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Reconstruction of Digital in-line Holograms and Suppression of the Twin-image in Gabor Holography

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Abstract: This report deals with experimental and theoretical investigation of methods of reconstruction of images of micro particles from digital holograms. It is mainly focused on the problem of existence on reconstructed images parasitic signal known as twin-image. It was suggested and investigated two methods of elimination of this effect – individual registration of twin-image with subsequent subtraction of it and averaging of series of holograms obtained from several individual channels. It was provided analysis of results and comparison of these methods.

Keywords: Digital holography, In-line, Twin-image, Convolution, FFT, Modelling holograms.

1. Introduction

Recording of dispersed phase parameters in high-speed processes requires the use of methods offering high spatial resolution in a combination with short exposure time. Digital Gabor holography is one of the most promising methods satisfying these conditions. Digital holography enables to obtain information on 3D location of microscopic objects within the limits of the explored volume. Reconstruction of a 3D scene is executed by mathematical processing of the recorded interference pattern.

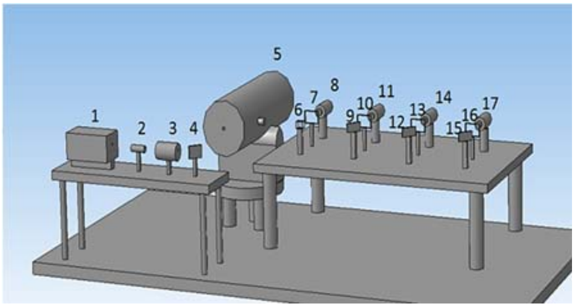
Simulation of illumination by a reference wave is applied in this case to reconstruct an image [1]. After obtaining that hologram it appears undesirable effect - ring structure around particle.

Development of methods to remove these effect is a vital task in the context of improving the quality of reconstructed images and broadening capabilities of holographic recording.

2. Techniques

In Gabor holography a laser beam propagates through the volume of investigation and some of the light scatters by the micro particles. The other light propagates through the volume as unscattered. Both wave fronts interfere so that the scattered light is a signal wave and the unscattered one is a reference wave. So it is a process of forming a hologram.

In this article setup is a tele centric system (Fig. 1), which allows us to record a holograms without scale distortion, so diameter of rings depends on just the distance from the object to the record plane [2-3]. A hologram was recorded using a four-channel recording setup, which allowed obtaining holograms at different distances from the object. The recording setup is shown in Fig. 1. The object is located between laser 1 and micro-objective 2. A beam from a laser 1 travels to the first subsystem of a tele centric system consisting of micro-objective 2 and objective 3, then a deflecting mirror 4 directs the beam to the second subsystem of tele centric system consisting of a telescope 5 and the lens 7, 10, 13, 16. The holograms are recorded on recording device 8, 11, 14, 17. Beamsplitter cube, deflecting mirrors 9, 12, 15 is needed for splitting a laser beam into for beams.



1 – laser, 2- micro-objective, 3- objective,
4, 9, 12, 15 – deflecting mirrors, 5 – telescope,
6 – beamsplitter cube, 7, 10, 13, 16 – lenses,
8, 11, 14, 17 – recording devices

Fig. 1. Four-channel recording setup.

3. Twin-image

A hologram is formed as a result of interaction between an object wave A_{obj}, and a coherent light beam A_{ref}. The total amplitude of waves is summed up $A = A_{obj} + A_{ref}$ and the intensity on the screen can be expressed as:

$$I_{screen} = A^*_{ref}A_{ref} + \left[A^*_{obj}A_{ref} + A^*_{ref}A_{obj}\right] + A^*_{obj}A_{obj} \quad (1)$$

Two terms in brackets are holographic terms, real and virtual images, respectively. The last term is cross-interference that is formed by interference of an object with itself, as in the conventional diffraction theory; the first term is an intensity background from a reference wave.

The virtual image is a twin-image located at the same distance as a real image but on the opposite side from the detector. A twin-image can cause problems at reconstruction of images in single-beam holography, as it is superimposed on a real image [4]. Fig. 2 gives an example of such a twin-image. This image is concentric rings located around each particle.

The reconstructed image Fig. 2 is only disturbed by the out-of-focus twin-image.

4. Suppression of the Twin-image

Two methods for suppression of a twin-image are proposed: 1 - Averaging of holograms written from different distances from an object, 2 - Recording of two holograms one of which is located at a doubled distance, with further subtraction of the second hologram from the image reconstructed from the first hologram.

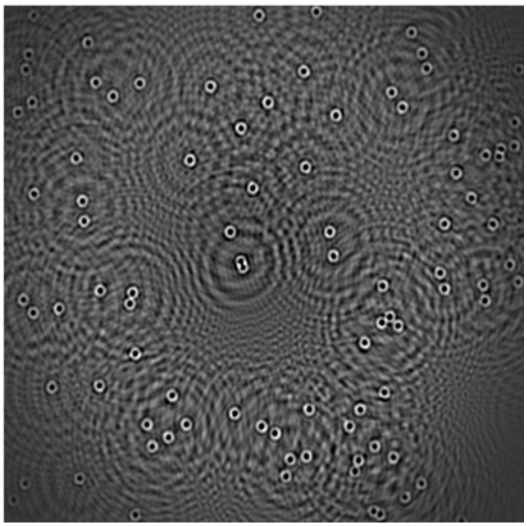


Fig. 2. Reconstructed image of particle and its defocused twin.

4.1. Method 1

Recording devices 11, 14, 17 are located at different distances from the object to be recorded, therefore the obtained images have different diameters of interference circles. When they are reconstructed different twin-images are observed.

4.2. Method 2

According to the geometry of record and reconstruction, a twin-image is located at a doubled distance from the detector (see Fig. 3).

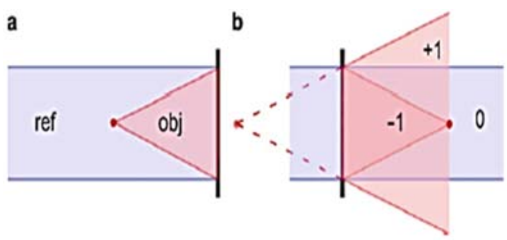


Fig. 3. Geometry of record and reconstruction of holograms.

Recording of the second hologram at a doubled distance 2d permits to record a twin-image that appears on the reconstructed hologram recorded at a distance d. A twin-image can be removed by subtracting the hologram, written at a distance 2d, from the reconstructed image [5-6].

5. Simulating

For providing numerical simulation on PC it was used software 'Fresnel'. This program is used for providing mathematical calculations of propagation of radiation and it is based on calculation of Fresnel-Kirchhoff integral for specified characteristics of radiation and propagation medium. Holograms were simulated from different distances between an object and detector. The results are shown on Fig. 5.

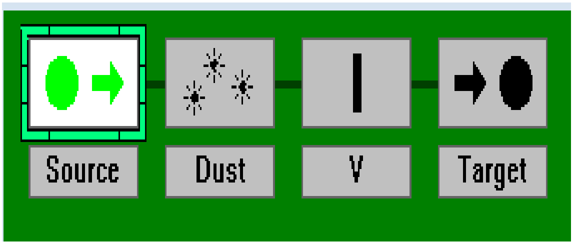


Fig. 4. Scheme of simulating of holograms.

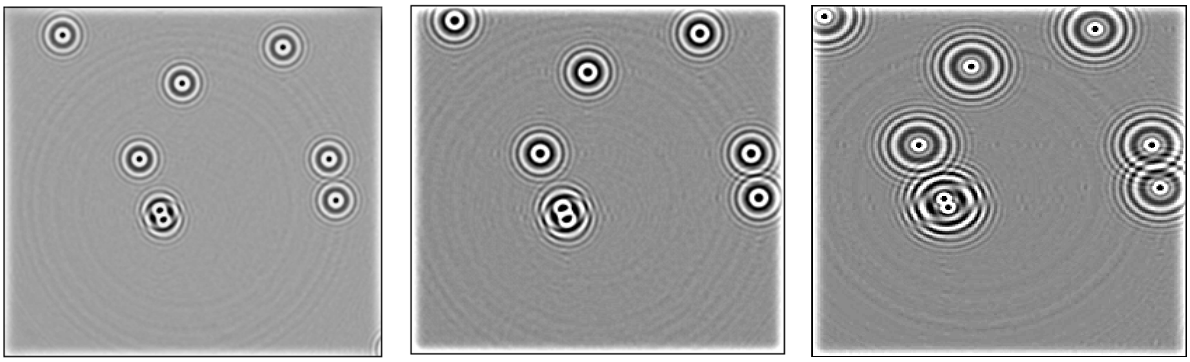


Fig. 5. Simulating holograms from different distances from recording device.

The result of averaging is shown on Fig. 6. It is shown that on the reconstructed image there is no twin-image.

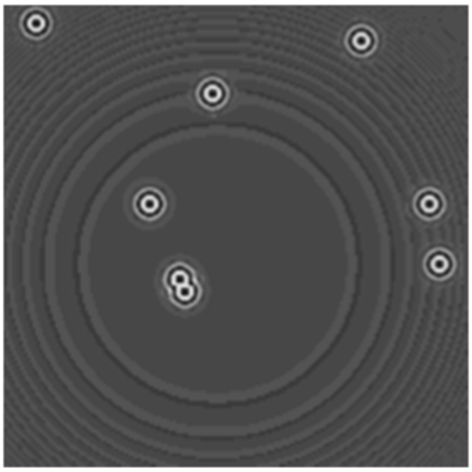


Fig. 6. Subtraction of twin-image by first method.

Also for confirmation of the second way of elimination of twin-image it was simulating two holograms for two distances d and 2d (additional hologram). From reconstructed hologram it was subtracted additional hologram. The result is shown on Fig. 7. The second way also allows completely remove twin-image.

6. Results

The First method of subtraction of twin-image allows complete removing the twin-image (Fig. 8), but for this method it's necessary to have four channels of registration at the same time, for the second method it is enough to have two channels of registration, but this method allows removing just a part of twin-image. The result is shown in the Fig. 5.

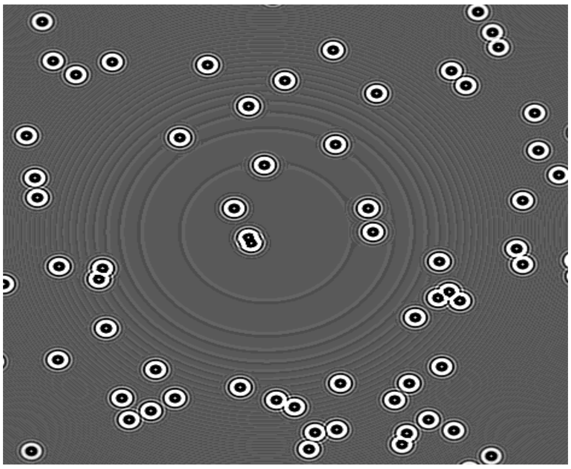
There were built light-intensity profiles along individual particles for evaluation of decreasing effect of twin-image. One of these profiles is shown on Fig. 9. Ratio of the difference maximum and minimum of the signal is equals 3.

So, it could be made a conclusion that the method of averaging is more affective and capable to reduce the effect of twin-image by 3 times.

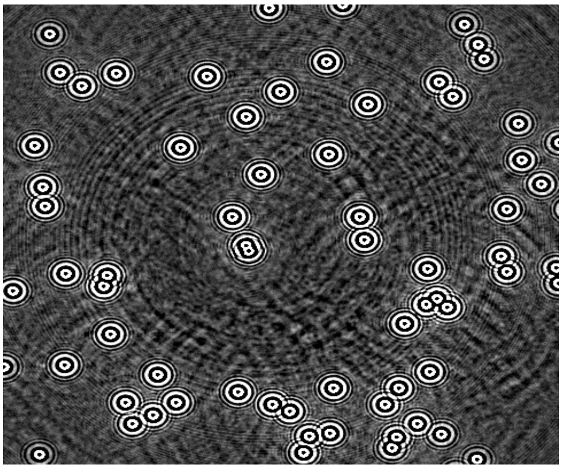
Elimination of twin-image effect plays an important role during determination of resolution of the system. For determination of resolution of four channels holographic system there were registered the image of resolution test target. Further received holograms were reconstructed using PSF function. The results are shown on the Fig. 11.

On the reconstructed image it could be seen that the elements of the target are not clear, that doesn't allows determining resolution accurately.

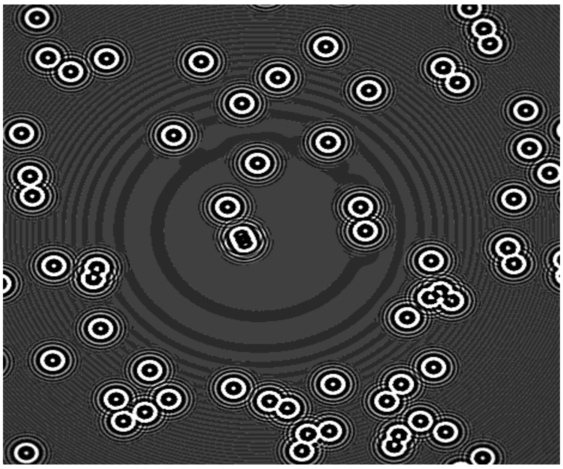
Using the method of averaging the image of obtained hologram was processed. The result is shown on the Fig. 12.



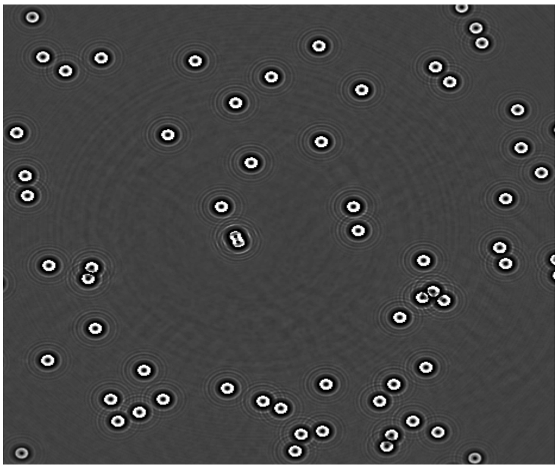
a) Hologram (distance d)



b) Reconstructed hologram from (a)

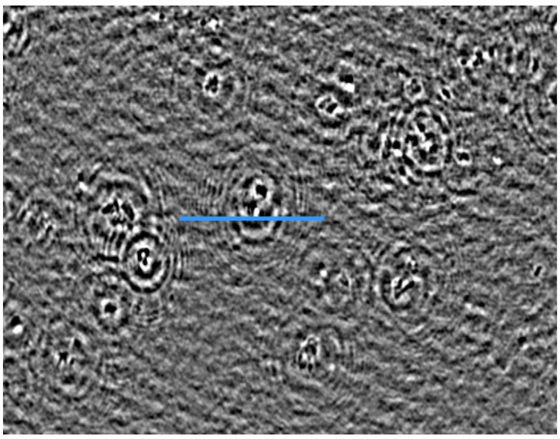


c) Additional hologram (distance 2d)

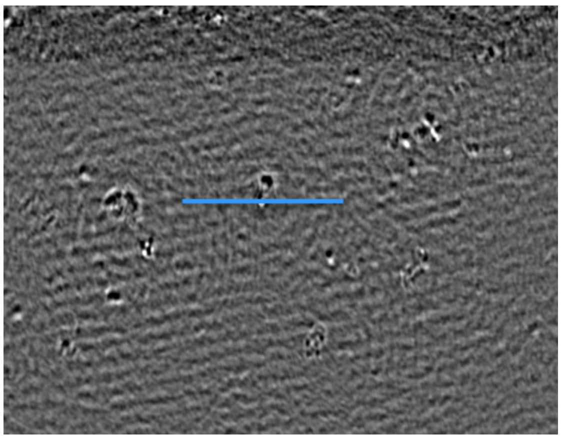


d) Reconstructed hologram after suppression of the twin-image

Fig. 7. Subtraction of twin-image by second method.



a) Reconstructed hologram before suppression



b) Reconstructed hologram after suppression

Fig. 8. Subtraction of twin-image by first method.

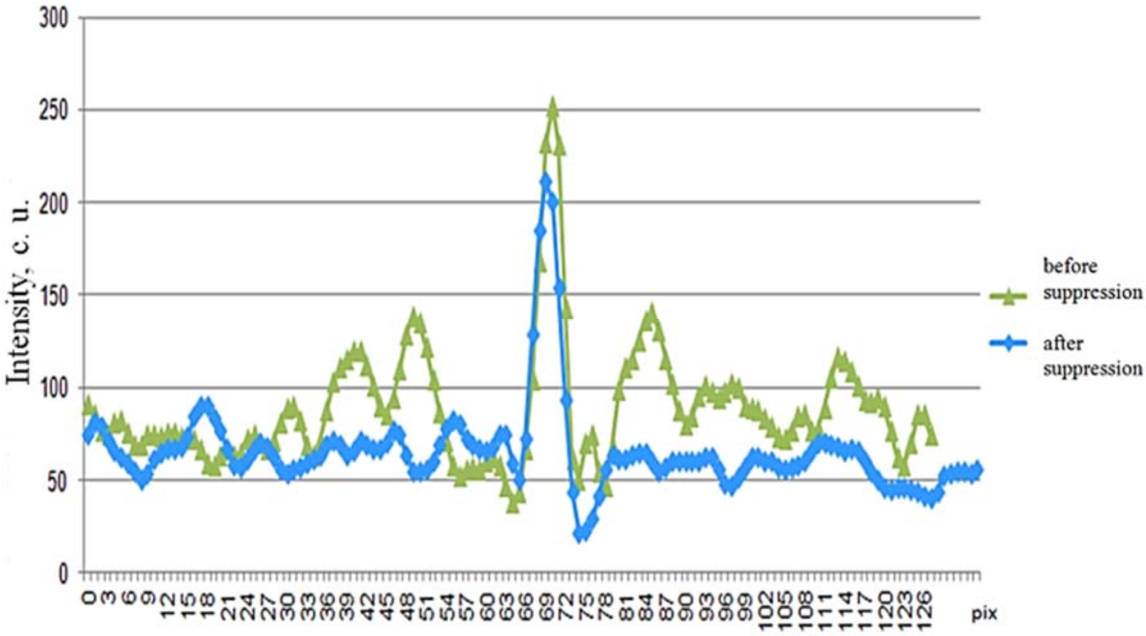
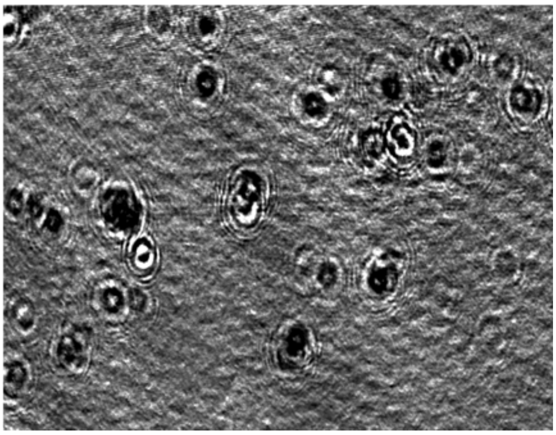
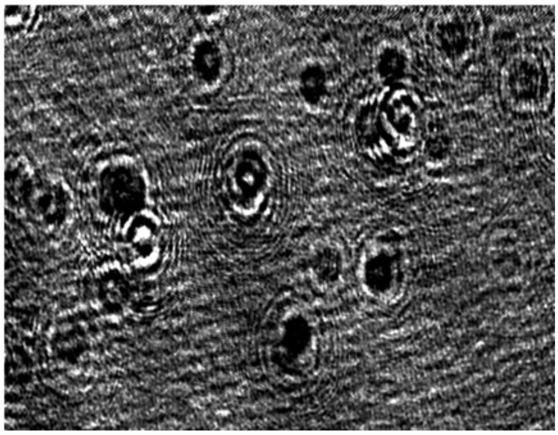


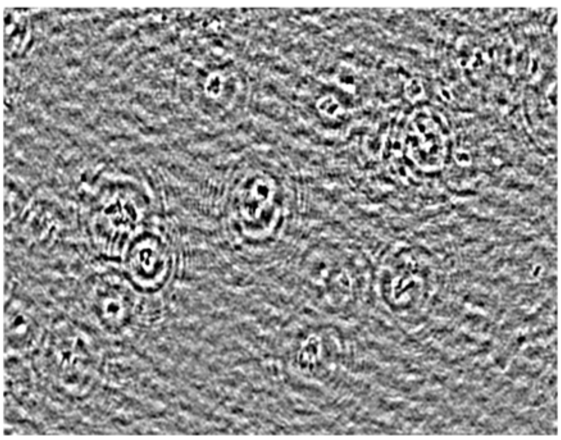
Fig. 9. The profiles of intensity.



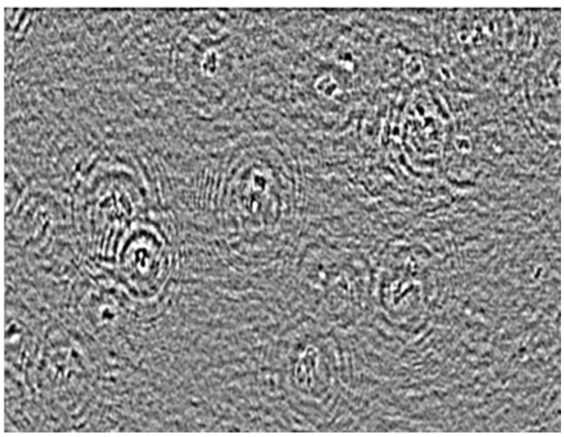
a –recorded hologram (distance d)



b – additional recorded hologram (distance 2d)



c – reconstructed hologram from (a)



d – reconstructed hologram after suppression of the twin-image

Fig. 10. Subtraction of twin-image by second method.

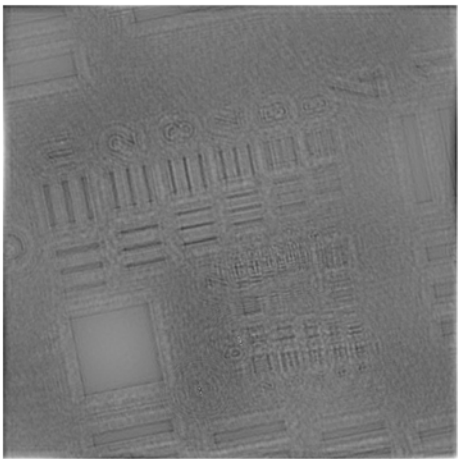


Fig. 11. Reconstructed hologram before suppression.

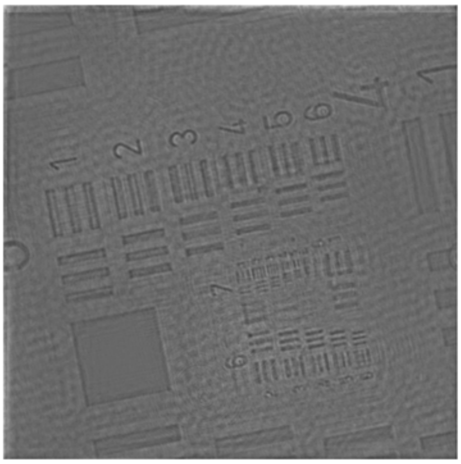


Fig. 12. Reconstructed hologram after suppression.

Obtained hologram is already without twin-image and resolution of the system is 2.5 µm. However some of the small elements couldn't be seen clearly. It could be explained that for such objects as double slit the most part of the reference wave is blocked and the object wave interfere to herself. Cross-interference component is prevailing on the image. That's why such way of registration has some limitation in determining of resolution.

7. Conclusions

There were received results of processing of in-line digital holograms which allows showing two different original methods of compensation twin-image of reconstructed object. Analysis of received results shows, that:

1. Suppression of a twin-image by recording an auxiliary hologram demonstrates rather low effectiveness because of higher requirements to the positioning accuracy of a matrix of recording device that records an auxiliary hologram. If the positioning accuracy is not sufficient, subtraction of an auxiliary hologram from the reconstructed image takes place only at local sections. Increased accuracy of matrix of recording device positioning may enhance effectiveness of this method.
2. Suppression of a twin-image by averaging several frames, restored from different holograms, demonstrates high effectiveness (intensity of a spurious signal decreases by more than 3 times) but requires the use of several recorders (at least 4) operating simultaneously. The use of this method permits to significantly decrease a contribution of the matrix noises, speckle noise and various reconstruction artifacts [7].

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