*Quantum Electronics* **42** (11) 1039 – 1041 (2012)

***PATTERN RECOGNITION***

PACS numbers: 42.79.Hp; 42.79.Kr; 42.30.Wb
DOI: 10.1070/QE2012v042n11ABEH015009

# Model of an invariant correlator with liquid-crystal spatial light modulators

N.N. Evtikhiev, S.N. Starikov, E.D. Protsenko, E.Yu. Zlokazov,
I.V. Solyakin, R.S. Starikov, E.A. Shapkarina, D.V. Shaulskiy

***Abstract.*** **Invariant pattern recognition using a model of a coherent holographic correlator with liquid-crystal spatial light modulators as input devices has been experimentally analysed.**

***Keywords:*** *pattern recognition, optoelectronic correlator, invariant correlation filter, computer generated hologram, spatial light modulator.*

## 1. Introduction

The use of modern spatial light modulators (SLMs) as input devices in the schemes of optoelectronic image correlators allows one to obtain processing speeds up to $10^{13}$ operations with integers per second or even more. Such high processing speeds make these systems very promising. The application of distortion invariant filters (DIFs) [1, 2] is an efficient way to obtain invariance of correlation pattern recognition when the object to be recognised is distorted as compared with a reference object due to various factors (rotation, variation in scale, change in illumination conditions, etc.); these filters also make it possible to reduce the time of correlation recognition and increase its flexibility. A DIF in the correlator optical scheme is a synthesised diffraction object (static or SLM-formed hologram). In this paper, we report the results of synthesising DIFs and experiments on their application to correlation pattern recognition in the scheme of coherent holographic Van der Lugt correlator using liquid-crystal SLMs as input devices.

## 2. Model scheme

A model scheme is shown in Fig. 1. The light source is a Nd : $YVO_4$ laser generating the second harmonic with a wavelength of 0.53 μm and a power of 30 mW.

The laser radiation intensity and polarisation state were controlled using two crossed polarisers. The laser beam, formed by a collimating optical system (COS) with a cleaning unit, was applied to the first Fourier cascade. The input image was introduced using an SLM1 (Holoeye LC2002), operating in the regime of transmitted intensity modulation (modulator size 800 × 600 pixels, pixel size 32 μm). The holographic filter (Fourier hologram) was introduced in the common focal plane of the first and second Fourier cascades using an SLM2 (Holoeye Pluto VIS), operating in the regime of phase modulation in reflection (modulator size 1920 × 1080 pixels, pixel size 8 μm). SLM2 was installed on an optical mount with micrometer reading, which can be rotated around the optical axis. Both SLMs were controlled by personal computers (PCs) of standard configuration. A photodetector array (PDA) of a standard 10-megapixel reflex camera was used as a detector of the images formed by the second Fourier cascade of the correlator. The output correlator signals were recorded in the RAW format as grayscale images with a 16-bit shade of gray.

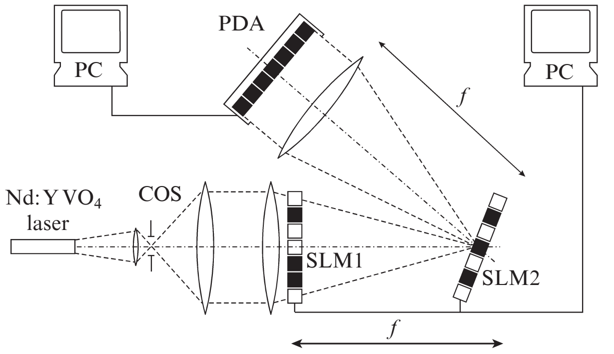

**Figure 1.** Schematic of the experimental setup with spatial light modulators (polarisers are omitted).

## 3. Synthesis and realisation of holographic filters

The experiments on pattern recognition were performed using DIFs of two types: for binary contour images and for greyscale images. The corresponding Fourier hologram (holographic filter) was calculated for both DIFs. The hologram response contains spatially separated regions with a δ function in the zero order and two conjugate images of the initial DIF in the (+1) and (–1) diffraction orders.

An invariant correlation filter with a linear phase coefficient (LPCC filter), which provides rotation invariance, was synthesised to recognise binary contour images [3]. A corresponding holographic filter was calculated, different versions of which (binarised and with a limited number of transmission gradation levels) [4] were applied to the SLM. The examples of processed binary contour image, the distribution of the filter real part, the calculated response of the holographic

---

**N.N. Evtikhiev, S.N. Starikov, E.D. Protsenko, E.Yu. Zlokazov, I.V. Solyakin, R.S. Starikov, E.A. Shapkarina, D.V. Shaulskiy**
National Research Nuclear University (MEPhI), Kashirskoe sh. 31, 115409 Moscow, Russia; e-mail: evtikhiev@mail.ru, edprotsenko@mephi.ru, rstarikov@mail.ru

Received 5 July 2012; revision received 29 September 2012
*Kvantovaya Elektronika* **42** (11) 1039 – 1041 (2012)
Translated by Yu.P. Sin'kov

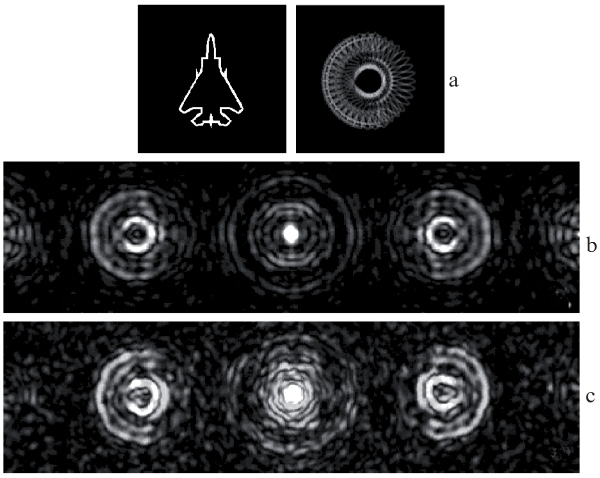

**Figure 2.** Recognisable image, invariant DIF, and optical response of the LPCC filter. (a) A binary contour image and the distribution of the LPCC filter real part (rotation invariance in the range from 0° to 180°), (b) the calculated response of the corresponding holographic filter binarised by the Otsu method, and (c) the measured response of a holographic filter binarised by the Otsu method and introduced using the SLM2.

filter, and the measured response of the holographic filter introduced using the SLM2 (Fig. 2) show the potential of an LPCC filter realisation for recognising binary contour images.

Similarly, a Gaussian – minimum average correlation energy (GMACE) filter was synthesised to process greyscale images [5]. The synthesised GMACE filter provides correlation peak invariance under rotation of input greyscale image. The corresponding holographic filter was calculated for the GMACE filter. The examples of the processed greyscale image, the distribution of the filter real part, the calculated response of the holographic filter, and the measured response of the holographic filter introduced using the SLM2 (Fig. 3) demonstrate the potential of GMACE filter realisation for recognising greyscale images.

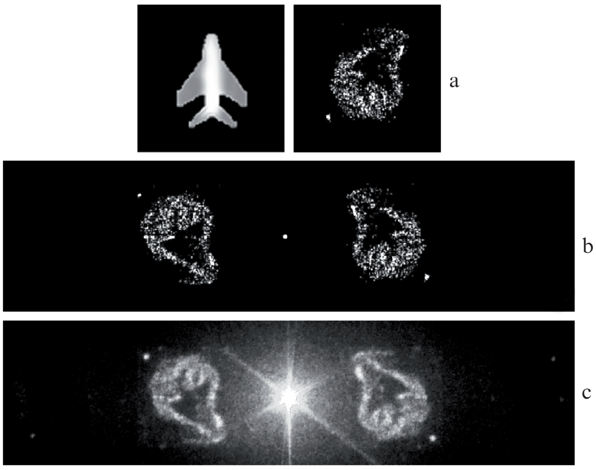

**Figure 3.** Recognisable image, invariant DIF, and optical response of the GMACE filter. (a) A greyscale image and the distribution of the real part of the GMACE filter (rotation invariance in the range from 0° to 90°), (b) the calculated response of the corresponding holographic filter, and (c) the measured response of the holographic filter introduced using the SLM2.

## 4. Model signals

Optical signals were recorded in the output plane of the system in the experiments. The output correlator field contains a spatially separated zero-order input image and the convolution and correlation regions in the (+1) and (–1) diffraction orders, respectively. The experiments showed that the correlation peak is retained while the input image is rotated in the total angular range specified in the DIF synthesis.

Figure 4 shows the calculated (by numerical simulation) and measured optical signals in the correlator output plane. It can be seen that the experimental data are in good agreement with the simulation results.

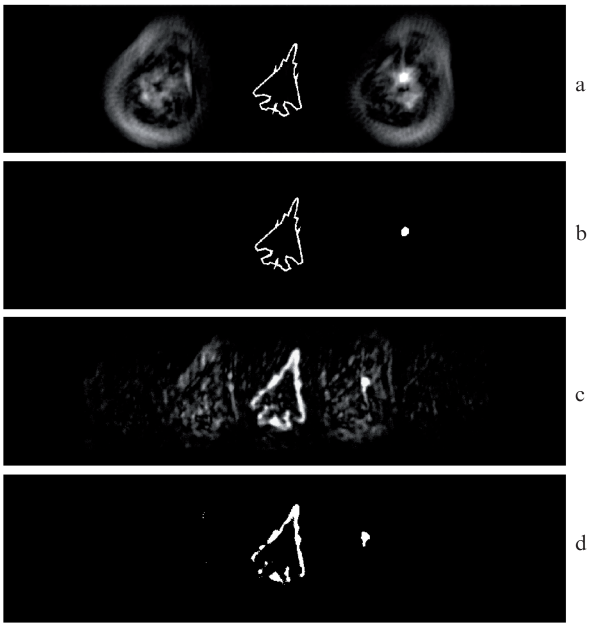

**Figure 4.** Output signals of the correlator model: (a) calculation, (b) calculation (threshold 0.8), (c) experiment, and (d) experiment (threshold 0.8). A holographic filter binarised by the Otsu method is used.

## 5. Conclusions

We developed an experimental model of a coherent correlator with liquid-crystal spatial light modulators as image input devices and invariant correlation filters. It was experimentally shown that two types of invariant correlation filters can be implemented: one with a minimum correlation energy for processing greyscale images and the other with a linear phase coefficient for processing binary contour images. The modelling results show that correlation peak invariance can be obtained using invariant correlation filters in the form of synthesised Fourier holograms.

***Acknowledgements.*** This work was supported by the federal targeted programme The Scientists and Science Educators of Innovative Russia and the Russian Foundation for Basic Research.

## References

1. Vijaya Kumar B.V.K., Mahalanobis A., Juday R. *Correlation Pattern Recognition* (Cambridge: Cambridge University Press, 2005).
2. Vijaya Kumar B.V.K. *Appl. Opt*., **31**, 4773 (1992).
3. Hassebrook L., Vijaya Kumar B.V.K., Hostetler L. *Opt. Eng*., **29**, 1033 (1990).
4. Evtikhiev N.N., Starikov S.N., Shaulskiy D.V., Starikov R.S., Zlokazov E.Yu. *Opt. Eng*., **50**, 065803 (2011).
5. Casasent D., Ravichandran G., Bollapraggada S. *Appl. Opt*., **30**, 5176 (1991).