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Speckle Reduction Techniques in Digital Holography

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Abstract. We have studied several speckle reduction techniques, applicable to digital holography. These include the use of optical diffusers, wavelet filtering, simulating temporal incoherence and filtering in the Fourier domain. The Digital Holograms (DHs) used in this study are captured using a Phase Shift Interferometric (PSI) in-line setup and subsequently reconstructed numerically.

Digital holography [1], (DH) involves the use of discrete electronic devices, such as CCDs to record the hologram. Reconstruction may be performed either optically using a Spatial Light Modulator or numerically by simulating the propagation of the wave field back to the plane of the object. When coherent illumination is reflected from an optically rough surface, the resulting intensity pattern has a random spatial intensity variation known as speckle pattern. Speckle is a significant hindrance in imaging applications, such as DH, and acts to severely degrade the performance of coherent optical systems. Over the years many different techniques for reducing speckle have been developed, unfortunately however these techniques tend to reduce the resolution of the imaging system [3]. If several speckle fields are summed on an intensity basis the speckle contrast can be reduced significantly, see for example the discussion in Chap 5 [3]. Replaying holograms with a source that is not temporally coherent reduces speckle

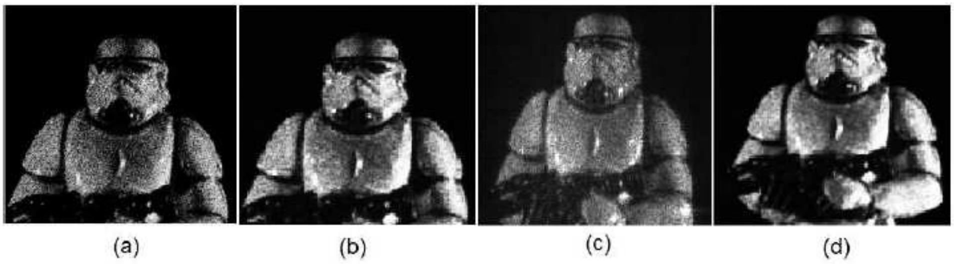

Figure 1. (a) Original intensity, (b) after simulation of temporal incoherence, (c) after discrete Fourier filtering, (d) using wavelet thresholding

contrast. The process may be simulated by calculating the reconstruction at the correct distance

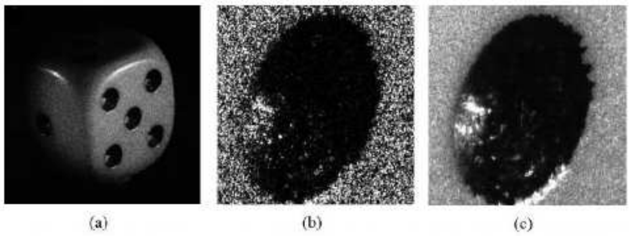

Figure 2. Speckle reduction using multiple diffuser illuminations.

for the hologram plane for a series of different wavelengths [4]. Each of these reconstructions is then summed on an intensity basis. We choose the difference in wavelengths such that the speckle patterns in the reconstructions are statistically independent. There is an blurring of the image itself when replaying at incorrect wavelengths which limits the number of statistically independent reconstructions that can be added together. The original reconstruction is shown in Fig. 1(a). Fig. 1 (b) shows the results 9 reconstructions have been added together on an intensity basis. The second technique we investigated is called Discrete Fourier Filtering [5], where the Fourier transform of the hologram is repeatedly spatially filtered and the resulting intensities are added together. Each spatial filter corresponds to a different rectangular band in the frequency domain. By moving the spatial filter in the Fourier domain we allow different parts of the hologram's Fourier spectrum to contribute to the holographic reconstruction. Again there is an inherent reduction in resolution. Fig. 1(c) shows the result 16 reconstructed segments have been added together on an intensity basis. In this case the final resolution is only one quarter that of the system. We also investigated wavelet filtering [6] on the reconstructed intensity. This method is the fastest and shows results that are at least as good as the other techniques but again there is a reduction in the resolution of the final image. Fig. 1(d) shows the results for an SWT wavelet transform, attained using a balance sparsity normal threshold applied by soft thresholding using a 'Haar' mother wavelet used with 3 levels. Our studies have shown that the only way to reduce speckle in digital hologram reconstructions without a reduction in resolution is to record multiple holograms with different diffuse illumination and then sum the intensities of the reconstructions. In Fig. 2(a) we show the result of summing 35 such intensities together. A zoomed in comparison of before and after this improvement is shown in In Fig. 2(b) and (c)

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