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Synergetic combination of median filtered images to reduce speckle noise in digital holography (DH) and digital holographic microscopy (DHM)

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Abstract: We present a single-shot image processing method to reduce speckle noise mitigating undesired blurring effects in both amplitude and phase reconstructed images. The implementation is based on the average of multiple median filtered images with different kernel size. This approach provides final reconstructed amplitude and phase images with reduced speckle contrast and without penalizing the spatial resolution.

1. Introduction

Speckle noise is a random pattern of dark and shiny spots on the reconstructed images in any coherent interferometric imaging system such as digital holographic (DH) systems and digital holographic microscopes (DHMs). Several computational approaches [1-7] have been developed for reducing the speckle noise in DH and DHM. The common drawback of those computational approaches is that they are subject to a tradeoff between the resolution limit and the speckle noise. The higher the reduction in the speckle noise, the lower the resolution in the holographic reconstructions. In this work, we present a computational method that synergically combines the median filter and mean approach, which are two standard denoising methods in image processing. The novelty of the proposed method, named a hybrid median-mean approach, is the cascaded application of these techniques to reduce the speckle noise in the reconstructed amplitude or phase images from DH and DHM systems.

2. Hybrid median-mean filter

The hybrid median-mean filter is based on the speckle noise is a coherent statistical noise and, therefore, the superposition of multiple uncorrelated-speckle images provides a resultant image with reduced speckle noise. From the noisy reconstructed amplitude and phase images, we propose to create K partially uncorrelated images by using a median filter with different kernel size. In other words, we have implemented the median filter K times over the noisy reconstructed amplitude and/or phase image, increasing the square kernel size of the median filter by (2K-1) for each iteration. Because the median filter with kernel size [1×1] provides an identical image to the input image (e.g., the noisy reconstructed amplitude and/or phase image), the first iteration in the hybrid median-mean method corresponds to K = 2. Thus, for the second iteration, the kernel size of the median filter is [3×3] and, consequently, the kernel size is [11×11] in the sixth iteration (K=6). The novelty of the proposed method to other methods reported in the literature is how the average is done, mitigating the tradeoff between the reduction in the speckle noise and the resolution limit. For each K iteration, the median-filtered image with kernel size [(2K-1)×(2K-1)] is averaged with the previous (K-1) denoised image. For example, for K = 3, the final reconstructed image (e.g., denoised image) is the average result between the original noisy image and the median filtered image of kernel size [3×3]

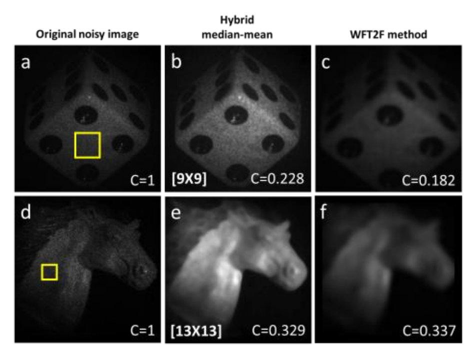

Fig. 1. DH results for dice and horse. Panel (a) and (d) are the noisy reconstructed amplitude images. (b) and (e) are the images obtained applying the hybrid median-mean approach. Finally, (c) and (f), corresponds to the results after implement the WFT2F method.

Figure 1 compares the performances of the proposed hybrid median-mean method and the 2D windowed Fourier transform filter (WFT2F) approach [4]. This figure shows the denoised amplitude images for two different samples (a dice and a horse model) which were recorded in a DH system operating in off-axis architecture. Both holograms were recorded using a setup operating in a Mach-Zehnder interferometer architecture [29]. Comparing the results obtained by applying the hybrid median-mean, and the WFT2F methods, we realize that both methods show reduced speckle contrast, values reported in the lower right corner. This speckle contrast was measured inside the yellow square marked in Fig. 5. Since the difference between these values is negligible, less than 0.03 a.u., one can conclude that the performance in the reduction of the speckle noise is almost the same for both methods. However, the WFT2F method provides images with more blurring effect and lower contrast, compare Fig. 1(f) vs Fig. 1(e).

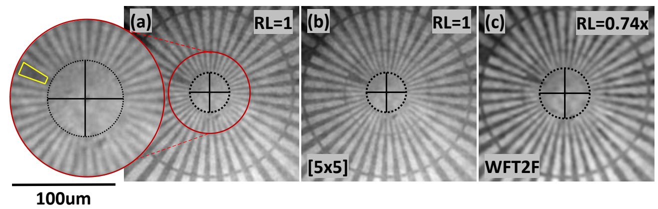

Fig. 2. Experimental results for the star target in DHM. Panel (a) is the noisy reconstructed phase image. Panels (b) shows the reconstructed phase images after applying the hybrid median-mean method for a kernel size of [5×5]. Panels (c) is the reconstructed phase images using the WFT2F method.

We have also validated the hybrid median-mean approach to reduce speckle contrast and mitigate the blurring effect using in a DHM system [9]. Figure 2 shows the performance of the hybrid median-mean approach for the reconstructed phase image of a star target. The star target allows us to quantify the experimental resolution limit, estimating how much the resolution has been penalized at each approach. The black dashed circles inside each panel mark the minimum resolved star pattern (e.g., experimental resolution limit, RL). From all these images, we have estimated the resolution limit. Whereas the reconstructed image from the hybrid median-mean approach does not penalize the resolution (e.g., RL = 1), the WFT2F method provides a reconstructed image in which the resolution limit has reduced by a factor of 26% (e.g., RL = 0.74). Thus, the hybrid median-mean method shows superior performance in DHM than the WFT2F method, mitigating the tradeoff between reduced speckle noise and deterioration of the resolution limit.

3. Conclusions

The hybrid median-mean approach allows reducing the speckle contrast up to 72% for amplitude images of DH and 30% for phase images of DHM, keeping the resolution up to 98% from the original value (e.g., no adding blurring effects). The hallmark characteristics of the proposed method are its simplicity and efficiency. Those features allow reducing the processing time from 334.32 seconds using the WFT2F method [4] to 12.10 seconds using the proposed method on an image of 1024 × 1024 px^2, running both approaches in a computer Core-i5, 2.30GHz, RAM 8.00 GB. We predict that the proposed method could be applied to any image distorted by speckle noise from any interferometric system such as ultrasound and optical coherence tomography.

4. References

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