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Narrow-band radiation wavelength measurement by processing digital photographs in RAW format

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Abstract. **The technique of measuring the mean wavelength of narrow-band radiation in the 455–625-nm range using the image of the emitting surface is presented. The data from the camera array unprocessed by the built-in processor (RAW format) are used. The method is applied for determining the parameters of response of holographic sensors. Depending on the wavelength and brightness of the image fragment, the mean square deviation of the wavelength amounts to 0.3–3 nm.**

Keywords: *colorimetry, determination of wavelength, digital camera, RAW format.*

The colorimetric method, proposed in [1, 2], was used for dealing with digital images of narrow-band-emitting surfaces – holograms, recorded in different media. The work was performed with graphic formats BMP, TIFF, JPEG. To know how a particular camera represents radiation of different wavelengths, the so-called spectral calibration procedure was carried out, since it appeared that the relative response in colour channels depends in a rather complex way not only on the wavelength of the incident light, but also on the exposure. The technique was developed for constructing a spectral calibrating characteristic, which is a surface in the 3D space, relating the chromaticity and brightness, recorded by a single pixel, with the wavelength of narrow-band radiation acting on this pixel. As a result the photo camera could be used as a spectral instrument, the operation ranges of wavelength and intensity being rather narrow due to the smallness of the monotony domain of the characteristic curves. Actually the operation was possible only within the range of 570–600 nm.

In the present paper the colorimetric method is modified to allow operation practically in the entire visible region of the spectrum. When dealing with digital images, obtained using a photographic camera in any graphic format (e.g., BMP. TIFF, JPEG), the information about the recorded radiation (intensity, colour) essentially changes in the course of processing by the camera built-in processor. Designers try to make the intensity proportion and the colour reproduction such that the digital image would possess maximal similarity with the picture, perceived by the human eye. For example, the relative brightness of the image points is varied to match the effective light sensitivity of the camera to the logarithmic sensitivity of the eye.

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For the purpose of measurements the unprocessed RAW (read-after-write) format is more suitable. Without conversion it is not intended for visual representation. Besides the technical descriptions of shooting conditions and data, concerning the camera, a RAW file contains an array of digitised data from each pixel of the light-sensitive matrix of the camera. The signal intensity is linearly reproduced in the region up to 58 dB [3]. At this stage of the image formation, the colour for each pixel is not definite; available is only the information about the arrangement of Bayer filters matrix for the particular camera used. Processing of the data by camera built-in processor or by computer programs, visualising the RAW images (Photoshop, ACDSee, etc.) transforms the colour coverage of the camera into the sRGB system, which is accompanied with certain side effects. For example, when using the camera for recording monochromatic radiation with different wavelengths the hue of the digital image remains the same within the wavelength range 540–570 nm. Moreover, in the far red and violet regions of the spectrum the relative response of colour channels strongly varies.

Figure 1 demonstrates the changes introduced into the relative signals in colour channels and, therefore, into the hue function, when the image of the continuous spectrum, produced by means of a dispersive element [1, 2] and recorded by the camera matrix is processed by the camera built-in processor. The wavelength calibration was implemented using the mercury lamp spectral lines, observed against the continuous spectrum background. The line half-width in the image amounted to nearly two pixels; the separation between the components of the yellow doublet (577 and 579 nm) was 10 pixels. Figure 1a represents the comparison of intensities in the colour channels of the image, obtained directly from the camera matrix, avoiding nonlinear procession (for convenience of comparison the constant background is eliminated and the 12-bit signals in the channels are reduced to 8-bit representation, i.e., ranging from 0 to 255). Figure 1b shows the signals in the colour channels for the same frame, taken from the ACDSee viewer without any additional correction of the image (Photoshop and the camera built-in processor yield the same result). It is seen that the signals of the red and blue sensors (Fig. 1b) are suppressed in the central part of spectrum, so that in the range of wavelengths 540–570 nm only the green signal is 'allowed'. One should keep in mind that pure colours are rare in everyday photography. The examples are rainbow, certain periodic multilayer structures (e.g., wings of butterflies). That is why the distortion of colour reproduction, although undoubtedly present, usually is not striking. In

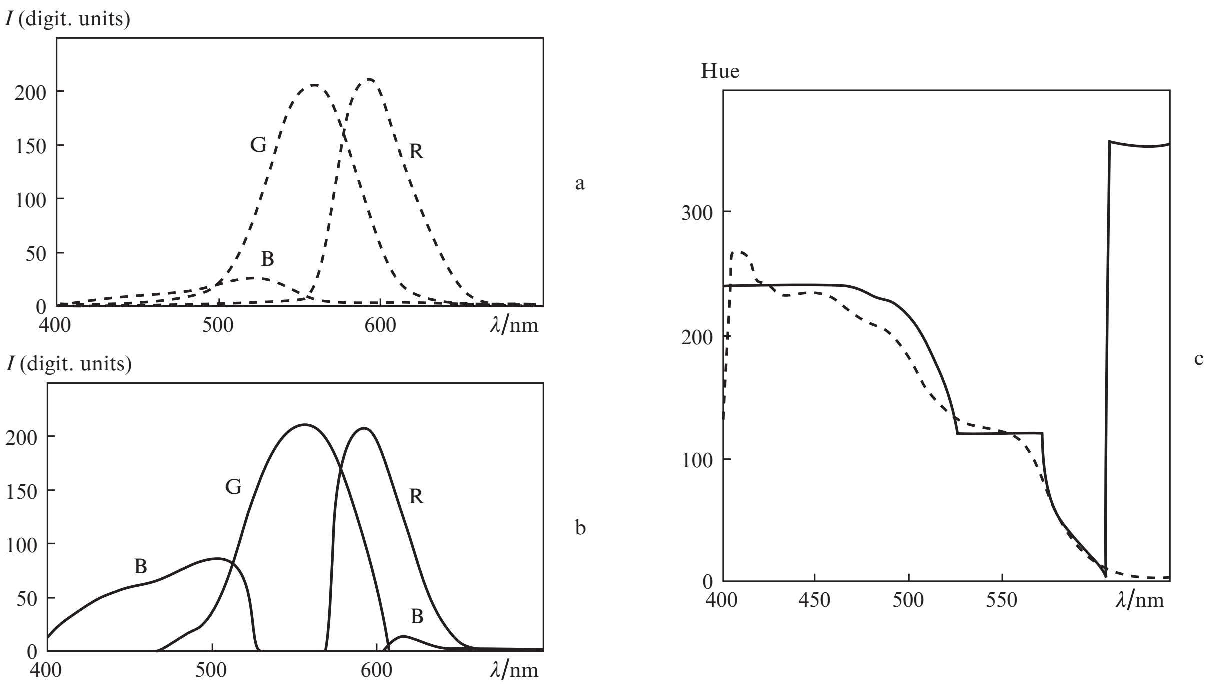

Figure 1. Colour components of the image in the continuous spectrum (R – red, G – green, B – blue) without processing by the camera processor or visualisation software (a) and after the camera processor (b), as well as (c) the relation between the wavelength and the hue function (Hue) for processed (solid line) and unprocessed (dashed line) images. Hue = 0 corresponds to the red, Hue = 120 to the green, and Hue = 240 to the blue colour.

our case this property of modern cameras makes it impossible to measure wavelengths in this range using photographs in standard graphic formats. Besides, from Fig. 1b it is seen that the relative intensity of the blue component of the signal from the matrix is several times magnified, and in the red region, near the sensitivity cut-off of the green sensors, a weak blue signal is emulated by the program, which introduces slight violet tint into the image of the far red region of the spectrum.

The dependences of the hue function of an image point (Figs 1a and b) on the wavelength are presented in Fig. 1c. The solid curve represents the hue function for the spectrum in a standard graphic format. The main disadvantage of colour reproduction in Fig. 1b is the presence of a horizontal segment (Fig. 1c), where the hue in constant and the wavelength measurement is impossible. In the unprocessed photograph the hue varies monotonically with the wavelength in the range 455–625 nm, and this may be considered as an operating range for wavelength determination.

The procedure of camera calibration is the following. A series of photographs of the spectrum (continuous with reference lines superimposed on it) is produced with different exposures in the RAW format. The unprocessed signal is taken directly from the receiving matrix of the camera and divided into colour channels, taking the arrangement of Bayer sells with appropriate filters into account. Each coordinate in the frame is associated with a wavelength. Figure 2 shows the dependence of the wavelength in the radiation spectrum on the horizontal coordinate (pixel number) for a series of calibration photographs. For linear approximation of the dependence we used the lines of the mercury spectrum at 404.7, 435.8, 491.6, 546.1, 577.0, and 579.0 nm. Then for each wavelength of the continuous spectrum, using photographs with different exposure, the samples of relative intensities in colour channels for different brightness of the image were collected. As a result, after the noise averaging, we get the dependence of the wavelength in the spectrum image on the hue and the image intensity – somewhat of a calibration surface. An example of such a surface, obtained by calibrating the Canon EOS10D camera, is shown in Fig. 3, where the intensity $I = {}^{1}/_{3}(I_R + I_G + I_B)$ varies within the range 5–100, the hue within 0–240, and the wavelength is determined within 455–625 nm. The dependence of the wavelength on the intensity is very weak (in contrast to the analogous function for standard graphic formats [1, 2]), and mainly the dependence of the wavelength on the hue is essential.

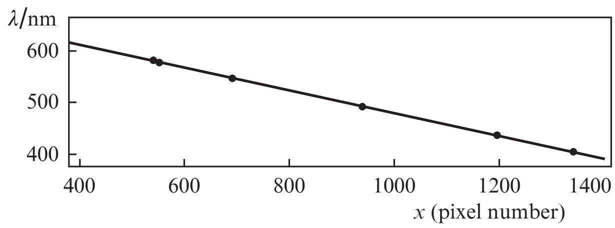

Figure 2. Dependence of the wavelength in the calibration spectrum on the horizontal coordinate in the frame (pixel number). The points show the data for mercury lines, the straight line is the result of their linear approximation.

Testing of the method was performed by measuring the wavelengths using the image of the mercury spectrum and superimposed continuous spectrum from an incandescent lamp. In the map of wavelength distribution over the image, both the wavelengths of mercury lines and the linear depen-

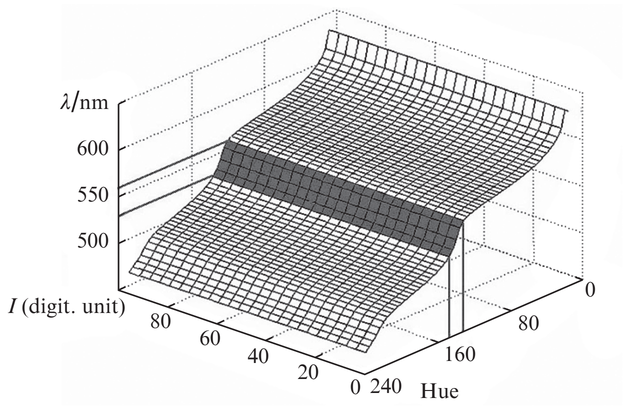

Figure 3. Calibration surface.

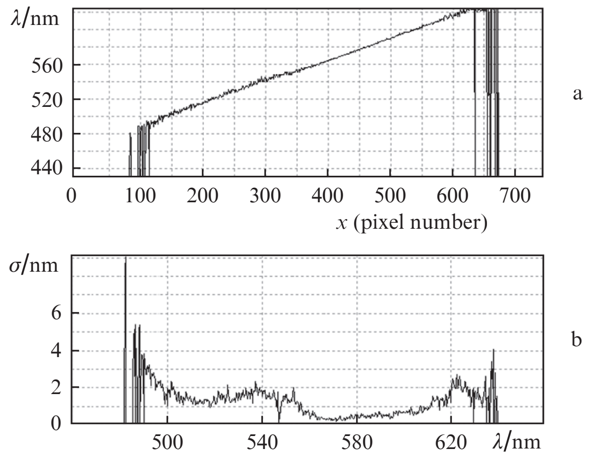

Figure 4. Calculated distribution of wavelengths over the frame section in the direction of dispersion (a) and the corresponding dependence of the mean square deviation of the wavelength (b).

dence of the wavelength on the coordinate in the continuous spectrum were reproduced with good accuracy (Fig. 4).

The mean square deviation of the wavelength amounts to 0.3–3 nm. The value of the error depends mainly on two factors. The first one is the brightness of the image fragment: in case of low brightness of the image the noise strongly grows and the accuracy of the wavelength determination becomes worse. The second factor is the wavelength and the slope of the calibration surface at the appropriate wavelength. In the green region (530–560 nm) a small change of hue (15 units) corresponds to the difference of 30 nm in the wavelength scale (Fig. 3). The mean square deviation in this range even at sufficient intensity of radiation amounts to 1.0–2.0 nm. In the yellow spectral region the calibration surface is sloping milder, and in the region 570–580 nm the hue changes by almost 40 units. In this region of the spectrum the wavelength can be determined with higher accuracy, and the mean square deviation amounts to 0.3–0.5 nm.

We used the described method for measuring the distribution of the mean wavelength of reflected radiation over the surface of a hologram. Thus one can monitor different parameters of holographic sensors: the degree of swelling, homogeneity of the hydrogel emulsion, rate of reaction on the change of the solution composition, etc.

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References

1. Kraiskii A.V., Mironova T.V., Sultanov T.T., et al. Patent of Russian Federation No. 2390738. Priority of 21.05.2008.
2. Kraiskii A.V., Mironova T.V., Sultanov T.T., *Kvantovaya Elektron.*, **40** (7), 652 (2010) [*Quantum Electron.*, **40** (7), 652 (2010)].
3. Konnik M.V., Manykin E.A., Starikov S.N. *Kvantovaya Elektron.*, **40** (4), 314 (2010) [*Quantum Electron.*, **40** (4), 314 (2010)].