3. Automation and computer technology

TWO-DIMENSIONAL VIDEO IMAGE MODELING WITH MEASUREMENT INFORMATION ON GEOMETRIC PARAMETERS OF OBJECTS

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One of the effective methods for measuring geometric parameters of objects is the formation and algorithmic processing of their video images. To obtain measurement information about geometric parameters, it is necessary to form a digital video image, which is a two-dimensional image of the object of measurement and to insert this image into a computer. Algorithmic processing (for example, filtering and restoring images) provides compensation for distortions that arose during the formation and transfer of images. In order to establish methods of algorithmic processing and evaluation of the accuracy of the determination of geometric parameters, it is necessary to have test video images that, in their statistical characteristics, are similar to video images of real objects of measurement. Numerical simulation methods provide the generation of two-dimensional arrays with statistical characteristics as specified by the researcher.

We shall consider a function $f_0(x, y)$ that characterizes a two-dimensional projection of an object of measurement, such as the realization of a random process with spatial coordinates x and y. This two-dimensional function is recorded by the camcorder as a digital video image $\hat{f}_0(n,m)$. For the achromatic surface of the object of measurement, the halftone digital video image contains one channel $\hat{f}_0(n,m)$, which characterizes the surface brightness. For a chromatic surface of a measuring object, a color digital image contains three channels that characterize the brightness and color of the surface according to one of the color models [1, p. 426-438]. Each of these channels also represents a function $\hat{f}_0(n,m)$.

The mathematical model of a two-dimensional function $f_0(x,y)$, as a random process, is its first and second statistical moments, that is, the mean value of the amplitude $E[f_0(x,y)]$and a two-dimensional correlation function $R(\tau_x,\tau_y)$, where τ_x,τ_y – are the spatial coordinates of the correlation function. Algorithmic processing methods for video images as source data use the correlation functions or spectral densities obtained from the correlation functions by means of a two-dimensional Fourier transformation. Therefore, we will consider mathematical models of video images of the surface of objects of measurement on the basis of their two-dimensional correlation functions.

The two-dimensional correlation function can be calculated by the formulas [2, p. 27, 134; 3, p. 16]:

$$\begin{gathered} R(\tau_x,\tau_y) = E[\bar{f}_0(x+\tau_x, y+\tau_y) \cdot \bar{f}_0(x,y)], \\ \bar{f}_0(x,y) = f_0(x,y) - E[f_0(x,y)], \end{gathered} \tag{1}$$

where $\bar{f}_0(x,y)$ – is a two-dimensional function, centered as for the mean value.

Discrete samples $R(n_1,m_1) = R(\tau_x,\tau_y)\big|_{\tau_x=n_1\delta_x,\ \tau_y=m_1\delta_y}$ of two-dimensional correlation function are calculated on the basis of formula (1). In this case $n_1 \in \overline{0,N-1}$, $m_1 \in \overline{0,M-1}$. We will further assume that the video image has been extended beyond its borders by reflection. On the basis of formulas (1) we have:

$$E[\hat{f}_0(n,m)] = \frac{1}{NM}\sum_{m=1}^{M}\sum_{n=1}^{N}\hat{f}_0(n,m), \quad \bar{f}_0(n,m) = \hat{f}_0(n,m) - E[\hat{f}_0(n,m)], \tag{2}$$

$$R(n_1,m_1)=\frac{1}{NM}\sum_{m=1}^{M}\sum_{n=1}^{N}\bar{f}_0(n+n_1,m+m_1)\cdot\bar{f}_0(n,m).$$

To develop a mathematical model of video images of objects the counting of the correlation function (2) is necessary to approximate the analytical expression. For video images, a typical mathematical model is a two-dimensional Markov process of the first order. In this case, the analytical expression of the correlation function is [2, p. 28]:

$$R(\tau_x,\tau_y)=\sigma_f^2\exp\left\{-\sqrt{(\alpha_x\tau_x)^2+(\alpha_y\tau_y)^2}\right\}. \qquad (3)$$

Let us consider the two-dimensional correlation function (3). The projection of lines of equal values of this function onto the plane of the spatial coordinates of a video image has the form of a circle or an ellipse. In the first case, the video image is an isotropic random field with $\alpha_y=\alpha_x$, in the second case, an anisotropic random field with degree of anisotropy $L_{\text{a}}=\alpha_y/\alpha_x$. Then the parameter identification can be performed for one-dimensional correlation functions $R(\tau_x)=R(\tau_x,\tau_y)\big|_{\tau_y=0}=\sigma_x^2\exp\{-\alpha_x|\tau_x|\}$ and $R(\tau_y)=R(\tau_x,\tau_y)\big|_{\tau_x=0}=\sigma_y^2\exp\{-\alpha_y|\tau_y|\}$ based on the values $R(n_1)=R(n_1,m_1)\big|_{m_1=0}$, $\sigma_x=R(n_1)\big|_{n_1=0}$, $R(m_1)=R(n_1,m_1)\big|_{n_1=0}$, $\sigma_y=R(m_1)\big|_{m_1=0}$, calculated for the rows and columns of the video images. The two-dimensional correlation function is determined on the basis of one-dimensional correlation functions, taking into account L_{a} and equation (3).

For one-dimensional correlation function, the least squares method is given by the following equations with a substitution $R_1(\tau_x)=\ln R(\tau_x)$:

$$R_1(\tau_x)=\ln\sigma_x^2-\alpha_x|\tau_x|,$$

$$I=\sum_{n_1=0}^{N-1}\left(\ln R(n_1)-\ln\sigma_x^2+\hat{\alpha}_x n_1\delta_x\right)^2\to\min,$$

$$\frac{\partial I}{\partial\hat{\alpha}_x}=2\sum_{n_1=0}^{N-1}\left(\ln R(n_1)-\ln\sigma_x^2+\hat{\alpha}_x n_1\delta_x\right)\cdot n_1\delta_x=0,$$

$$\hat{\alpha}_x = \frac{\sum_{n_1=0}^{N-1} n_1 \left(\ln\sigma_x^2 - \ln R(n_1)\right)}{\delta_x \sum_{n_1=0}^{N-1} n_1^{\,2}} .$$

Taking into account the relationship

$$\sum_{n_1=0}^{N-1} n_1 = N(N-1)/2, \quad \sum_{n_1=0}^{N-1} n_1^{\,2} = N(N-1)(2N-1)/6,$$

finally get:

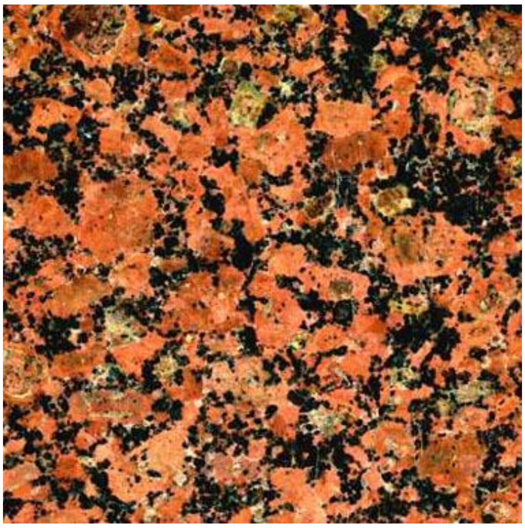
$$\hat{\alpha}_x = \frac{3\ln\sigma_x^2 - \frac{6}{N(N-1)} \sum_{n_1=0}^{N-1} n_1 \ln R(n_1)}{(2N-1)\delta_x} . \qquad (4)$$

For a one-dimensional correlation function $R(\tau_y)$, we obtain in the same way:

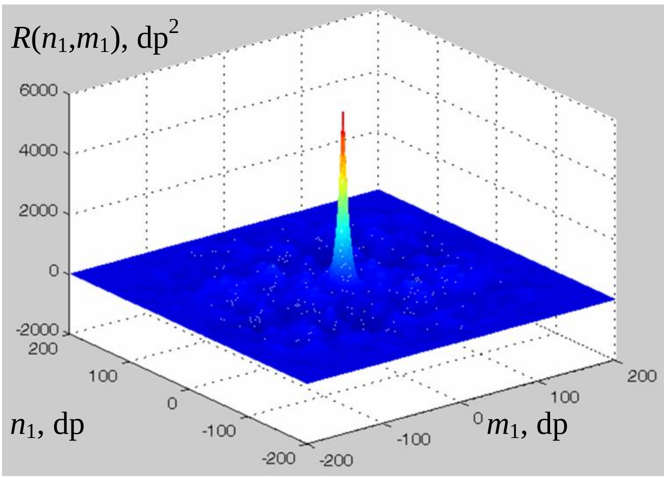
$$\hat{\alpha}_y = \frac{3\ln\sigma_y^2 - \frac{6}{M(M-1)} \sum_{m_1=0}^{M-1} m_1 \ln R(m_1)}{(2M-1)\delta_y} . \qquad (5)$$

The determination of the parameters of the mathematical model (3) was performed for a series of video images of the surface of industrial products made of natural stone (Fig. 1). These video images can be used to measure geometric parameters and to control quality of industrial stone products [4].

To evaluate the accuracy of the parameters identification results $\hat{\alpha}_x$, $\hat{\alpha}_y$, a two-dimensional correlation function was calculated using formula (3) with coefficients (4), (5), and the results of calculations were compared with the experimental data obtained by the formula (2). Estimates of the parameters $\hat{\alpha}_x$, $\hat{\alpha}_y$ were calculated in (mm) $^{-1}$ and in (dt) $^{-1}$ (dt – discrete points of digital video images). In the latter case, division into δ_x and δ_y needs to be exclude from the formulas (4) and (5). The error in determining the parameters of a mathematical model according to the given method was (3 ... 9) %.



a)



b)

Fig. 1. Video image of the surface of granite from Omelianovskyi deposit in Zhytomyr region (a) and its two-dimensional correlation function received for the channel of red color (b) (1 dt = 0.25 mm)

Research results can be used to develop methods for algorithmic processing of two-dimensional video images with measurement information about geometric parameters of objects and to improve the accuracy of determining these geometric parameters.

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