scene constituted with a rough dielectric region such as paper typically producing a reflected wave with a polarization degree ≈ 0 and a rough metallic region to have a polarization degree ≈ 1. Yet, it would be more difficult to find a full set of surfaces presenting depolarization properties capable of reflecting waves with a degree of polarization uniformly covering the whole range $[0, 1]$. Alternatively, a partial depolarization of an incident polarized wave can also be controlled by liquid crystal devices (like in [6, 7]). And also, multimode optical fibers are known [8] to partially depolarize light. Because they are cheaper than liquid crystal devices and easier to implement than a set of surfaces of variable roughness, a set of variable length optical fibers appears as a good candidate to propose a future experimental validation of the theoretical results presented here.

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