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Carrier Noise Reduction in Speckle Correlation Interferometry by a Unique Averaging Technique

Chandra S. Vikram, University of Alabama in Huntsville,
Center for Applied Optics, Huntsville, Alabama 35899

and

Martin J. Pechersky, Westinghouse Savannah River Company,
Savannah River Technology Center, Aiken, South Carolina 29802

ABSTRACT

We present experimental result of carrier speckle noise averaging by a novel approach to generate numerous identical correlation fringes with randomly different speckles. The surface under study is sprayed with a new dry paint or a layer each time for the repetitive experiments to generate randomly different surfaces of the carrier speckle patterns.

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One of the problems in speckle correlation interferometry [1-6] fringes is speckle noise. These speckles are basically used as a carrier of the information. The degree of correlation ultimately yields the desired information in form of correlation fringes. At that stage the speckle become unwelcome. They give spatial noise and become troublesome particularly as the correlation fringe frequency increases. Thus, if one can remove them or reduce their contrast, the errors will reduce and measurement range will enhance. There has been attempts to solve this problem. [7, 8]

Phase stepping interferometry, at least in principle provides an ideal solution. However, algorithms demand uniform intensities and constant fringe contrast - rare in practical situations and more so in presence of speckle noise. That is why preprocessing such as Fourier filtering is often recommended. Unfortunately, these techniques reduce spatial resolution. Then there are isolated applications such as using a scale-space filter for the speckle noise reduction, [9] direct correlation computations, [10] and fast Fourier transform based image compression. [11]

Thus, in spite of what phase stepping interferometry or other post processing tools may ultimately offer, it is of great advantage to eliminate/reduce the speckle noise to begin with. One of the most effective ways to reduce the speckle noise is to superimpose several patterns with identical fringe function but with uncorrelated speckles. The speckles can be decorrelated by changing the direction of illumination, rotating a diffuser in the illumination, or rotating a subaperture in the imaging lens. This kind of averaging of multiple uncorrelated frames (but with identical fringe function) is very effective in improving the SNR. [7, 8] Let us summarize some undesired effects of the known frame averaging techniques. In the direction of illumination change approach, substantial change may be required for the desired decorrelation effect. That changes the sensitivity vector - going against precision measurements which is basis of removing the speckle noise to begin with. The same is true for rotating diffuser in the illumination beam - no precise definition of illumination angles. As we may know, collimated beams with known illumination angles is most desired for quantitative applications.

Having several uncorrelated frames but with identical fringe functions is difficult but still possible in a large number of laboratory experiments where the experiment can be repeated. Material response upon loading in the elastic domain, characterization of a solid phase object (like the wedge prism used in our experiment), etc. are often encountered in a laboratory. Such experiments can be repeated to obtain the identical fringe patterns but with randomly different carrier speckles.

In this letter we demonstrate a very simple but effective way, and without the undesired effects as stated above, to obtain randomly different carrier speckles. We spray the surface with a dry coating. [12] Such developer paints are common in processes involving weld inspection, local surface flaw detection, etc. The paint can easily be removed using a damped wipe. More importantly, we have found in numerous strain analysis experiments that the paint locally moves with the surface and reveals the true surface deformation underneath. Incidentally, coatings have been used in holographic and other interferometry applications to increase surface reflectivity. However, our main goal here is to obtain randomly different speckle carriers. Recoating on the clean surface or over previously coated surface creates randomly different surface with randomly different carrier speckle patterns. By repeating the experiments with such different surfaces to obtain correlation fringes, successful averaging of the speckle noise can thus be performed as stated above.

The experiments reported here are using the common speckle correlation interferometry with two symmetrical beams to illuminate the object. [13] Two collimated HeNe (632.8 nm wavelength) beams derived from the same laser illuminate the object (a metal sheet of 1.27 cm width) at 45 ° to the surface normal or the optical axis. In one of the arms, a fused silica wedge prism of wedge angle slightly more than 2 arc min is kept but rotated in plane by 180 ° before the second storage. Upon subtraction, the usual speckle correlation fringes are obtained showing the wedge (double the effect because the rotation) effect. About 7 fringes per centimeter on the object surface as expected are obtained. Figure 1 shows some of the results. The frames represent 2.7 cm $\times$ 2 cm of the object space. The usual experiment of Fig. 1(b) was repeated five times with a different layer of the paint on the surface. Each correlation fringe pattern was appearing similar to that of Fig. 1(b) but obviously with different carrier speckle pattern. However, once averaged, the result [Fig. 2 (c)] showed remarkable improvement. It is known [7] that when N uncorrelated patterns are added, the average speckle contrast (from standard single correlation fringe experiment, i.e. one corresponding to ($N = 1$) is reduced to a factor of $1/\sqrt{N}$. Even a single averaging step ($N = 2$) can result in holographic speckle contrast ! Although as large as possible N is better, after $N = 50$, there is hardly any visual improvement. [7]

Nevertheless, as shown in the experiment, a more practical just a few frames yields a remarkable reduction in the contrast of the carrier speckles.

In conclusion the spray process provides a simple but effective alternative process for reducing the carrier fringe contrast in speckle correlation interferometry.

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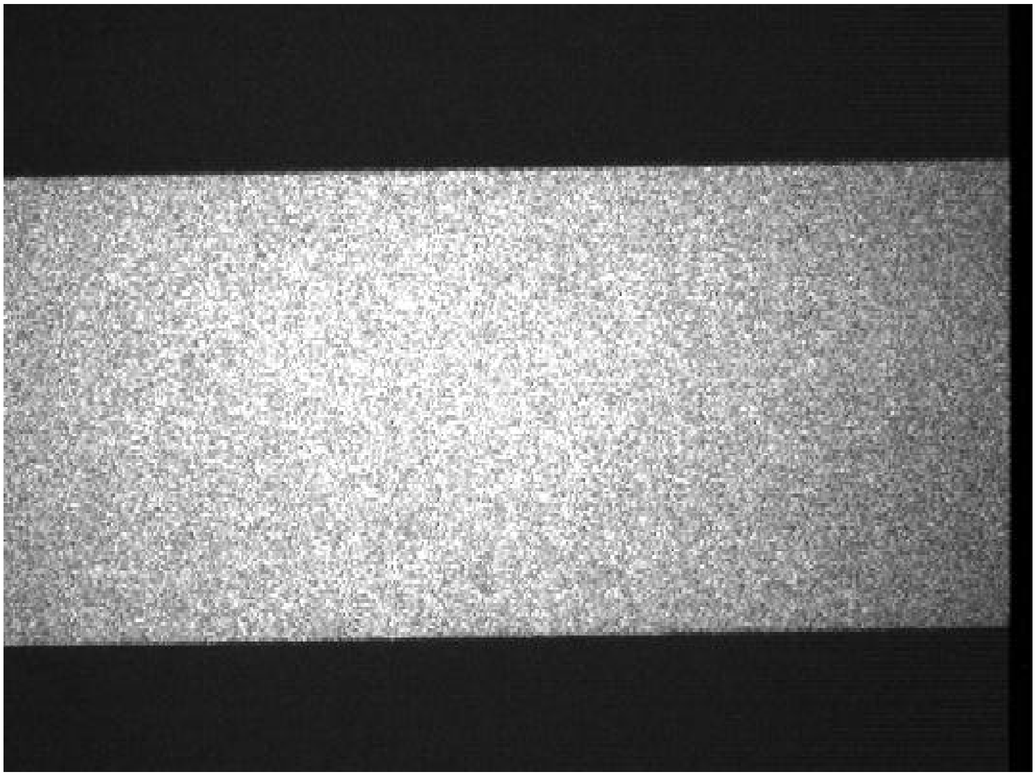
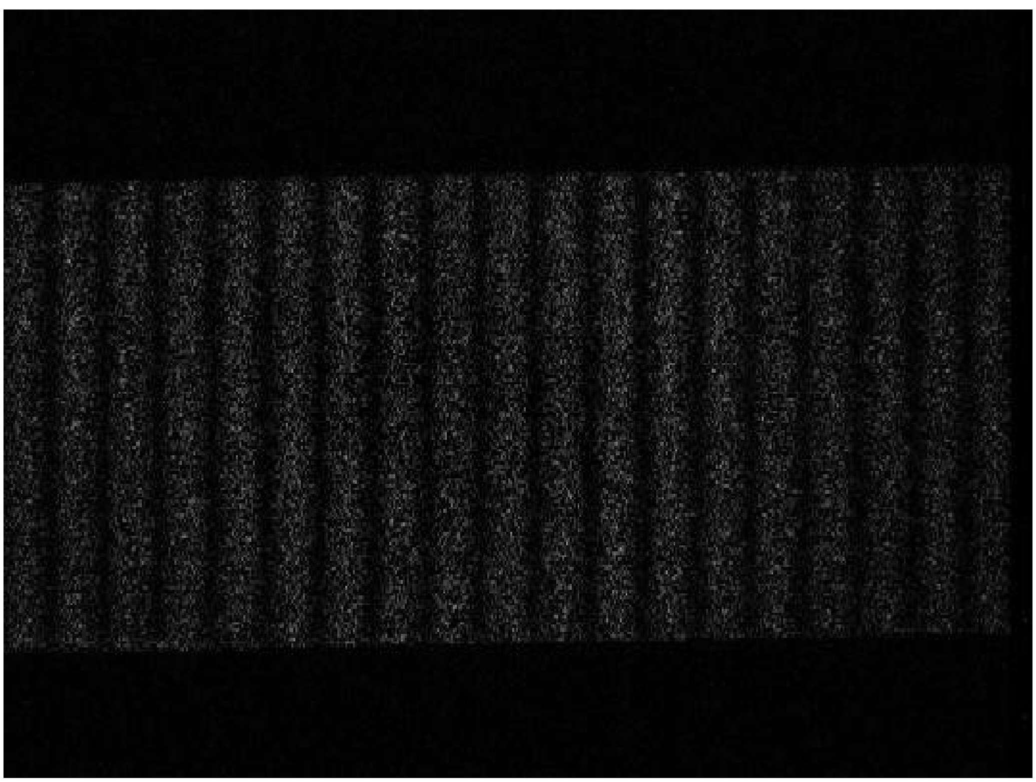
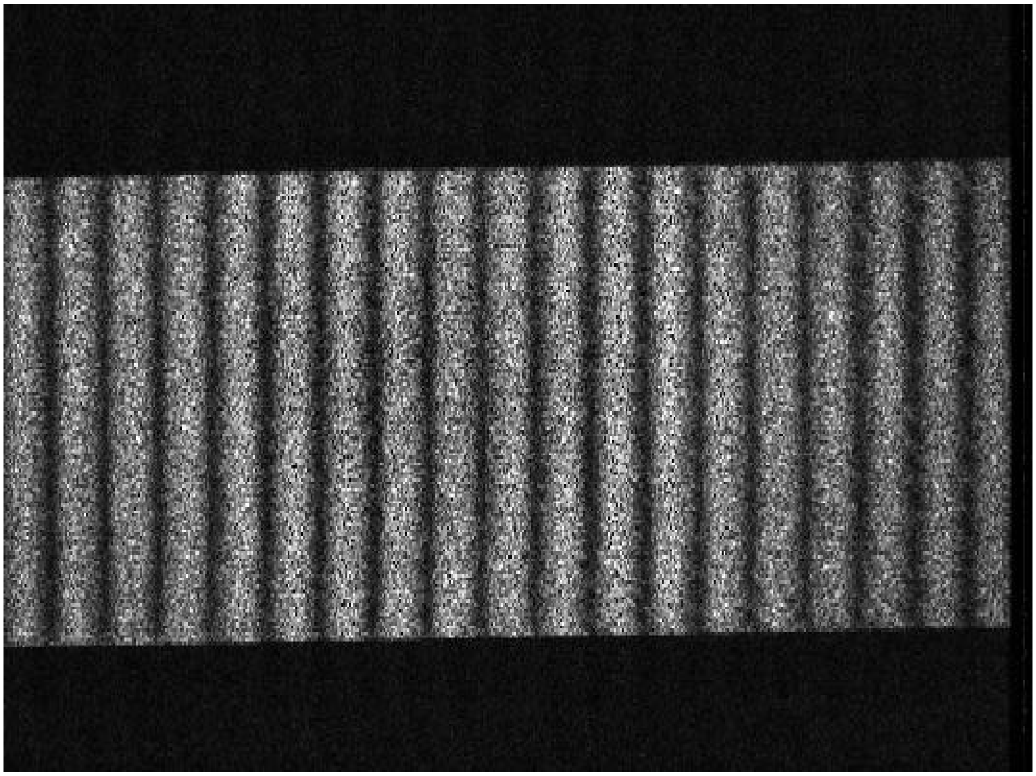


(a)



(b)



(c)

Fig. 1 (a) A typical image frame. (b) The usual correlation or subtraction fringes due to the prism. (c) Average of five correlation fringe patterns with different painted surface.