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Pseudocolouring of directional structures by spatial frequency filtering*

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The results of pseudocolouring of the directional structures with help of optical setup for spatial frequency filtering with quasi-point white light source and multicolour sectional spatial filter are presented. Apart from the test objects the examples of pseudocoloured biological and metallographic photomicrographs as well as aerial and satellite photographs are shown.

1. Introduction

Human eye is a very sensitive colour detector. The number of colours distinguished is much greater than that of different gray levels discriminable by eye. Therefore coloured image can include essentially more useful information than its black and white equivalent. Moreover, the information included in the colour image is frequently more convenient to readout and easier to interprete for an observer in comparison to the same information encoded in the black and white image. This is one of the reasons for the increasing interest in the techniques of the colour image processing. It may be not only the matter of copying the natural colours but also of obtaining the images the colours of which would be ascribed to the given features of the objects analysed according to an accepted conventional rule (as it is, for instance, in the case of maps colouration). The rules ascribing the respective colours to the particular featires o the object may be different; so are the techniques which allow to obtain the fpseudocoloured images.

While considering the colour encoding process from the viewpoint of optics it is possible to distinguish three groups of the goals that may be achieved by the pseudocolouring of the black and white input image. These are: optical density pseudocoloring (when the differences in optical density are converted into the colour differences in the image) [1–7], spatial frequency pseudocolouring (when the colour changes in the image are related to the changes in content of the Fourier spectrum components in object) [8–15], and hybride pseudocolouring (when colour in the pseudocoloured image depends simultaneously

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on its optical density and on the Fourier spectrum in the different parts of objects) [16, 17].

The techniques used for pseudocolouring can be divided also into three main groups. The first contains the electronic and/or numerical techniques of the image processing (e.g., [18, 19]). The holographic techniques belong to the second group [6, 7, 14, 15]. The third group includes a number of methods employing the optical filtering in spatial frequency plane [1–6, 8–13, 16, 17].

Regardless of the technique used for optical pseudocolouring the light source used in the optical system plays the main role. Incoherent or partially coherent illumination seems, however, to have still growing importance in this application.

The present work shows the results of spatial frequency filtering in the optical system operating in the white light and employing the multicolour spatial frequency filter for pseudocolouring of directional structures. The method proposed can be applied to visualize the structures and details of directional character contained in the black and white images, for instance, metallographic photomicrographs, photomicrographs of the biological objects or aerial and satellite photographs.

2. Pseudocolouring of directional structures

Our method of distinguishing in optical images differently directed structures is based on the spatial frequency filtering process performed in the optical system with a quasi-point white light source. The essential element of this system is multicolour spatial frequency filter located in the Fourier plane. In the input plane of the optical system there is placed an object in form of a black and white transparency. Light bundles diffracted on the region covered with regular or semiregular structures of definite direction (in particular straight lines) are focussed in the Fourier plane of a system along lines crossing the centre of this plane and perpendicular to the directions of the line structures in the object. A multicolour spatial frequency filter is located in the Fourier plane. Its spatial distribution of spectral transmittance is arranged in such a way that the light of a specified colour is transmitted only along certain radial directions. If the latter correspond to the directions along which spatial frequency spectrum of the considered structure is spread, then the parts of objects having this structure will appear in the mentioned colour in the image formed in the output plane of the system. Thus, different parts of the object the microstructure of which has more or less linear character will be displayed in different colours, depending on the prevailing directions appearing in its structure.

The same principle of pseudocolouring is valid for straight lines present in the input image, i.e., long, thin, linear details, boundaries of different regions, etc.

The method described above is an adaptation of the *theta modulation* technique used for coding and decoding of true colour images on the black and white photographs [20–23]. Colour spatial filters typical of this method were adapted and applied to the pseudocolouring system. This allowed to distinguish the directional structures by their pseudocolour. The filters described in the literature are sensitive to the image structure, independently of its direction, while in some applications that is directionality of the objects microstructure which is essential for its interpretation.

3. Experimental setup

A diagram of an optical system used for pseudocolouring of directional structures is shown in Fig. 1. It is s typical setup for two-step spatial frequency filtering enabling to eliminate the light passing through the background of the processed photographs [24, 25].

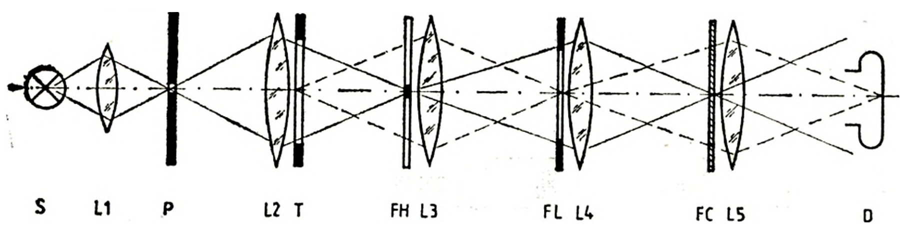


Fig. 1. Diagram of optical setup

Halogen microscopic lamp which acts as a light source *S* producing approximately white light is imaged by means of a lens *L*1 onto the pinhole *P* which plays a role of a secondary quasi-point light source. The transforming and imaging lenses are respectively denoted by *L*2, *L*3, *L*4 and *L*5. A black and white transparency, which is an object for pseudocolouring, is placed in the plane *T*. High pass spatial filter *FH* blocks-out the non-diffracted part of light coming through the object. The diameter of a stop in the filter centre is fitted to that of the pinhole *P*, the magnification of the lens *L*2 being encountered. Low pass filter *FL* removes the light coming from the boundaries of the object. The actual colour spatial frequency filter is placed in the plane *FC*. The pseudocoloured image can be observed and registered in the plane *D*.

Two different colour filters produced photographically on the ORWO UT 18 colour film used in the experiment are shown in Fig. 2. First of them enables to ascribe three fundamental colours to three structures of predominant directions contained in the sectors of $\pi/3$ angles radians. The filter used was composed of red, blue, and green sectors of the colour described by predominant wavelengths: $\lambda_R = 620$ nm, $\lambda_B = 475$ nm, $\lambda_G = 520$ nm, respectively (colour saturation varies from about 0.6 to nearly 1.0). The second filter offers 6 fundamental colours corresponding to six directions contained in the sector angles of $\pi/6$ radians.

The presented optical setup operates in partially coherent light. This fact influences the pseudocolouring efficiency by which we mean the possibility of obtaining a wide spectrum of well saturated colours, unmistakable relation between colours and directions and the possibilities of imaging without serious loss of information about smal details. The quality of the optical system may be expressed, for instance, in terms of its transfer function. The influence of the

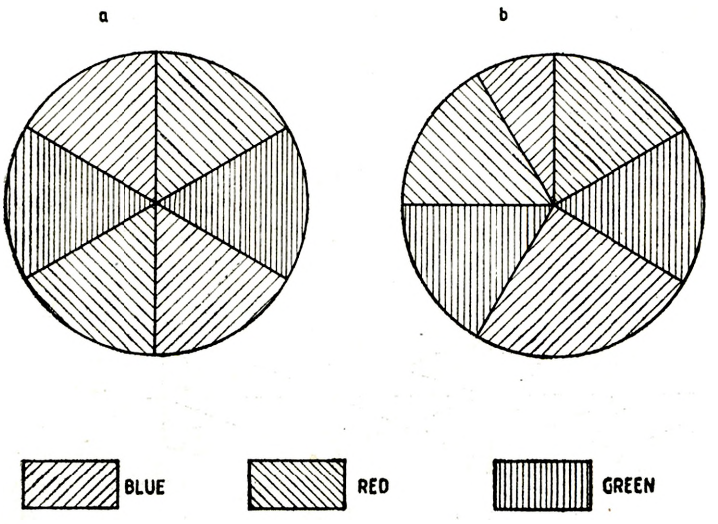


Fig. 2. Multicolour spatial frequency filters

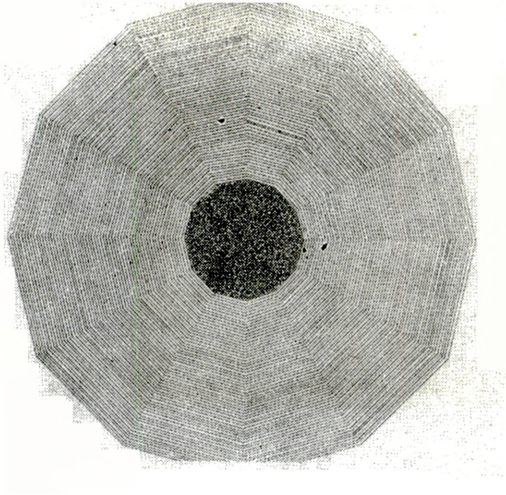
source and filter size on the transfer function of the partially coherent filtering system has been already investigated and presented elsewhere. We will quote here a paper [26] as an example. The analysis of the influence of the source size on the colour saturation in the pseudocolouring filtering system can be found in [8, 27]. The choice of geometry of the used setup, and specifically that of the high pass filter and source sizes, was based on the papers referenced above.

In the present work we are not interested in theoretical analysis of the pseudocolouring process, however, but in its practical possibilities.

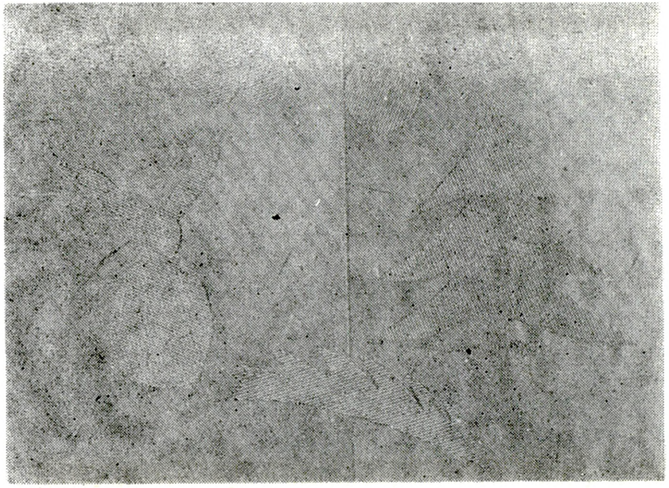
5. Experimental results

In this Section the photographs illustrating the effect of directional pseudocolouring of several test objects will be presented and some possible applications of this technique will be shown.

Figures 3a and 4a show black and white line test and its pseudocolouring image obtained with the help of the sectional filter presented in Fig. 2b. Six principal colours corresponding to the particular segments of the filter are seen. Central part of the test approximates the neutral colour, i.e., gray, as it contains the lines arranged along six directions corresponding to the particular segments of the spatial frequency colour filter.



a



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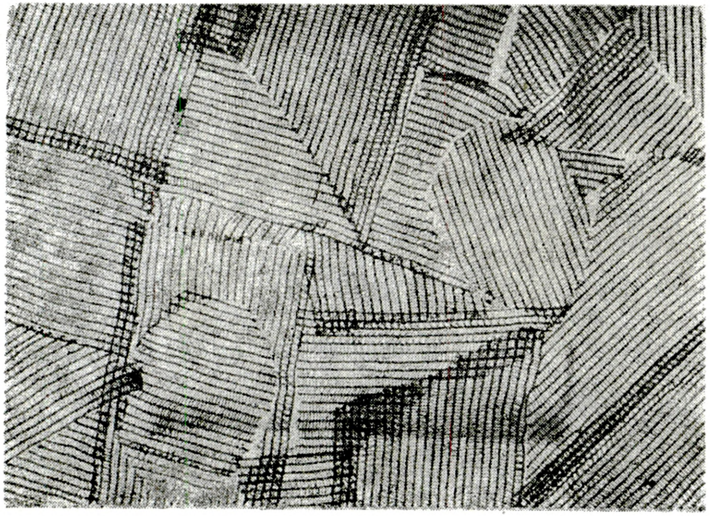
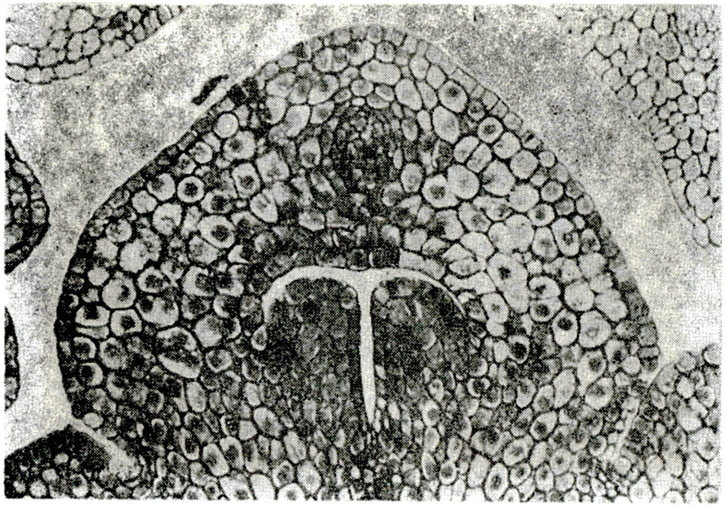


b



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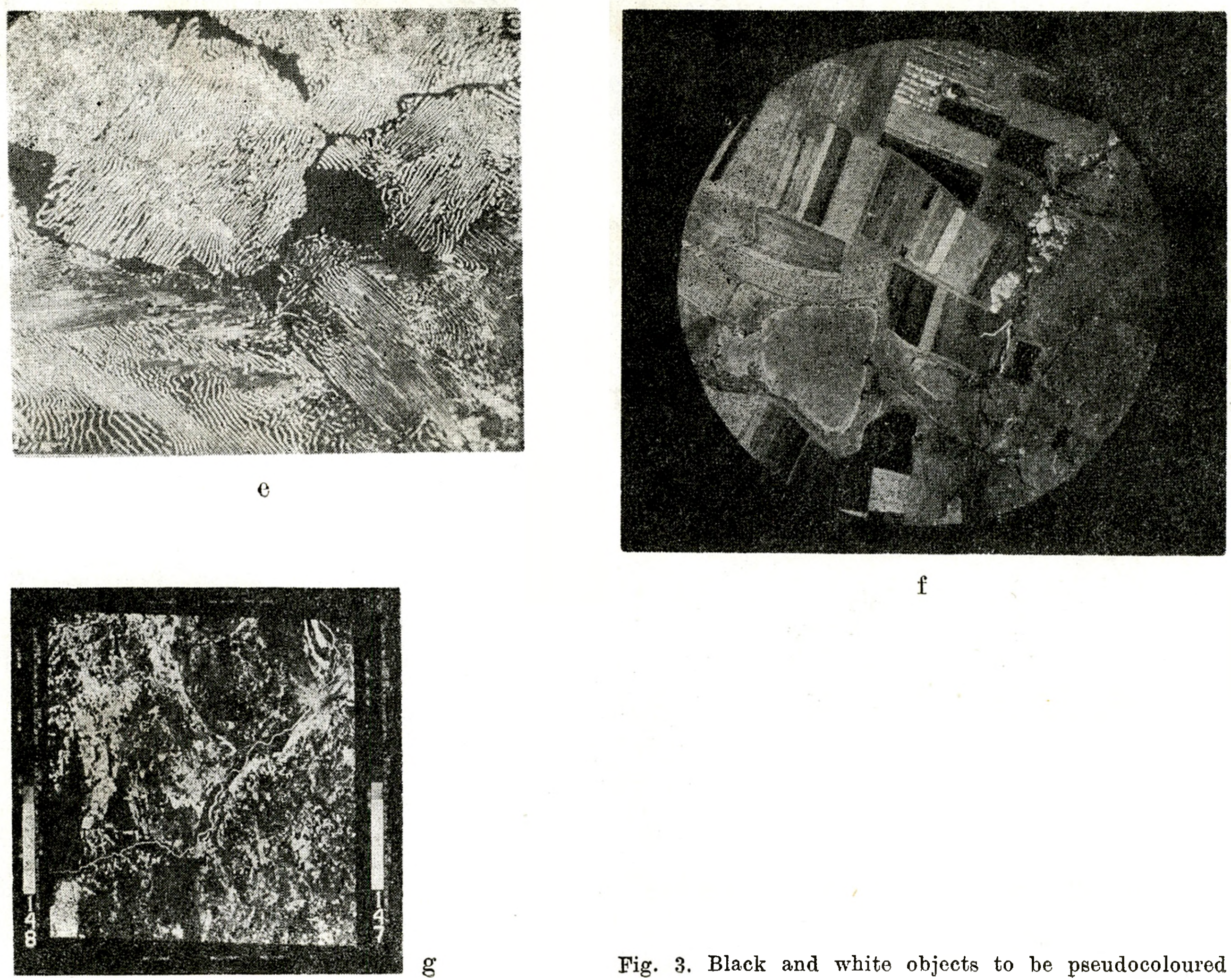

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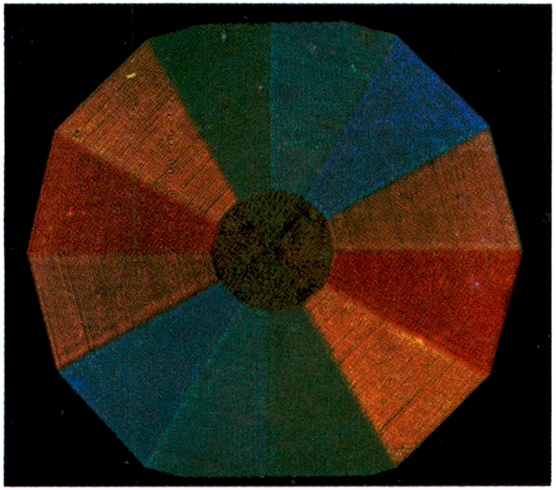
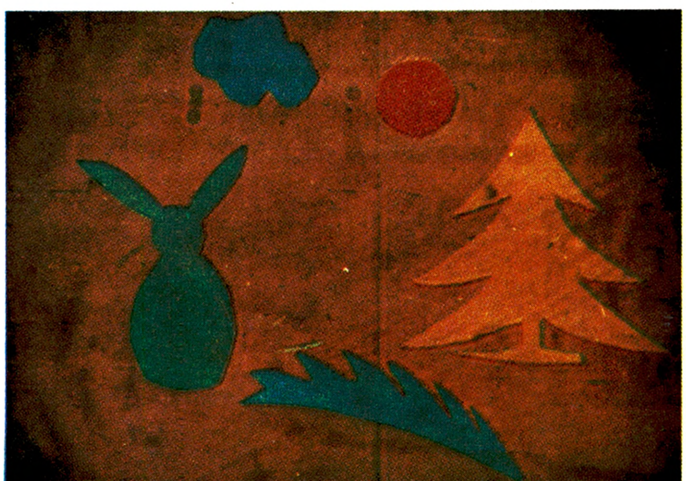
Fig. 3. Black and white objects to be pseudocoloured



a



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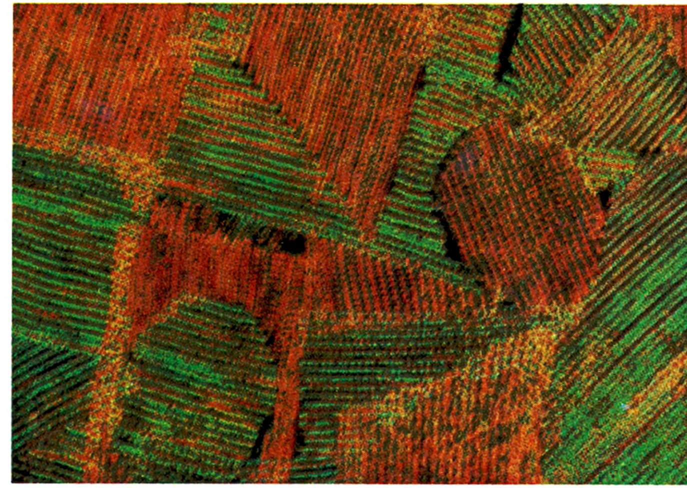

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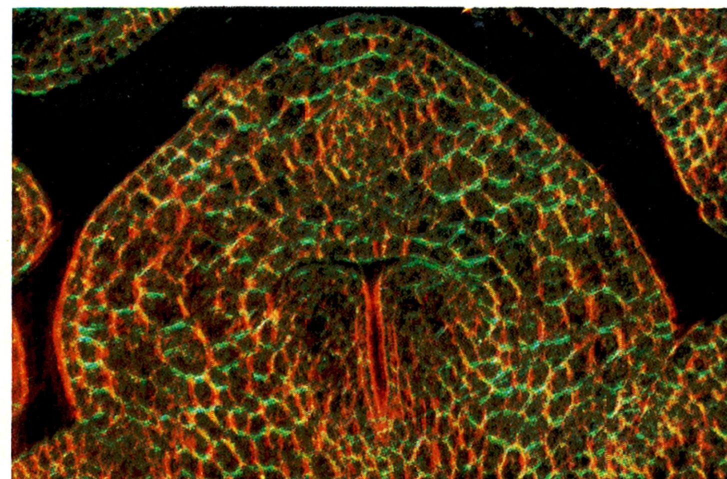

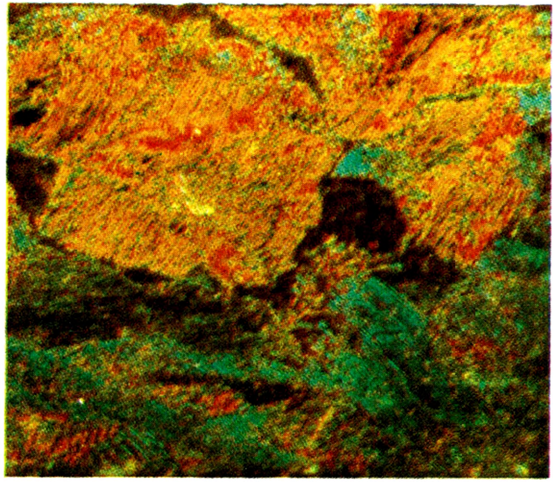

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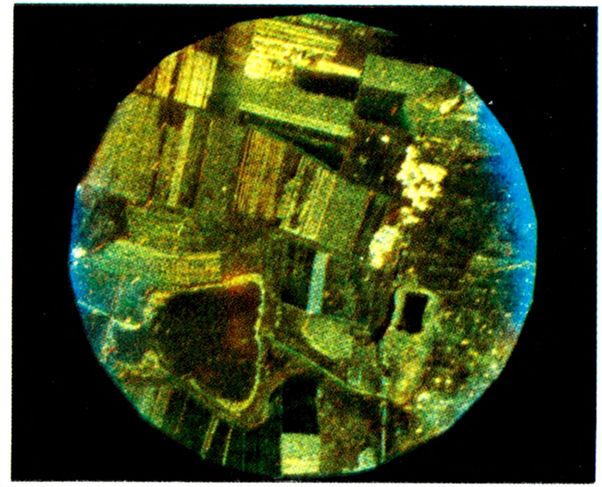

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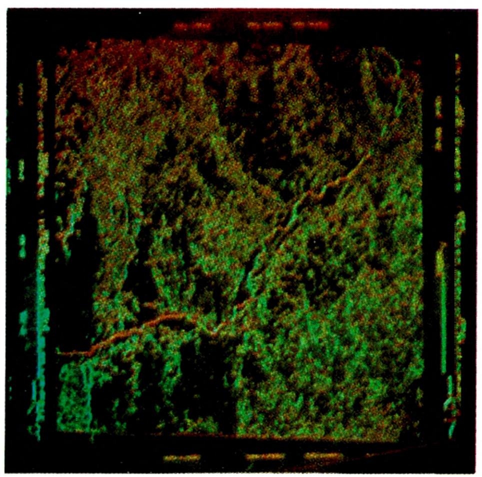

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Fig. 4. Pseudocoloured images

Figures 3b and 4b show the black and white as well as pseudocoloured images of the test pattern containing several regions covered with differently directed line grid. The colours obtained are analogous to those seen in the photograph 4a.

Another test object composed of parts covered with fine, nearly regular, but differently directed microstructure and its pseudocoloured image are presented in Figs. 3c and 4c. The obtained colour scale is poorer than in the cases presented in Figs. 4a and 4b, due to the applications of colour filter *2a*, which enables to obtain only three different colours. For this reason in the next experiments the filter *2b* was employed.

Figures 3d and 4d present the effect of pseudocolouring of the typical biological photomicrograph (fragment of a plant tissue). It can be seen that the colours of cells pellicles depend on their directions.

Two pseudocoloured metallographic microphotographs are presented in Figs. 3e and 4e (different colours visualize the areas of different directionality).

Typical aerial photograph and its pseudocoloured version are shown in Figs. 3f and 4f. The shadows of the power network pylons, poorly visible in the black and white photograph, are enhanced in orange colour in the pseudocoloured photograph.

An example of the pseudocolouring of the satellite photograph is shown in Figs. 3h and 4h. The river contour is the most distinctly coloured.

The presented examples indicate that this pseudocolouring method by improving of the detectability of some kinds of directional details and structures registered in black and white photographs might be successfuly applied whenever more comfortable visualization is needed. The advantage of the described method lies in simplicity of the optical setup and of the filter construction. The fact that a non-laser light source is employed seems to be especially favourable.

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Квазикрашение разнонаправленных структур при помощи пространственной фильтрации

В работе приведены результаты квазикрашения разнонаправленных структур при помощи оптической системы для фильтрации пространственных частот с квазиточечным источником белого света и с многоцветным сегментным фильтром. Кроме тестовых предметов представлены примеры квазицветных металлографических и биологических микрофотографий, а также воздушных и спутниковых снимок.