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On the Investigation of the reduction of Phase Singularities in Speckles Interferometry

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Speckle interferometry is a well-established method for the measurement of rough surfaces like deformation in optical metrology. Although the multiple beam interference, which is caused by the roughness of the specimen, leads to a random phase distributed in the detection plane, the phase still holds in it the information regarding the studied specimen. By acquiring the phase information of the same object twice, one at a static initial mechanical state, and one deformed, the mechanical deformation applied and its strength can be characterized. But the acquired raw phase usually is noisy, leading to considerable errors, especially after the phase unwrapping process. The main source of this noise is due to the presence of phase singularities [1]. Reducing the number of phase singularities is commonly achieved by post-processing via computational means, in particular by smoothing and filtering operations. It is the aim of this research to investigate the reduction process by physical means at the source level [2]. One of the methods to reduce the number of phase singularities is to reduce the spatial coherence of the source by taking a larger incoherent light source. However, it was shown that the reduction mechanism does not follow the $1/\sqrt{N}$ reduction behaviour regardless of the speckles sizes, where N is the number of uncorrelated speckle fields [1]. For that purpose, a setup was built in order to achieve an experimental verification of the reduction mechanism based on a Michelson interferometer, the setup and the results are shown in Fig. 1. The promising results of the reduction show an almost complete elimination of the noise for relatively low frequency fringes at the source level, which would be also useful at the higher frequencies fringes compared to the conventional computational techniques. Such a technique promises to enhance the accuracy of the deformation and form measurements.

Furthermore, since the reduction mechanism shows more complex and rich behaviour than a commonly assumed $1/\sqrt{N}$ behaviour, simulations were carried out which have provided two main causes regarding the reduction mechanism. The results of these simulations indicate that incoherent averaging based on an extended light source has two effects:

1- Smaller speckles.

2- More ordered speckles.

In order to verify those effects and broaden our understanding of the reduction mechanism, the Michelson setup was enhanced that allows for an experimental investigation of the derived speculations from simulations. The setup achieves a separation of the reference arm from the object arm, where on the path of the latter a speckle stop is placed to control the investigated speckles size, see Fig. 2. Firstly, a rotated binary grating was used for providing lateral shifted point sources along one axis, the resulted intensities are added later using Matlab. Later on, a Damman grating replaced the binary grating for the selection of multiple discrete point source along the X and Y axis as it has been done using the simulations.

Part of the results of such an experiment by placing a rotated binary grating are shown in Fig. 3. The experiment confirmed what the simulation has shown, the speckles get smaller for incoherent averaging. This has the effect of forcing the phase edges to become smaller, hence, to be more averaged out. The result of the experiment by placing a 3x3 Damman grating is shown in Fig. 4. Similarly, the experiment confirmed what the simulation has shown namely that, the addition of mutually incoherent discrete point sources leads to re-position the speckles field in an ordered manner. The main result of such a behaviour is raising the likelihood of placing phase edges at the same position before and after the deformation measurements, such that during the calculations of the deformation phase these phase edges tend to cancel each other out.

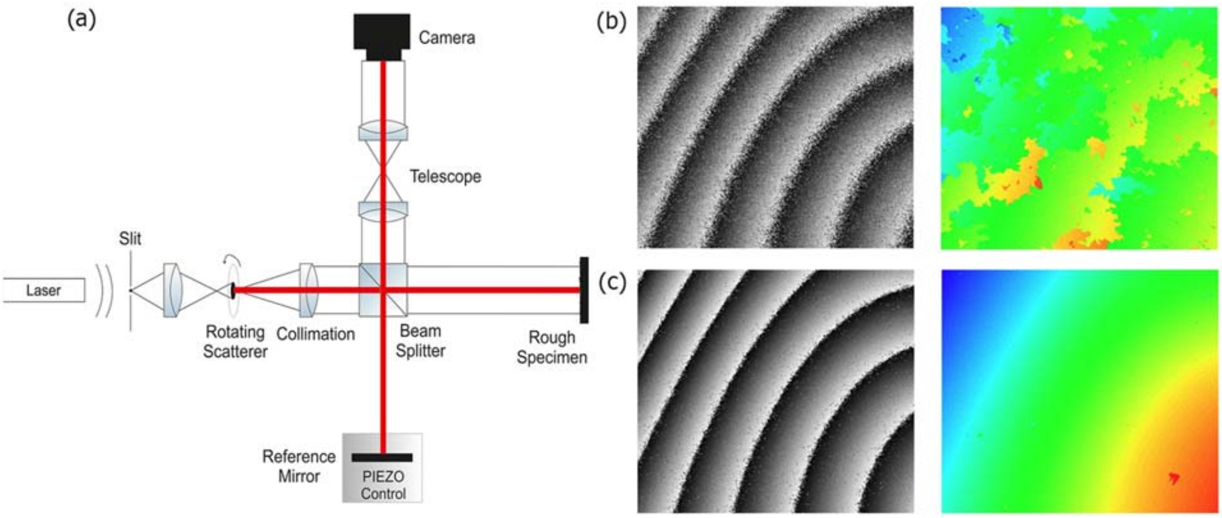

Fig. 1. (a) Deformation measurements setup. (b) Left: attained fringes due to the deformation process from the setup in (a), Right: the unwrapped phase map. (c) Left: attained fringes due to the deformation process after introducing a rotating scatterer, Right: the unwrapped phase map. Results from [2]. A simple unwrapper was used to indicate the noise level of the deformation phase.

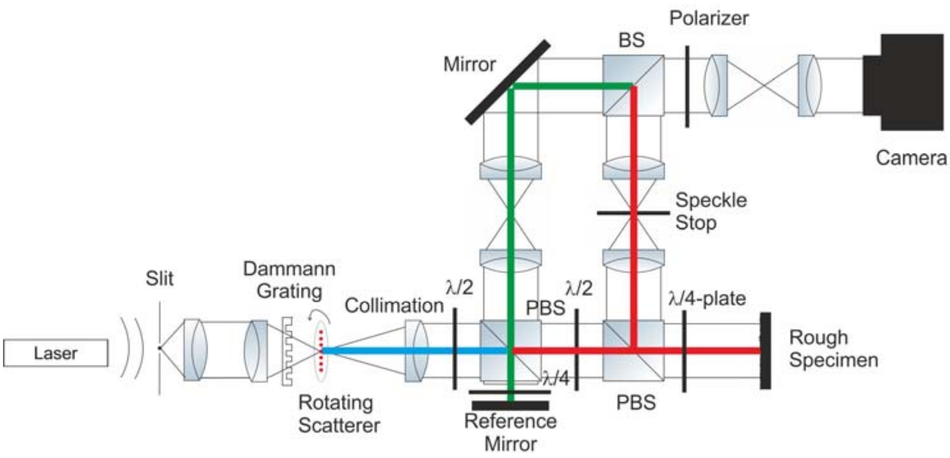

Fig. 2. A hybrid between Mach-Zehnder and Michelson speckles interferometer with a Damman grating.

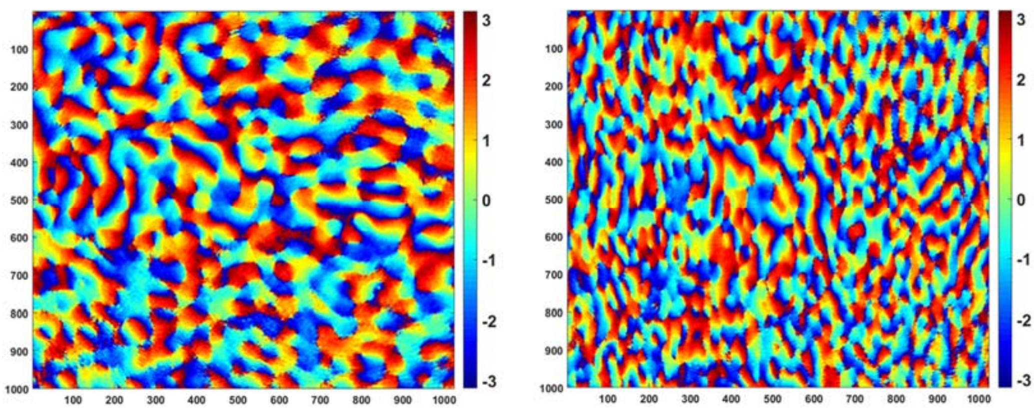

Fig. 3. Raw phase maps. Left: Centred light point source. Right: The incoherence addition of 1x7 discrete point sources, achieved by tilting a binary grating around the X axis for +7°, -7°, +15°, -15°, +23°, -23°.

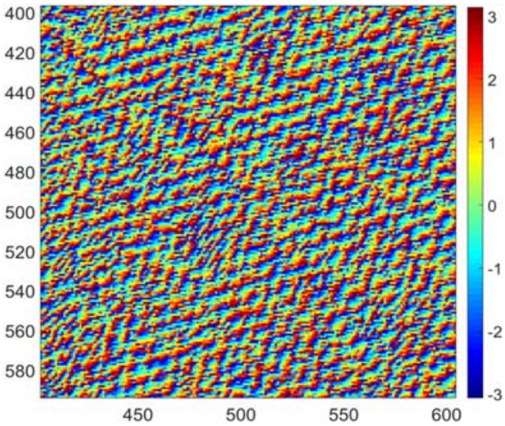

Fig. 4. Raw phase map. The resulted phase map of the mutually incoherent addition of 3x3 point sources.

References

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