Reduction of Phase Singularities in Speckle Interferometry

K. Mantel*, V. Nercissian**

** Max Planck Institute for the Science of Light, Erlangen*
*** Institute for Optics, Information, and Photonics, FAU Erlangen-Nürnberg*

mailto:Klaus.Mantel@mpl.mpg.de

We apply a tailored spatial coherence of the illuminating laser light to speckle deformation measurements. The number of phase singularities present in the deformation phase is drastically reduced, such that even a simple unwrapper for smooth surfaces can unwrap the phase data without almost any residual errors. The underlying mechanism is subtle and requires further investigations.

1 Introduction

Speckle interferometry is impaired by the ubiquitous presence of phase singularities [1]. Elaborate software algorithms for evaluating speckle phase maps [2] notwithstanding, it is useful to consider physical mechanisms to reduce the number of phase singularities in the first place, as Fig 1. illustrates. Firstly, the phase maps become smoother without loosing the fine details of the object structure itself; secondly, high freqeuency fringes which have been smeared out by the phase singularities can be discerned and evaluated again, which is important for specimens with high dynamics [3].

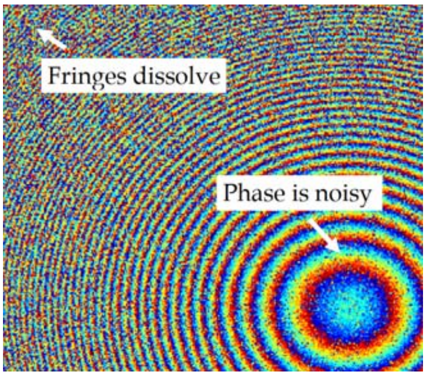

Fig. 1 *A physical reduction of phase singularities is useful.*

The physical reduction of phase singularities is done by tailoring the spatial coherence of the illuminating laser light in a Michelson interferometer [4]. As a specific example, deformation measurements have been chosen, although the procedure may also be used for form measurements.

2 Experimental results

As an illustration of the deteriorating effect phase singularities have on the deformation phase, a result from a deformation measurement under fully coherent illumination has been fed to a software unwrapper originally designed for smooth surfaces only. As expected, the unwrapping completely fails, see Fig. 2.

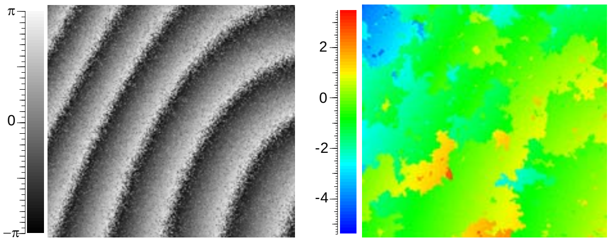

Fig. 2 *Deformation fringes with fully coherent illumination. Left: deformation phase. Right: unwrapping result with a simple, unsophisticated algorithm.*

This situation changes, however, when the spatial coherence of the light field is reduced by introducing a rotating scatterer, forming an extended, incoherent light source, Fig. 3. The spatial extension of the light source as well as the mutual incoherence of the light source points generate a superposition of several independent, mutually incoherent speckle intensity fields. The incoherent averaging that ensues allows the physical reduction of the phase singularities present in the deformation phase. It should be noted, however, that the light source is placed outside of the interferometer, which means that the light source not only has an influence on the specimen, but also on the reference arm. This will be important for the explanation of the effect, see section 3.

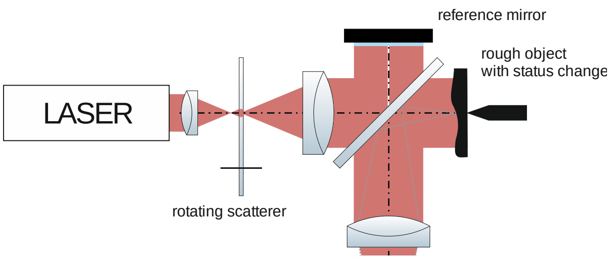

Fig. 3 *Setup with a disc shaped light source. The light is defocused onto the rotating scatterer to emulate a spatially incoherent source.*

The deformation phase therefore becomes much more clearly defined, and the simple unwrapper succeeds in unwrapping the phase data, as Fig. 4

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illustrates. Only a few unwrapping errors remain in the unwrapped phase.

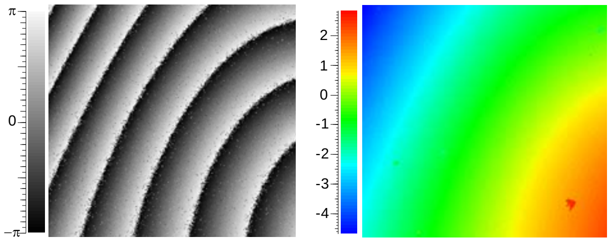

Fig. 4 *Deformation fringes with a disc shaped light source. Left: deformation phase. Right: unwrapping result with the same simple, unsophisticated algorithm.*

It is known from the interferometry of smooth surfaces that for spatially extended sources, the arm lengths of the interferometer must be balanced to ensure sufficient visibility. The same holds true for the speckle case. Since this might be a restriction in practice, either for the dynamics of the specimen or the flexibility in adjusting the arm lengths to match the experimental needs, the disc source was replaced by a multi-point source, Fig 5. This alleviates the restriction on the arm length balance, such that, for the 5x5-source used here, an imbalance of several centimeters didn't have a noticeable effect on the speckle visibility.

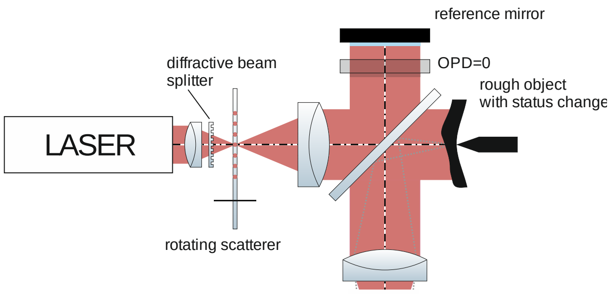

Fig. 5 *Setup with a multi-point light source. A diffractive beam splitter is used in combination with a rotating scatterer. A more flexible positioning of the reference mirror is possible, as well as an object with higher dynamics.*

Figure 6 shows the measurement results. Although the reduction effect was slightly less pronounced than for the disc source, the fringes are still considerably smoother than for the coherent case.

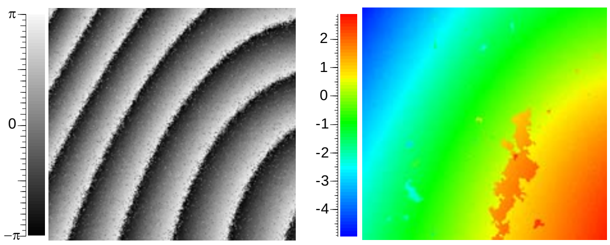

Fig. 6 *Deformation fringes with a multi-point light source. Left: deformation phase. Right: unwrapping result with the simple, unsophisticated algorithm.*

3 The reduction mechanism

Regarding Fig. 4, it could be asked if the light source diameter could be chosen to be larger, getting rid of the few remaining unwrapping errors. As it turns out, however, increasing the light source diameter makes the unwrapping results worse again. The diameter leading to Fig. 4 in fact gave the optimum result (at least for the interferometric setup that was used). This is in contrast to the situation for smooth surfaces, where rotating scatterers are used to reduce coherent noise. There, no such optimum light source diameter exists, to our knowledge, and increasing the source diameter always improves the smoothness of the interferogram. This is a first indication that there is more behind the reduction process than is apparent at first sight.

Indeed, it turns out that the influence of the light source on the reference arm plays a vital role. It can be shown that the phase distributions of single measurements (either before or after the deformation takes place) can be viewed, in a certain mathematical sense, as the sum of an averaged object phase, and a contribution coming from the influence of the light source on the reference arm of the interferometer. Figure 7 illustrates this for the multi-point source. The periodicity of this contribution is a direct consequence of the periodicity of the multi-point source. Thus, the incoherent averaging has two effects: The effective speckle size is reduced, and the speckle phase appears more ordered, leading to an increase in the correlation between the phase singularities in the phase maps before and after deformation. Both effects can explain a reduction in the number of phase singularities.

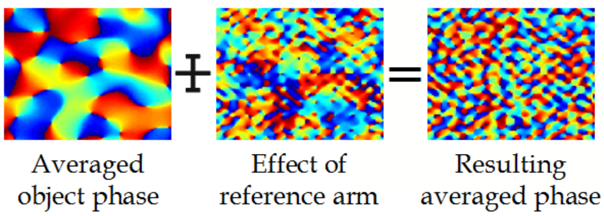

Fig. 7 *Symbolic representation of the reduction mechanism for a multi-point light source.*

References

[1] J. F. Nye, and M. V. Berry, “Dislocations in wave trains,” in *Proc. R. Soc. London Ser. A* **336**:165-190 (1974)

[2] D. C. Ghiglia, and M. D. Pritt, *Two-dimensional phase unwrapping,* (John Wiley & Sons, 1998)

[3] L. Aulbach, priv. comm.

[4] K. Mantel, and V. Nercissian, “Reducing phase singularities in speckle interferometry by coherence tailoring,“ *arXiv:1611.02987 [physics.ins-det]* (2016)