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Experimental study of noise and image resolution in holographic projection with different spatial division techniques

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Abstract—In lens-less projection it is reasonable to display on the Spatial Light Modulator various holographic phase distributions and decide which gives the best results on the projection screen. The merit functions are high contrast and low noise ratio in projected images. For that reason we designed holograms to be displayed on the light modulator in 7 different methods. In particular, different resolutions and placements of mosaics of sub-holograms were examined.

Modern holographic projection methods allow highly efficient and highly miniaturized image projection in full colour and almost in real time [1-4]. Nevertheless, the main limitation of this concept lies in the low resolution of the spatial light modulators which we used. Therefore, a detailed study of image resolution and its relation with speckle noise [5, 6] in various holographic encoding algorithms is necessary.

The purpose of this work is to assess the quality parameters of projection as a function of a different use of the surface of the Spatial Light Modulator (SLM). In particular, here we measure the influence of the pixel counts of the SLM on the final image resolution. Additionally, we check the method of the SLM spatial division and its influence on the resolution and the speckle noise on the projection screen. The spatial division can be used to display a mosaic of sub-holograms on the SLM, which instantly gives noise suppression, because two or more intensity fields with different speckle distributions are displayed and averaged [7]. Moreover, this method speeds up calculations due to smaller matrices, which can be computed in parallel.

In the experiment there was used a lens-less Fourier based image formation, as described in our previous work [8]. The basic scheme of the setup is presented in Fig 1.

The quasi–spherical wavefront from a single-mode fiber illuminates the SLM and the reflected, phase-modulated light reaches the CMOS matrix of the camera through a 50:50 non-polarizing beam splitter. The distance between the light source and the SLM was 125 mm and the reconstruction distance was ca. 300 mm. The used SLM was a Holoeye Pluto model with a resolution of 1920 by 1080 pixels and a 8µm pixel pitch. In this work, red light was used (wavelength of 671nm). The area of the SLM is uniformly illuminated in order to achieve the optimal effective aperture of the projection setup. The SLM was addressed with phase – only Fourier holograms optimized in 10 iterations of the Gerchberg – Saxton (G-S) algorithm [9].

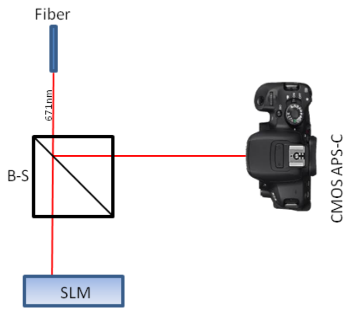

Fig. 1. Scheme of the experimental setup.

In order to correctly measure the image resolution, we first needed to suppress speckle noise, because high noise heavily affected the visibility of the fine details of the resolution test pattern. For this reason, we displayed 25 different holograms of the same object but with different initial phase patterns [10].

In the experiment 7 different cases were examined:

1. hologram with a size of 512 by 512 pixels placed in the centre of the SLM (integration of 25 random initial phase distributions),
2. hologram with a size of 512 by 1024 pixels placed in the centre of the SLM (integration of 25 random initial phase distributions),
3. hologram with a size of 1024 by 1024 pixels placed in the centre of the SLM (integration of 25 random initial phase distributions),
4. hologram with a size of 1920 by 1080 pixels placed in the centre of the SLM (integration of 25 random initial phase distributions),
5. 3 x 2 mosaic of identical 512 by 512 pixels holograms (integration of the 25 random initial phase distributions),
6. 3 x 2 mosaic of 512 x 512 pixels sub-holograms, each calculated with a different initial random phase

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(4 mosaics displayed in a sequence, given a total of 3x2x4=24 initial phase distributions integrated),

7. two 1024 x 1024 pixels holograms placed side by side (integrated in 25 different initial random phases).

This set of cases allowed us to assess image quality in a typical, practically feasible situation. The theoretical limit of resolution was initially calculated in numerical simulations of the Point Spread Function (PSF) spot. The numerical experiment assumed the same geometry and imaging distance as the real experiment and the use of the whole area of the SLM (i.e. 1920 by 1080 pixels). The size of the PSF spot was $12x24\mu m^2$, therefore the vertical resolution limit was estimated at 183 image lines and the horizontal resolution at 366 image columns.

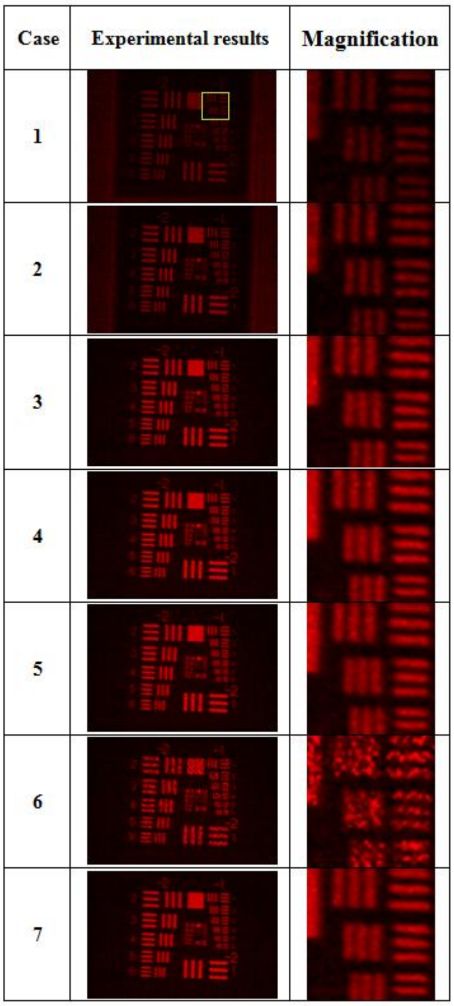

Fig. 2. Images obtained in the experiment with magnification.

In order to focus the image exactly at the plane on the CMOS matrix (see Fig. 1), a corrective lens factor was added to every phase pattern displayed on the SLM. The image size was approximately 18 by 18 mm and it was captured directly on the CMOS matrix of the Canon EOS 650D digital camera. For noise suppression, the exposure time was long enough to time-integrate all the holograms displayed in a loop. The obtained images are presented in Fig. 2. We used the standard USAF – 1951 resolution test pattern as the input image with a size of 2048 x 2048 pixels.

The critical statistical parameters of the captured images were examined – namely vertical and horizontal resolution, contrast and noise ratio. The contrast was calculated as the division of average light intensity in the bright test area and average light intensity in the dark test area. The noise ratio was calculated as the division of standard deviation in a bright test region and average intensity in the same region.

The resolution was assessed by the direct measurement of the lateral size of the most densely resolved group of lines in the recorded USAF – 1951 pattern. The results of the resolution study are given in Tab. 1 and Tab. 2 (vertical and horizontal resolution, respectively).

Tab. 1. Vertical resolution.

Case	Group number	Element number	Columns per picture
1	0	4	221
2	0	4	221
3	0	5	234
4	0	5	234
5	0	3	200
6	-1	5	117
7	0	5	234

Tab. 2. Horizontal resolution.

Case	Group number	Element number	Lines per picture
1	-1	6	124
2	-1	6	124
3	0	1	140
4	0	1	140
5	-1	4	103
6	-1	3	91
7	-1	4	103

The resolution is given as the number of image lines or columns displayed by the optical setup on the whole projection screen with a particular placement and dimensions of holograms addressed on the SLM. In this way one can estimate the effective information density of this projection technique. The columns "Group number" and "Element number" describe the smallest element of the USAF pattern which was still resolved.

Additionally, the noise and contrast values for the seven cases are presented in Fig. 3 and Fig. 4, respectively. The increased number of pixel count allows better image contrast, resolution and lower noise ratio for the price of increased computational complexity.

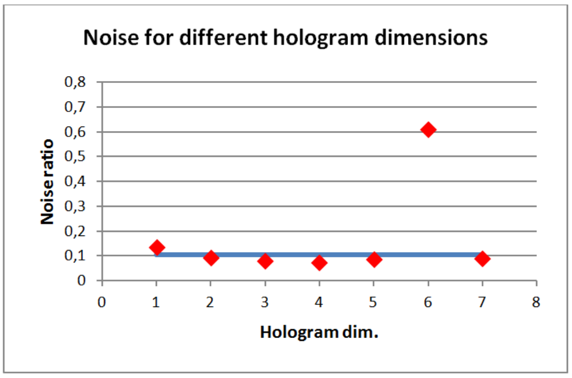

Fig. 3. Noise ratio in different hologram placement cases.

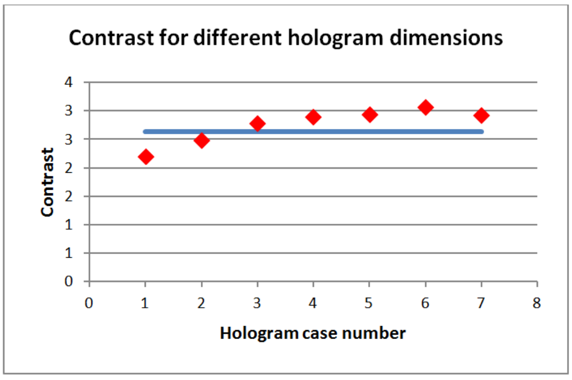

Fig. 4. Contrast in different hologram placement cases.

On the other hand, using low resolution holograms in a form of 3 by 2 mosaics (case 5) leads to an increased contrast and reasonable speckle noise suppression, while the computation time is very efficient because the calculation of numerous small matrices can be effectively performed on multi-threaded processors.

Moreover, the use of a 3 by 2 mosaic of holograms with a different initial phase distribution (case 6), allows speckle noise suppression in a short time period, because only 4 frames are to be displayed on the SLM instead of 25. In this case, potentially, real-time speckle suppression with a Spatial Light Modulator with a 60 Hz refresh rate could be achievable. Nevertheless, in this case we achieved higher noise, which leads to a conclusion that more care should be taken about phase relations between sub-holograms. Without taking this into account, unwanted interferences occur between the images created by the 6 sub-holograms, which leads to an increased noise ratio, as seen in Fig. 2 and Fig. 3. Another option for future research would be to use a light source with a limited spatial coherence so that the diffraction patterns from different sub-holograms would be added incoherently, leading to suppressed speckles.

The described experiment confirmed that in holographic projection, image resolution grows with the number of pixels which are displayed on the SLM. Additionally, we showed that even with a low resolution of holograms, efficient noise suppression and contrast increase are possible by using mosaic placement of sub-holograms on the surface of the modulator. The optimal merit function describing image quality should be a combination of noise level, contrast and resolution. By doing this we can distinguish number 4 and number 7 as the best cases. In this we proved that a mosaic of two 1024x1024 holograms on the SLM gives optimal image quality with lower computational complexity, as compared to the calculation of a single 1920x1080 hologram.

Therefore, it is possible to obtain reasonable projection quality with inexpensive, low resolution SLMs having a relatively small frame rate.

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References

[1] M. Makowski, I. Ducin, K. Kakarenko, J. Suszek, M. Sypek, A. Kolodziejczyk, Opt. Expr. **20**, 25130 (2012).
[2] M. Makowski, Opt. Expr. **21**, 29205 (2013).
[3] M. Makowski, A. Siemion, I. Ducin, K. Kakarenko, M. Sypek, A.M. Siemion, J. Suszek, D. Wojnowski, Z. Jaroszewicz, A. Kolodziejczyk, Chin. Opt. Lett. **9**, 120008 (2011).
[4] M. Huebschman, B. Munjuluri, H. Garner, Opt. Expr. **11**, 437 (2003)
[5] L. Golan, S. Shoham, Opt. Expr. **17**, 1330 (2009).
[6] N. Pandey, B. Hennelly, Appl. Opt. **50**, B58 (2011).
[7] C. Quan, X. Kang, C.J. Tay, Opt. Eng. **46**, 115801 (2007).
[8] T. Shimobaba, M. Makowski, T .Kakue, M. Oikawa, N. Okada, Y. Endo, R. Hirayama, T. Ito, Opt. Expr. **21**, 25285 (2013).
[9] R.W. Gerchberg, W.O. Saxton, Optik **35**, 237 (1972).
[10] A. Czerwiński, K. Kakarenko, M. Sypek, M. Makowski, I. Ducin, J. Suszek, A. Kolodziejczyk, J. Bomba, Opt. Lett. **37**, 4723 (2012).

