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Lateral speckle size in Phase Retrieval systems

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We utilise a Phase Retrieval algorithm for estimating the complex amplitude of a wave field. As input to our system speckle fields are applied. We investigate the speckle size in retrieved and propagated distributions.

1 Introduction

Holography and Phase Retrieval (PR) systems are commonly used to recover the phase information of an optical signal. Holography is based on interferometry. The phase information is encoded in the intensity distribution. Phase retrieval algorithms use only intensity distributions. For phase recovery an iterative algorithm is utilised.
We use two intensity distributions captured in distinct planes and a Gerchberg-Saxton type algorithm [1, 2]. Our test field for the phase retrieval is a speckle pattern.

2 Experimental setup

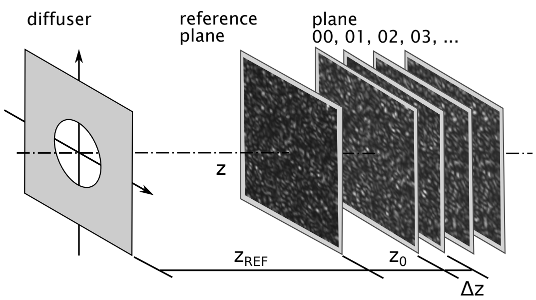

Fig. 1 *Experimental setup. The diffuser is illuminated with a laser beam (λ = 633 nm). The speckle field is captured with a CCD-camera (Kodak KAI-4022, 2056×2056, 7.4 µm) in distinct planes:* z_{ref} *= 49 mm,* z_0 *= 10 mm,* Δz *= 1 mm.*

A set of speckle patterns using a laser (λ = 633 nm) is recorded in distinct planes. The probability density functions of the captured intensities follow a negative exponential distribution. This is interpreted as an indicator that the speckle field is fully developed. The speckle size is determined by an autocorrelation of the speckle intensity and is four times greater than the pixel size and hence is well sampled in a Nyquist sense.

3 Phase retrieval algorithm

At the start two adjacent intensities from the set of captured speckle patterns are chosen. The square root of the intensity in Plane 00 is multiplied by an initial phase to obtain a complex wave. We use a plane phase. The complex wave is propagated to Plane 01 using the spectral method or convolution method. The pixel size in the Fresnel plane has no scaling factor when using the spectral method instead of the direct method. The non-scaling property of the spectral method is very convenient for our purposes, since intensity distributions in different planes can be easily compared against each other. In plane two the phase of the propagated complex wave and the square root of the captured intensity yield a new complex distribution that is propagated back to Plane 00. Back in Plane 00 one iteration step of the PR algorithm is completed. The convergence of the algorithm is commonly monitored using the RMS error

$$\mathrm{RMS} = \sqrt{\mathrm{mean}((\sqrt{I} - A_{1,n})^2)}. \tag{1}$$

We expect that if the PR algorithm converges the speckle size of the measured intensity at Plane 00 as should match the speckle size of the "iterated intensity". Hence the speckle size in the iterated intensities can be considered as another metric. After every iteration step the speckle size in the retrieved amplitude distribution $A_{1,n}$ is determined. Fig. 2 reveals that the speckle size converges towards the speckle size in the captured image. [1, 3, 4]

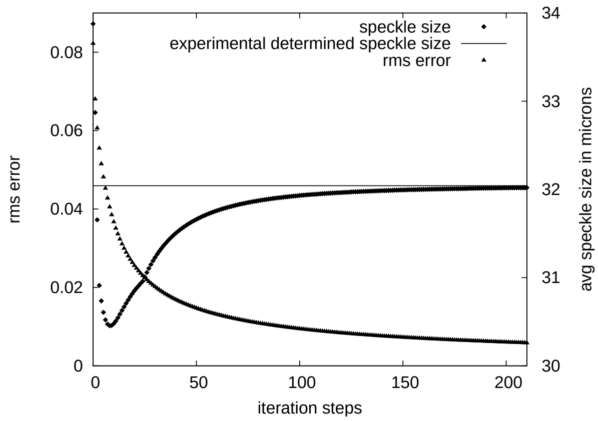

Fig. 2 *Speckle size in microns and RMS error vs iteration steps*

4 Propagation of retrieved distributions

The PR algorithm provides us with an estimate of the complex amplitude and we can numerically propagate to other planes. In our experiments we recored a set of speckle patterns and hence we know the real intensity distributions in several planes. These intensity distributions can be compared with retrieved and propagated ones.
For the PR algorithm two planes at a distance of 1 mm are utilised. Following the termination of the algorithm, the retrieved complex amplitude is propagated to the reference plane, see Fig. 1. The reference plane lies 49 mm behind the diffuser and the complex amplitude has to be propagated 10 mm backward. For the propagation the spectral method is applied. The "iterated intensity" and the measured intensity are compared in terms of speckle size.

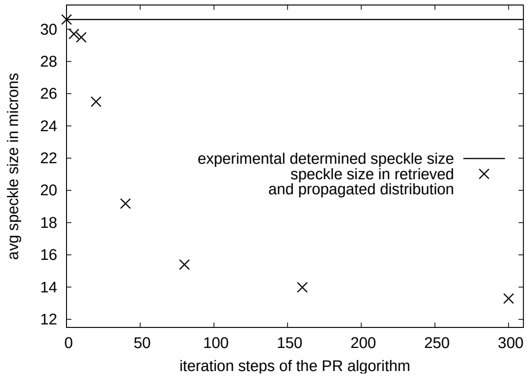

Fig. 3 *Speckle size in microns vs iteration steps (reference plane)*

Fig. 3 depicts the speckle sizes in the reference plane of retrieved and following propagated distributions. The PR algorithm is terminated after a certain number of steps. The complex amplitude returned at this point is then used to estimate the intensity in the reference plane. A measure of the similarity between the "iterated" and measured intensities in the reference plane is given by the speckle size. Fig. 3 indicates that the more iterations steps used, the further the "iterated" and measured intensities in the reference plane diverge. The speckle size in the captured intensity is illustrated as a horizontal line in Fig. 3.

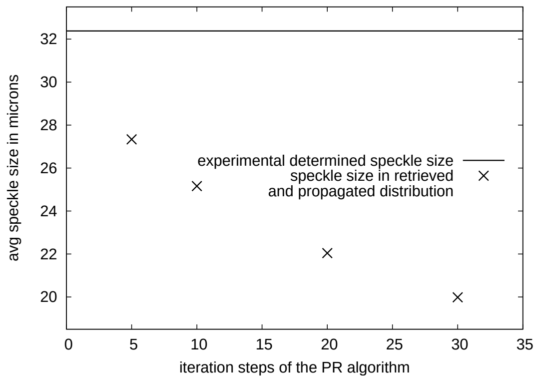

Fig. 4 *Speckle size in microns vs iteration steps (forward propagation for 3 mm in plane 03)*

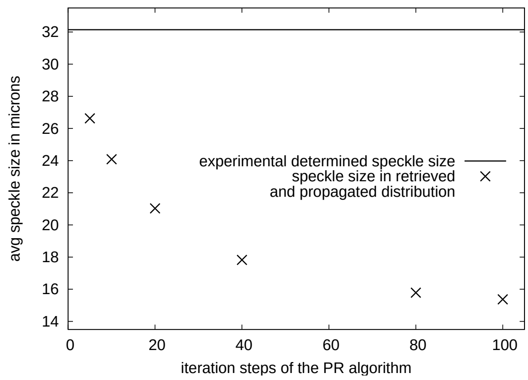

Fig. 5 *Speckle size in microns vs iteration steps (propagation in plane 01)*

An other way is to propagate the retrieved distributions forward in plane 03 (see Fig. 1) and compare the speckle sizes (see. Fig. 4). Or we feed the PR algorithm with two planes at a distance of 2 mm (plane 00 and 02) and propagate the retrieved one in the plane in between (plane 01) (see. Fig. 5). All investigations and also tests with different data sets demonstrate the same behaviour.

5 Summary and conclusions

The basic principles of a PR algorithm are discussed. The convergence of the algorithm applying as cost function the speckle size and the RMS error is presented. Concerning the converging speckle size towards the experimentell determined we expect the PR algorithm yields the right answer. The behaviour of retrieved and propagated distributions raises questions like Fig. 3-5 reveal.
The next step of our investigations is to integrate a holographic setup and check against the reconstructed and retrieved phase distribution.
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