# Optimized computation method for real – time holographic formation of color images

M. Makowski,* I. Ducin, K. Kakarenko, A. Kowalczyk, M. Bieda and J. Suszek

*Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warszawa*

Received August 13, 2014; accepted September 08, 2014; published September 30, 2014

**Abstract**—A simple method is presented of decreasing the calculation time of CGH for lensless Fourier holograms. The proposed method takes advantage of the fact that modern displays are rectangular with a high image proportion ratio of 16:9 or even higher. The CGH was calculated on a matrix of 512×1024 points. The use of small rectangular calculation matrices allowed three times fasters calculation with sustained contrast and noise ratio and greatly improved resolution.

The holographic projection concept [1-4] belongs to a class of methods based on electroholography [4]. The biggest problem of this class of methods is the computation time. Many hardware acceleration ideas have been proposed by now [6-7]. Nevertheless, there is a need for optimizing the calculation process itself, especially in high definition projection devices of the future.

In this paper we propose a very simple technique of increasing the calculation speed of CGH for lens-less color image projection based on Fourier holograms.

The proposed method takes advantage of the fact that modern displays are rectangular with a high image proportion ratio of 16:9 or even higher. Therefore, it should be natural to calculate CGH for image projection also on rectangular calculation matrices.

In our previous works square matrices of 2048 by 2048 points were used for simplicity and because most of the common test patterns were square–shaped. In this attempt, we calculated CGH on a matrix of 512×1024 points, which is more than three times faster than 2048×2048 points. Exemplary calculation times on one or eight threads of the average CPU are presented in Tab. 1.

Tab. 1. Calculation times.

| Matrix size [px] | Number of threads | |
|---|---|---|
| | 1 | 8 |
| 512 x 1024 | 7 (sec) | 6 (sec) |
| 2048 x 2048 | 25 (sec) | 15 (sec) |

The big advantage of calculation holograms of the 512 x 1024 points size, is the fact that one can easily place such three holograms side – by – side on the area of a full HD SLM, without any cropping and without dead space (unused pixels).

* E-mail: mcovsky@if.pw.edu.pl

On the other hand, when we previously calculated CGH on a matrix of 2048×2048 points, we needed to crop the resulting phase distributions to a size of 640×1080 points so that we could fit the hole area of the SLM. Yet, in this way, the strong cropping of holograms significantly increases speckles size, which compromised image quality.

To summarize, a simple change of matrix size from 2048×2048 to 512×1024 should allow faster calculation, lower speckle noise and increased image resolution. In this paper we proved experimentally that this method produces better results.

We compare the performance of two cases of CGH preparations (see Fig. 1).

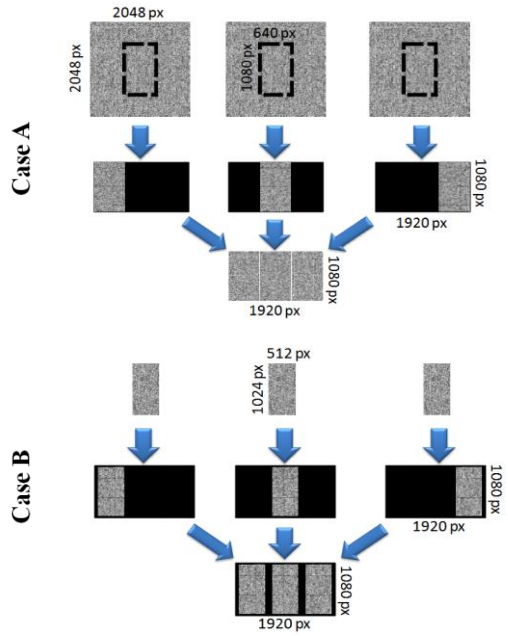



Fig. 1. The CGH preparation: case A – calculation matrix with size 2048×2048 points; case B – calculation matrix with size 512×1024 points.

Case A assumes that the calculation of three holograms of R, G, B color component on three 2048×2048 matrices. In both cases the input bitmap was 512×512 pixels.

Then, after 10 iterations of the Gerchberg–Saxton algorithm [8], the resultant phase distributions are cropped to the size 640×1080 pixels and placed on the

SLM side by side. Then, each of the sub – holograms on the SLM is illuminated by a separate light beam with a matching color (671, 532 and 445nm) similar to our previous work [1-3].

Thanks to the added corrective lens factor, the light reflected from the SLM creates three overlapping images directly on the Canon EOS 650D digital camera. Obviously, the color components of the input bitmap were properly resized in order to compensate for chromatic dispersion on kinoform–like phase holograms. In this experiment we used a Holoeye PLUTO SLM, with a pixel pitch of 8µm and resolution of 1920×1080 pixels. The images captured by the camera were then analyzed in terms of noise, contrast and resolution.

The second case (case B in Fig. 1) assumes the calculation of three RGB components on three 512×1024 matrices, which is much faster. Then without any cropping, the sub – holograms are displayed by the SLM side by side, with a little dead space between them. The rest of the reconstruction process is the same as in case A.

As the input bitmap there was used a standard USAF – 1951 resolution test pattern. In this way, we could estimate final image resolution (both vertical and horizontal), which is given as the number of unique image lines or columns possible to be displayed in a particular case.

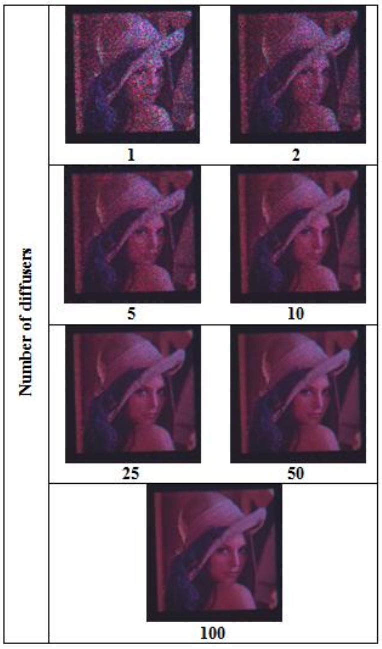



Fig. 2. Experimental results for increasing number of TDRP diffusers.

Obviously, in CGH the reconstructed images are highly speckled, which makes resolution assessment difficult. Therefore, we averaged speckle noise by using the Time Domain Random Phase (TDRP) [9], which assumed the integration of 1, 2, 5, 10, 25, 50 and 100 holograms of the same object with a different initial phase. The experimental images obtained for an increased number of TDRP diffusers and for cases A and B are presented in Fig. 2 and Fig. 3.

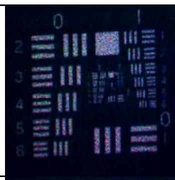
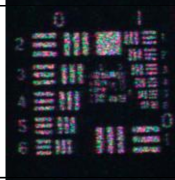
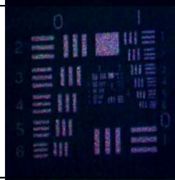
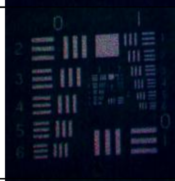
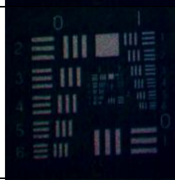
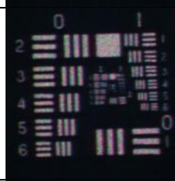
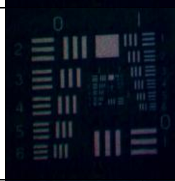
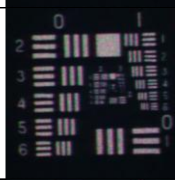
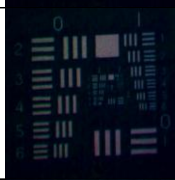
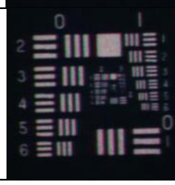
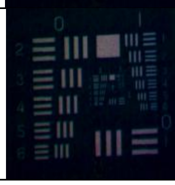
| **Number of diffusers** | **Matrix size 2048 x 2048 px** | **Matrix size 512 x 1024 px** |
|---|---|---|
| **1** |  |  |
| **2** |  |  |
| **5** |  |  |
| **10** |  |  |
| **25** |  |  |
| **50** |  |  |
| **100** |  |  |

Fig. 3 Experimental results for case A and case B.

One can easily see the superior quality in case B. This observation was concluded by the analysis of image resolution presented in Fig. 4 and Fig. 5 for horizontal and vertical resolution, respectively. The conclusion is that despite its lower pixel count, case B is superior thanks to the lack of cropping operation.

The increase of resolution occurs up to 25 TDRP diffusers, as seen in the graph in Fig. 4 and Fig. 5. Hence, we choose 25 to be the optimal number of integrated holograms for a matrix of 512×1024 points.

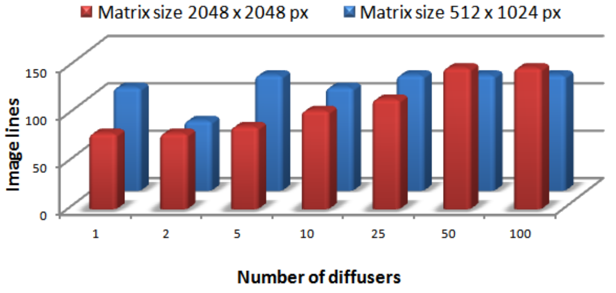



Fig. 2. Horizontal resolution.

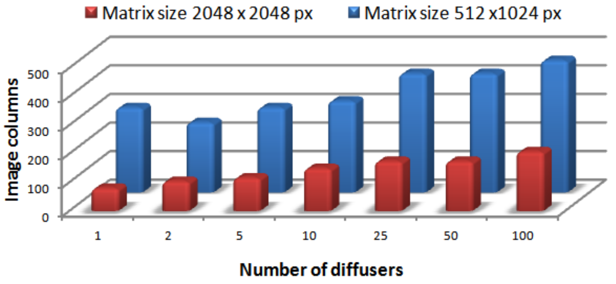



Fig. 3. Vertical resolution.

Moreover, the analysis of contrast and noise ratio presented in Fig. 6 and Fig. 7, also shows the advantage of CGH calculation on smaller rectangular matrices.

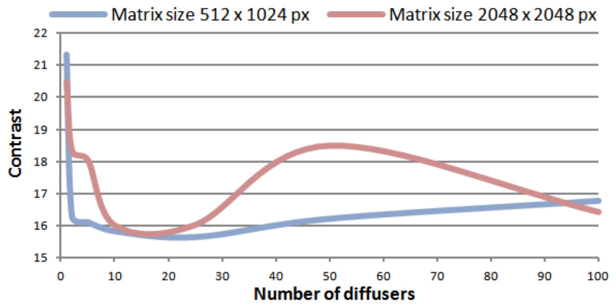



Fig. 4. Experimental results for contrast.

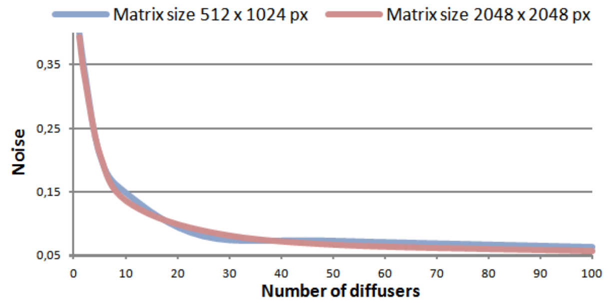



Fig. 5. Experimental results for noise ratio.

We have successfully demonstrated the time effective method of CGH calculation for the holographic projection.

The use of small rectangular calculation matrices allowed three times faster calculation with sustained contrast and noise ratio and greatly improved resolution. Moreover, the optimal number of integrated random phase holograms was established based on real color projected images and the analysis of resolution as a function of the number of integrated TDRP sub–holograms.

This work was supported by the Polish National Center for Research and Development grant LIDER/013/469/L-4/12/NCBR/2013.

## References

[1] M. Makowski, I. Ducin, K. Kakarenko, J. Suszek, M. Sypek, and A. Kolodziejczyk, Opt. Expr. **20**, 25130 (2012).
[2] M. Makowski, A. Siemion, I. Ducin, K. Kakarenko, M. Sypek, A.M. Siemion, J. Suszek, D. Wojnowski, Z. Jaroszewicz, A. Kolodziejczyk, Chinese Opt. Lett. **9**(12), 120008 (2011).
[3] M. Makowski, I. Ducin, M. Sypek, A. Siemion, A. Siemion, J. Suszek, A. Kolodziejczyk, Opt. Lett. **35**, 1227 (2010).
[4] M. Makowski, Opt. Expr. **21**, 29205 (2013).
[5] A. Shiraki, N. Takada, M. Niwa, Y. Ichihashi, T. Shimobaba, N. Masuda, T. Ito, Opt. Exp. **17**, 16038 (2009).
[6] T. Shimobaba, Y. Sato, J. Miura, M. Takenouchi, T. Ito, Opt. Expr. 16, 11776 (2008).
[7] T. Shimobaba, T. Ito, N. Masuda, Y. Ichihashi, N. Takada, Opt. Expr. **18**, 9955 (2010).
[8] R.W. Gerchberg, W.O. Saxton, Optik **35**, 237 (1972).
[9] A. Czerwiński, K. Kakarenko, M. Sypek, M. Makowski, I. Ducin, J. Suszek, A. Kolodziejczyk, J. Bomba, Opt. Lett. **37**(22), 4723, (2012).