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Effect of incoherent light source dimensions on the optical filtering of images

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Coherent optical filtering methods are well known and often used in many practical applications [1,2]. However, in some cases coherent light is not convenient for filtering because of the presence of a coherent noise: and this is the reason for using incoherent light. A typical method of image processing with incoherent light is the apodization technique [3]. This technique allows to filter the image by modifying the point spread function of the optical system. In other cases the optical set-up is coupled with electronic devices, and the image is processed in a two channel electro-optical device [4,5].

The optical system used in coherent techniques can be adjusted to incoherent signal processing. A possibility of image filtering in the incoherent light in a way similar to the coherent methods is considered in this work. It will be shown that such possibility exists, provided that the light source dimensions are limited and the light is quasi-monochromatic.

The experimental set-up is shown in fig. 1. A halogen lamp *LS* with reflector *R* is used as the light source. A diffuser *D* is placed in the narrowest region of light beam emitted from the lamp. A microscopic condenser L_1 placed behind the diffuser focuses the light on a diaphragm F_1. In our experiments diaphragms F_1 of various diameters were used. The diffuser *D* mixes light providing a quasi-homogeneous intensity in the diaphragm F_1 area. This is the light source for the filtering system. This system consists of the collimator lens L_2 (focal length 150 mm) and the transforming lens L_3 (focal length 100 mm) and is similar to the set-up for a coherent processing. The object is placed in the plane *OP* and the lens L_3 gives the image of the object in the plane *IP*. The light emitted from F_1 can be considered as incoherent. The

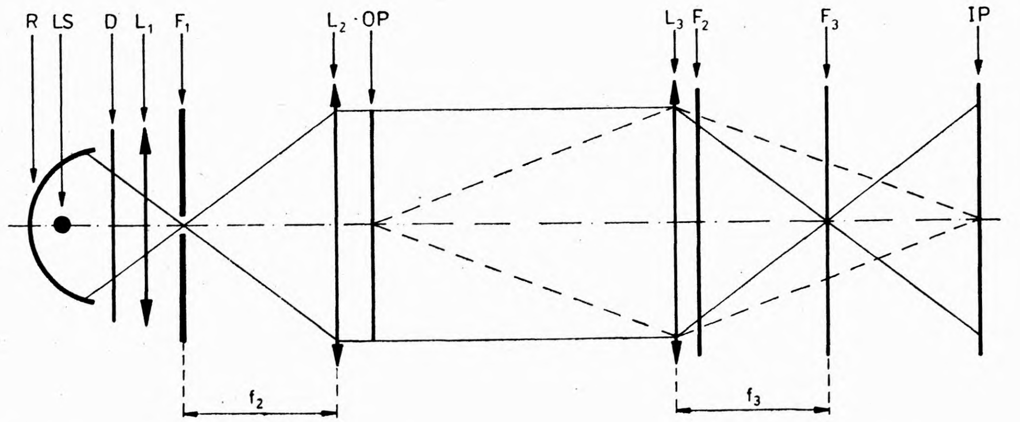


Fig. 1. Experimental set-up: *R* – reflector, *LS* – incoherent light source, *D* – diffusing screen, L_1, L_2 – lenses, F_1 – diaphragm, *OP* – object plane, L_3 – transforming lens, F_2 – interference filter, F_3 – spatial filter. *IP* – imaging plane, f_2, f_3 – focal lengths

intensity distribution in the plane F_3 (back focal plane of L_3) can be written, according to [6], as

$$I \sim |F(T_1)|^2 \otimes A \otimes D,$$

where $F(T_1)$ – is the Fourier transform of the amplitude transmittance in the plane OP,
A – is the intensity distribution in the plane F_1,
D – is the point spread function of the optical system L_2, L_3,
$\otimes$ – sign of the convolution.

The intensity distribution A convoluted with $D(A \otimes D)$ gives the intensity distribution in the source image formed in the plane F_3. When the light source is a point source, i.e. when $A \otimes D = \delta$, where δ is a Dirac function, the situation is such as in coherent systems and

$$I \sim |F(T_1)|^2.$$

Practically, the light source F_1 has some dimensions and this is the reason of smearing the diffraction pattern. In this case the zero diffraction order and the diffraction pattern from images structure overlap themselves and the filtering is ineffective. To avoid this effect a small diaphragm F_1 should be used. But this strongly reduces the light energy in the set-up. Thus, a compromise should be made between the light energy and filtering efficiency.

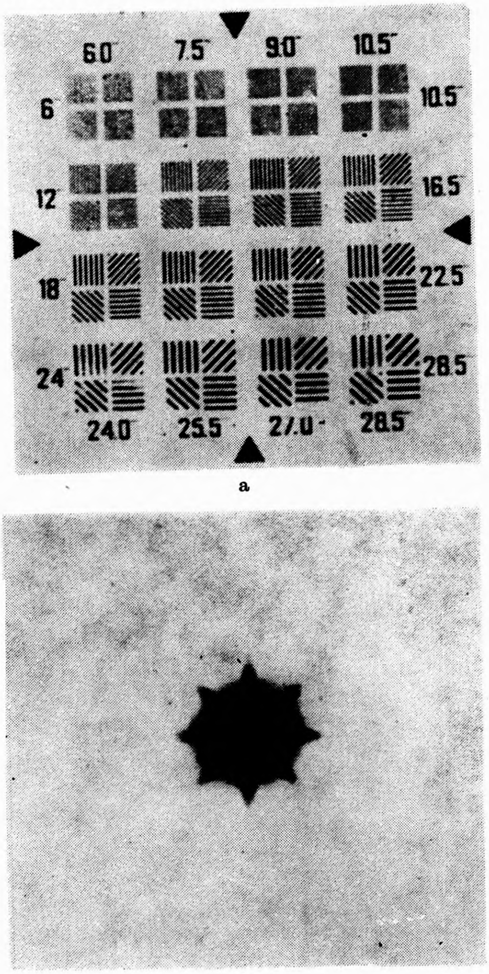
An important parameter in the incoherent filtering system is the relative source dimension K given by equation

$$K = d_1/f_2,$$

where d_1 – the diameter of the light source in plane F_1,
f_2 – the focal length of L_2.

Light source diameters, used in the experiments, their images diameters d_3 in plane F_3 and K parameters are shown in table.

The amplitude filters such as holes, slits and high-pass filters were placed in the plane F_3. The object which was processed in the incoherent system was the bar test, shown in fig. 2a. The highest spatial frequency in this test was not recorded in the image. The object has some small struc-



b

Fig. 2. The bar test used in experiment (a), and its diffraction pattern (b)

tures which are invisible in the image. These structures consisting of little holes, slits, scratches and so on, are defects of the object and can be visualised after processing.

The image formed in the Fourier plane is shown in fig. 2b. The results of low-pass filtering by hole filters are presented in fig. 3. As it is seen, the filtering effect is

Table

Source	d_1 [mm]	d_3 [mm]	K
I	0.48	0.32	0.0032
II	1.16	0.77	0.0077
III	1.90	1.26	0.0126

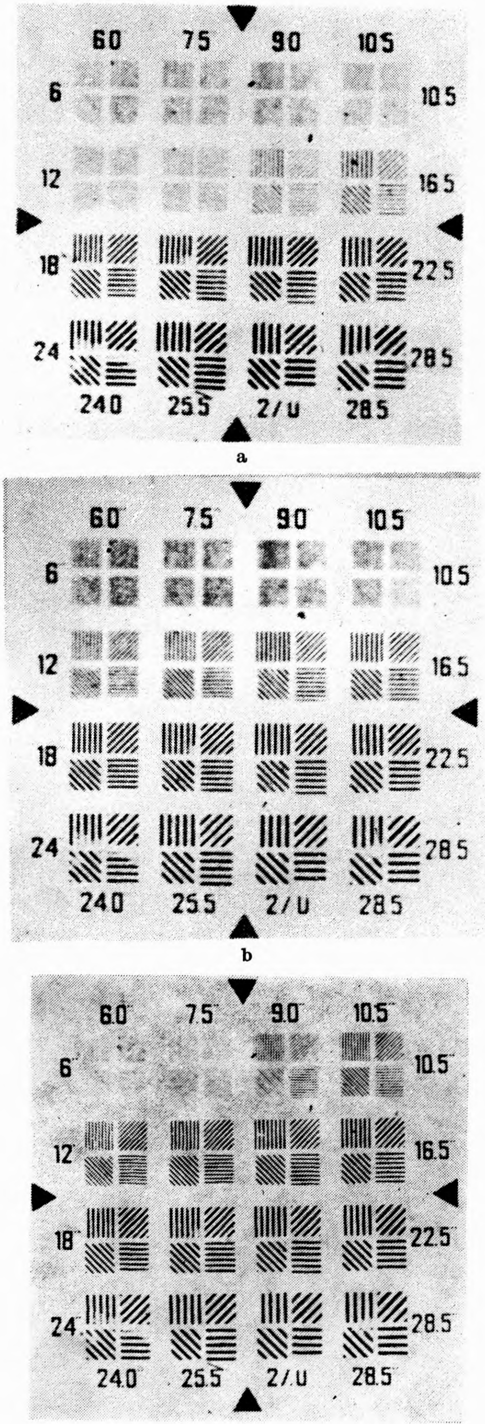


Fig. 3. Low-pass filtering. Filter diameter equal to 1.55 mm, a – $K = 0.0032$, b – $K = 0.0077$, c – $K = 0.0126$

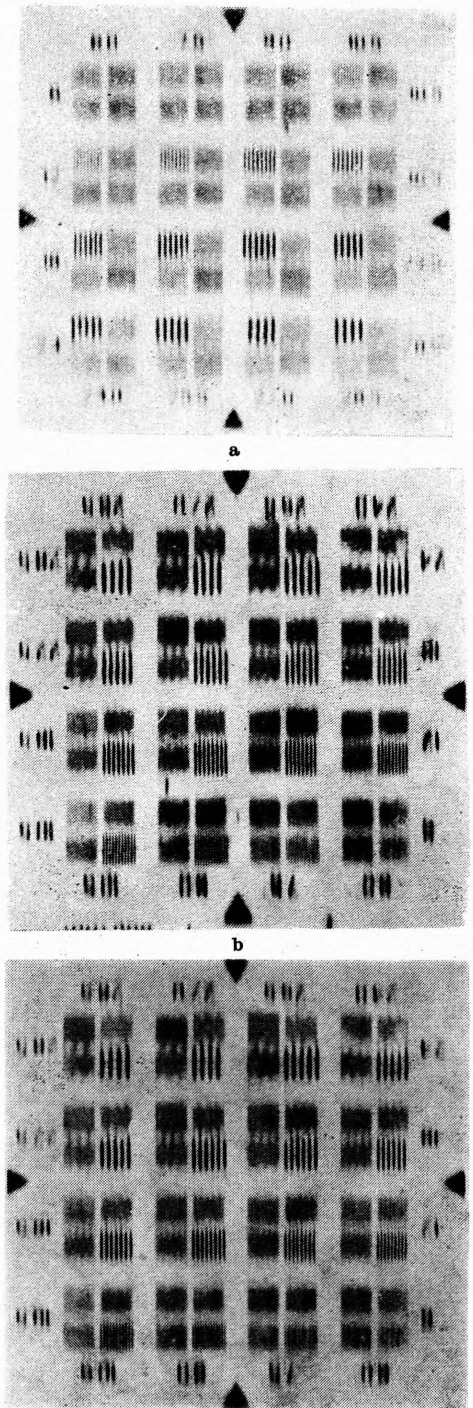


Fig. 4. Filtering by the slit filter. Slit width – 0.3 mm. a – $K = 0.0032$, b – $K = 0.0077$, c – $K = 0.0126$

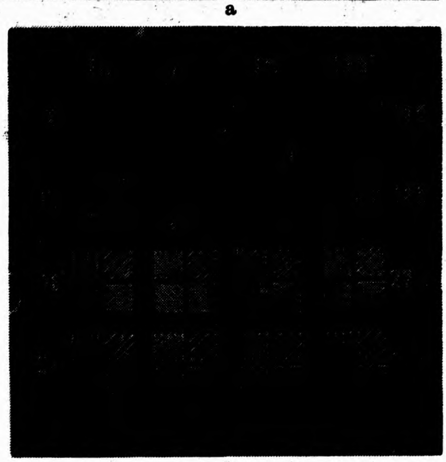
effective. In all cases, some groups of bars are ejected from the image.

Another example of the incoherent optical processing is the filtering with the slit filter. Figure 4 shows the filtering effect with the slit width of 0.3 mm. The filtering is also effective. The contrast of the group of bars which are not perpendicular to the slit direction vanishes. The bars perpendicular to the slit are better visible.

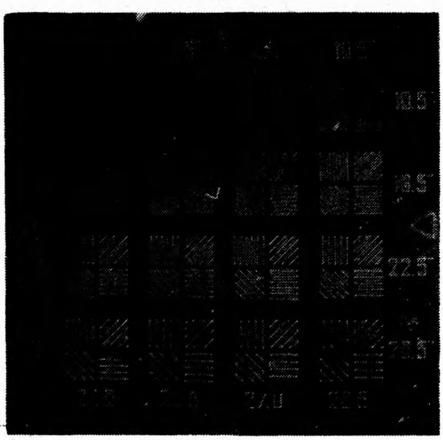
Very interesting effects are created by high-pass filters. This is shown in fig. 5. The dimensions of the blocking filters were matched to the size of the source image. For the source I (table) the filter diameter was 0.45 mm. In this case, the differentiation effect can be seen in fig. 5a. All inhomogeneities in the image, such as dust, scrathes and noise are very clearly observed. A similar effect can be seen on the image by using the source II and blocking filter dimension of 0.63 mm (fig. 5b). By enlarging the source size (source III) and the filter dimension to 1.96 mm (fig. 5c), it is also possible to differentiate the image. If the filter does not cover the whole image, the differentiation effect is not observed and only contrast of the image is decreased (fig. 5d).

As it is shown the filtering, the high and low spatial frequencies and directional filtering, using extended and quasi-monochromatic incoherent source, are very good. Results of experiments show, that in some cases incoherent methods are competitive to the coherent ones.

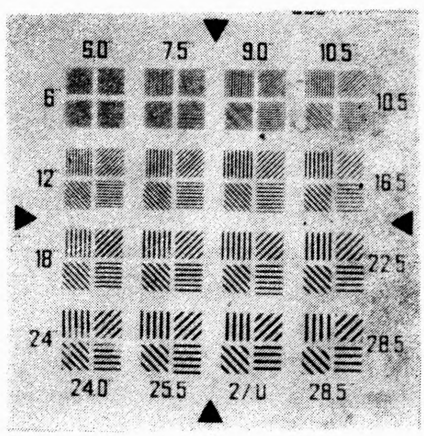
a



b



c



d

Fig. 5. High-pass filtering: a – $K = 0.0032$, filter diameter 0.45 mm, b – $K = 0.0077$, filter diameter 0.63 mm, c – $K = 0.0126$, filter diameter 1.96 mm, d – $K = 0.0126$, filter diameter 0.63 mm

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