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PATTERN RECOGNITION

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Realisation of invariant holographic filters with the linear phase coefficient in a Van der Lugt correlator

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***Abstract*. Invariant correlation filters with the linear phase coefficient are synthesised and pattern recognition experiments are performed by using these correlation filters in a coherent holographic correlator.**

Keywords: *invariant pattern recognition, optoelectronic correlator, invariant correlation filter, computer-synthesised hologram.*

1. Introduction

The well-known schemes of optoelectronic correlators offer considerable advantages in a number of cases compared to purely electronic devices, which attracts recent interest in their development and applications. The promising method for obtaining the invariance of correlation in the presence of distortions of the object being recognised with respect to the reference object (rotation, scale change, etc.) is the use of invariant correlation filters (CFs) [1].

The realisation of a CF in the case of an optoelectronic correlator requires the solution of the problem of synthesis of a diffraction element to form the complex pulsed response of the optical system which is adequate to the filter. In this case, the CF is represented by a synthesised diffraction object – a static hologram or a hologram formed by means of a space – time light modulator. The main problems of the CF realisation are the correct consideration and matching of the limited spatial frequency band and the dynamic range of real media for introducing computer synthesised holograms. One of the promising types of CFs is a linear phase coefficient composite (LPCC) filter [1, 2].

In this paper, we synthesised LPCC filters and performed experiments by using these filters for correlation pattern recognition in the scheme of a coherent holographic Van der Lugt correlator.

2. Linear phase coefficient composite filter

A linear phase coefficient composite filter is composed of N reference images $s_0, s_1, \ldots, s_{N-1}$, which are selected based on the invariance requirement [2],

$$h_k^*(x,y)=\sum_{n=0}^{N-1}\exp\left(-\mathrm{i}\frac{2\pi}{N}nk\right)s_n(x,y),\ k=0,1,\ldots,N-1.$$

For binary contour images, the LPCC filter has high selectivity parameters due to the large signal-to-noise ratio in the correlation field. The earlier studies have shown that for binary images with the white density of about 0.05, more than 20 images can be successfully combined in one LPCC filter. Compared to other types of correlation filters, the LPCC filter allows one to obtain the correlation function that is most close in its form to the self-correlation function. In addition, the LPCC filter is the only type of the composite filter which does not require the inversion of matrices in the synthesis and, therefore, it is 'economical' from the point of view of the computational burden required for its synthesis. Unlike a number of other CF types, the LPCC filter cannot be reduced to either an amplitude-only or a phase-only filter; however, it can be realised in the form of an amplitude-only or a phase-only diffraction element by the methods using the concept of the well-known Van der Lugt method [3, 4].

3. Synthesis of holographic filters

By using the available software [5], we synthesised a LPCC filter, which was invariant to the rotation of the input object in the range $\pm 90°$. A binary contour image of size 256×26 pixels was used as the reference object (Fig. 1a). The filter was calculated based on 18 mages of the reference object turned with a step of $10°$. Figures 1b, c show the distributions of the filter amplitude and correlation intensity of the reference object and filter. The test scene with the images of the turned reference object in the range $\pm 90°$ with a step of $5°$ and the intensity correlation distribution for the test scene and filter are shown in Figs 1d, e.

By using the available software [4] for realising the synthesised LPCC filter in the diffraction correlator scheme, we calculated the amplitude Fourier hologram. The dimensionality of the hologram was 512×512 counts with gray gradations in the 16-bit count (65536 levels). The magnified image of the central part of the hologram is shown in Fig. 2a, and the numerical reconstruction of the correlation filter amplitude is presented in Fig. 2b.

The Fourier hologram was fabricated by using a standard Scitex Dolev 800 laser phototypesetting device. The hologram represents a transparency with the binary amplitude-only transmission. The transmission levels of the calculated hologram counts were coded by using the frequency-modulated stochastic scanning at the maximal

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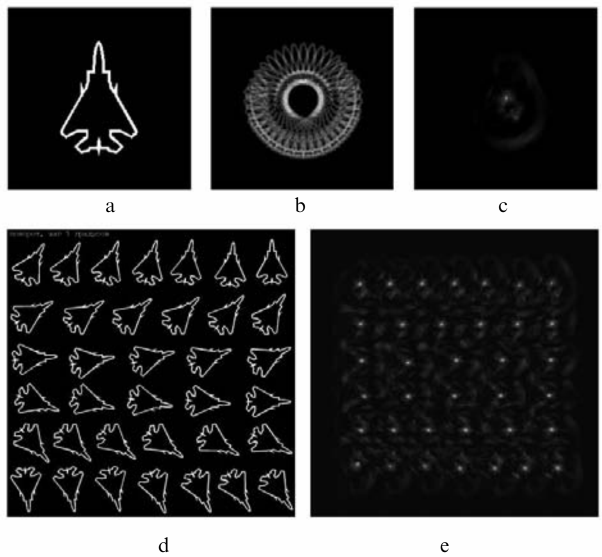

Figure 1. Synthesis of an invariant LPCC filter: reference image (a); the calculated filter amplitude (b); the amplitude of the filter correlation function and reference image (c); scene with the images of the rotated reference object (d); the intensity of the scene correlation function and filter (e).

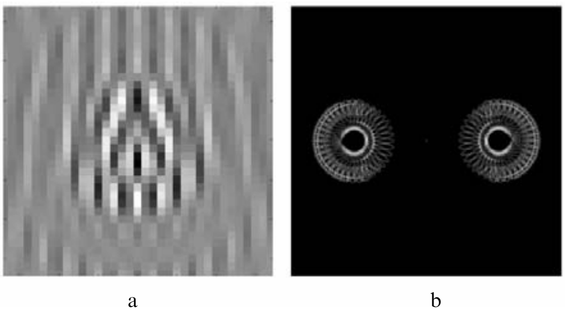

Figure 2. Synthesis of a hologram: the magnified image of the central part of the hologram (a); the numerically reconstructed amplitude of the impulse response of the hologram (b).

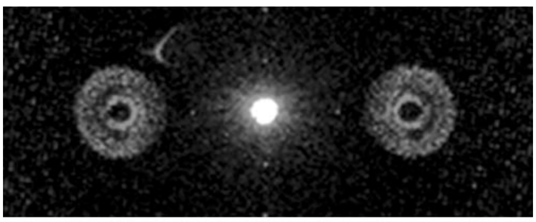

Figure 3. Photograph of the light field reconstructed by the hologram.

available black-and-white print resolution of 3048 dots per inch. For the number of gray gradations of 27 (less than 5 bits), the size of the hologram count was ~ 80 μm. Preliminary measurements of the reconstructed light-field intensity of the hologram showed that the geometry of the reconstructed image was in good agreement with calculations. The photography of the light field reconstructed by the hologram is presented in Fig. 3.

4. Experiments on the correlation pattern recognition

We assembled the model of a Van der Lugt correlator for experimental studies on the CF realisation. Figure 4 shows the scheme of the setup. The input image was introduced by using a binary transparency with the contrast ratio slightly exceeding 100 : 1, which was placed in a micro mount that could be rotated around the optical axis. The images formed by the output Fourier cascade of the correlator were recorded with an 8-megapixel array photodetector of a Canon EOS20D digital camera. The output correlator signals were recorded in the form of gray-scale images with 16-bit gray gradations in the raw format and fed to a PC for processing.

During experiments we obtained adequately localised correlation peaks in the correlation region of the output field of the correlator, which were reliably preserved upon rotation of the input image within $\pm 90°$. Figure 5 demonstrates the example of signals in the output plane of the correlator. When the input image was rotated, the ratio of the correlation peak intensity to the maximum noise intensity over the correlation field changed from 7.5 : 1 to 14 : 1, the average ratio being 9 : 1. Note that the parameters of correlation signals can be considerably improved by improving the optical scheme of the correlator and increa-

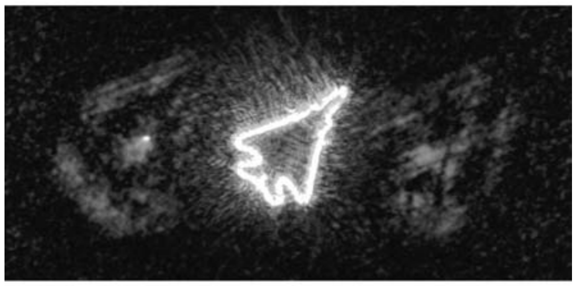

Figure 5. Example of signals in the correlator output plane. From left to right: correlation region, image region, convolution region.

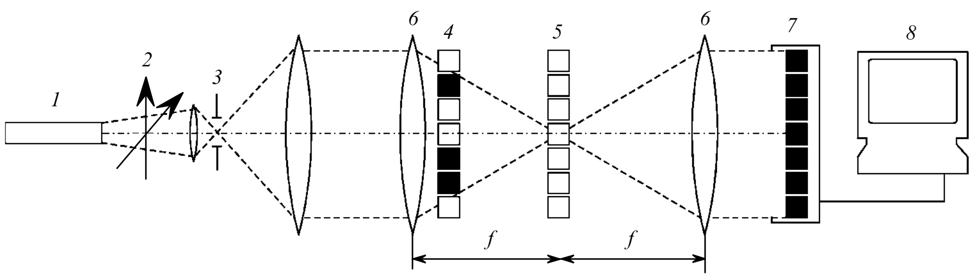

Figure 4. Scheme of the experimental setup: (*1*) 633-nm, 30-mW He – Ne laser; (*2*) intensity attenuation polarisation unit; (*3*) collimating optical scheme with a selection unit; (*4*) transparency with the input image fixed in the rotation mount; (*5*) holographic invariant filter; (*6*) Fourier lens; (*7*) array photodetector; (*8*) PC.

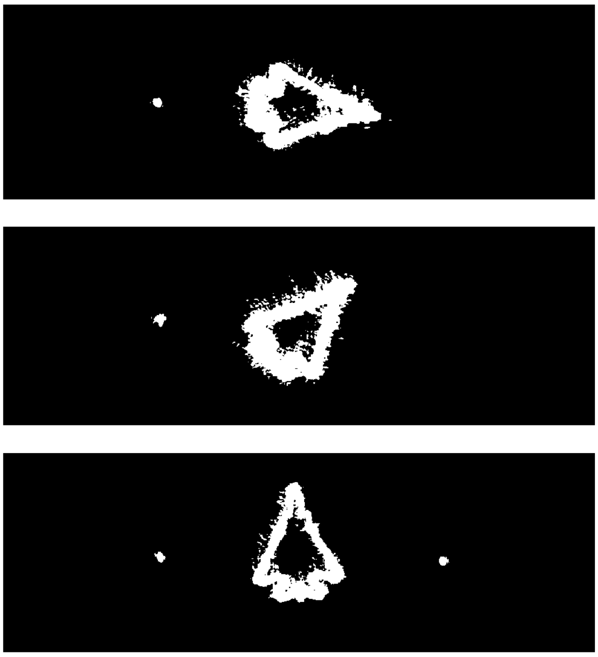

Figure 6. Examples of the correlator signals subjected to the threshold operation at the correlation peak half-maximum for the rotation angles 0, -45°, and -90° (in the latter case, a peak is also present in the convolution region because the filter contains symmetric positions -90° and 90°).

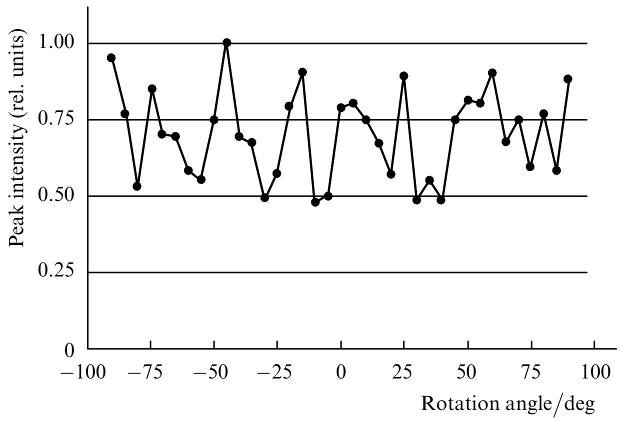

Figure 7. Dependence of the normalised correlation peak intensity on the rotation angle of the input image.

sing the contrast of elements which are used for introducing the input image and filter. The correlator signals subjected to the threshold operation at the correlation peak half-maximum are exemplified in Fig. 6. Figure 7 shows the dependence of the normalised correlation peak intensity on the rotation angle of the input image.

5. Conclusions

We have demonstrated that the invariance of correlation can be achieved by using LPCC filters in coherent diffraction correlators. The invariant correlation LPCC filters can be realised in the form of computer-synthesised amplitude holograms, in particular, by using holographic carriers with a limited dynamic range.

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