Precision increase in automated digital image measurement systems of geometric values

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Abstract. The article is devoted to the development of the algorithmic method of video image processing of natural stone products. These video images contain the measurement information about geometric parameters of products, and the parameters of their movement during production at stone processing plants. The developed methods provide the algorithmic compensation of random, dynamic and geometric errors of video images which occur at the forming stage. The measurement results of the above mentioned values are used to control the technological process in the stone processing plants, and to improve the quality of natural stone products.

Keywords: geometric parameters, motion parameters, algorithmic error compensation, video image.

1. Introduction

The enterprises of stone mining are the important component of the industry of Ukraine. Unfortunately, the effective realization of their capabilities is obtained by the outdated equipment and the means of mechanic values do not possess high precision and fast-acting. That is why, the task of development of new precision means and the increase of their fast-acting features in order to control the mechanic values at natural stone mines is becoming more and more urgent.

The modern visualization methods are suggested to be applied to increase the precision and fast-acting of measurements the geometrical parameters of product movement. These methods are aimed to form the product video image and to perform their algorithmic processing [1, 2]. The geometrical parameters of the natural stone product outer contour, along with the geometrical parameters of the processed surface structure of these products are measured on the basis of the captured on-line video

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images. The modern means of mechanic values include computer or microcontroller. As a result, these means are capable to process the measuring signals to obtain the mechanic values measurement and to increase their precision [3-5]. The algorithmic methods of video image processing have been considered in many papers. They are: the investigation of machine vision [6-8], the automated control systems with video sensors [9, 10], the television measuring systems [11, 12]. But these papers do not fully focus on the requirements of the metrological characteristics of the video images measurement information. .

2. The formulation of the task of the algorithmic error compensation of the geometric values measurement information

The existing methods of algorithmic processing of measuring information about mechanic values are mostly used to process one-dimension signals [13-15]. The existing solutions for two-dimension signals do not apply all possibilities of modern information computer technologies concerning video image processing [13-15].

There are also transient and adverse factors which influence the measurements of the mentioned mechanic values. The solution of this task is performed in the following sequence: the identification of transfer function of video image forming device, the parameters of geometric errors, the parameters of video image correlation function errors and random errors; the calculation of video image spectrum density and random errors by means of two-dimensional Fourier transformation of their correlation functions; the performance of algorithmic compensation of random, dynamic and geometric errors based on the results of their parameters identification; the estimation of geometric parameters precision measurements. The problem of video image forming device transfer function, the error parameters, and correlation functions is investigated in [16].

Therefore, the purpose of the given article is to develop new methods of algorithmic processing of video images with the measurement information about the geometric parameters and parameters of products movement, which provide significant precision increase of these measurements

3. Algorithmic compensation of random errors of video images

The method of algorithmic compensation of random errors [17] is developed to increase the precision mechanic value measurement. According to this algorithm a sample of natural stone from mineral deposit is fixedly placed at the digital camera; a set of video images is formed and input into computer; the video image averaging is performed and the estimation of measuring information about mechanic values is obtained.

The known criteria of video image fidelity reproduction are aimed to estimate the amplitude errors and visual quality of video images. So, the following indexes are suggested to estimate the precision of geometrical parameters in automated systems: the coordinates of the determination of the coordinates of the center of mass, the linear dimensions and area of a product and the structural elements of its surface, and also the average value of the error of a product coordinate contour measurement:

$$\Delta_{\text{cont}} = \frac{\sum_{n,m} \hat{f}_{0\,\text{c}}(n,m) \oplus f_{0\,\text{c}}(n,m)}{l_{\text{к}}}, \qquad (1)$$

where

$$f_{0\text{c}}(n,m) = \begin{cases} 1, & \text{if} \quad f_0(n,m) \in Q_{\text{OB}}, \\ 0, & \text{if} \quad f_0(n,m) \notin Q_{\text{OB}}, \end{cases} \qquad (2)$$

$$\hat{f}_{0\text{c}}(n,m) = \begin{cases} 1, & \text{if} \quad \hat{f}_0(n,m) \in \hat{Q}_{\text{OB}}, \\ 0, & \text{if} \quad \hat{f}_0(n,m) \notin \hat{Q}_{\text{OB}}, \end{cases} \qquad (3)$$

where: $\oplus$ – is the logical operation of the sum determination by the module 2; $l_{\text{к}}$ – is the contour length of a product in discrete points; Q_{OB} i $\hat{Q}_{\text{OB}}$ – is the set of points which belong to a product at the initial and the processed video image after their product/background segmentation, correspondingly.

This method provides the precision of the geometrical parameters determination of the fixed products made of natural stone (in 2,0…9,5 times for the correlation signal/noise $\psi_{\text{c/h}}$ = 55 dB on the video image and in 3,0…12,5 times for $\psi_{\text{c/h}}$ = 40 dB).

4. Algorithmic compensation of dynamic errors of video images

The method of reproduction of video images with dynamic errors for the measurement of geometric parameters and movement parameters under the conditions of non-stationary factor influence [18] is developed:

I. It is recommended to form the video image of a product $f_{\text{H}}(n,m)$, and to compensate the errors in accordance with the mentioned above recommendations. As a result, the estimation of the image with dynamic and geometric errors $\hat{f}_{\text{d}}(n,m)$ is obtained.

II. The image amplitude in relation to maximum value $\hat{f}_{\text{d}\max}$ is normalized and the normalized amplitude derivative of the video image is calculated.

III. The maximum value $f'_{\max}$ of the normalized amplitude derivative of the video image between the values is found.

IV.The discrete readouts transfer frequency function is calculated for the device which forms video images $H_{\text{H1}}(u,v)$ on the basis of [15], taking into account the correlations $\omega_1 = 2\pi u/(N\delta_x)$, $\omega_2 = 2\pi v/(M\delta_y)$, $u \in \overline{0,N-1}$, $v \in \overline{0,M-1}$:

$$H_{\text{H1}}(u,v) = \exp\left(- \frac{\pi\left(u^2/N^2 + v^2/M^2\right)}{\Delta^2_{f\max}} \right) \qquad (4)$$

where ω_1, ω_2 are the space frequencies in the video image spectrum.

V.The estimation $\hat{f}_0(n,m)$ is calculated by means of $\hat{f}_{\text{Д}}(n,m)$ usage with the digital fitter with frequency characteristics $H_{\text{H1}}^{-1}(u,v)$, obtained from the formula (4), and the geometric errors compensation according to the instructions [11, 12].

The developed method of reproduction uses the frequency transfer function of the device for video image forming. It absolutely corresponds to the conditions of the measurements at the current moment of time in contrast to the known methods which use the prior information of the average values for measurement conditions having been found before. It provides the precision increase of the contour points coordinate of products of 1,5…6,3 times.

5. The algorithmic processing of the video image sequence with the measuring information about geometric values

The time sequence of video images $f_i(x,y)$, $i \in \overline{1,K}$ characterizes the current position of the products and the industrial equipment at the moments of time $t_i = i \cdot \delta_\text{d}$. The i-video image has to be determined by the coordinate of the mass center and equipment x_{ci}, y_{ci}, and its angle position α_i. The indicated parameters characterize the two-dimensional movement of these objects in the image area. Thus area consists of the mass center onward movement, and the rotational movement around it.

The movement parameters of the product and equipment are determined in every coordinate x_{ci}, y_{ci}, α_i resulting in the obtained transition vectors, velocity and acceleration (the variable x_i can be represented by any coordinates among x_{ci}, y_{ci}, α_i).

The following mathematical model is used to estimate the movement parameters:

$$x_i = \sum_{l=1}^{N_\Pi} \theta_{il}\beta_l \text{ , } X = \begin{pmatrix} x_1 & \ldots & x_K \end{pmatrix}^T = \Theta\beta \text{ ,} \tag{5}$$

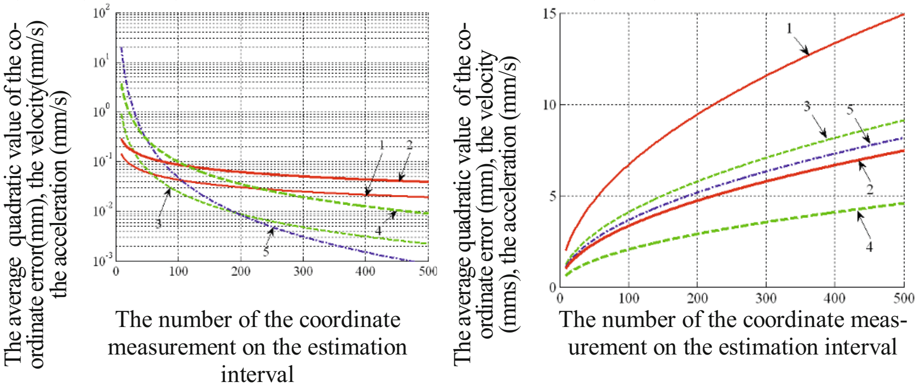
where $\Theta = [\theta_{il}]$ – is the value matrix prior to the known functions at the moments of time $i\delta_\text{д}$; $\theta_{il} = \dfrac{(i\delta_\text{д})^{l-1}}{(l-1)!}$; $\beta = \begin{pmatrix} \beta_1 & \ldots & \beta_{N_\Pi} \end{pmatrix}^T$ – is the vector of movement parameters which describe the process of movement.

The result of movement parameters estimation based on the maximum likelihood method equals:

$$\hat{\beta} = B^{-1}A \text{ , } B = \Theta^T R_{\Delta x}^{-1}\Theta \text{ , } A = \Theta^T R_{\Delta x}^{-1} X^* \text{ , } \Psi_{\hat{\beta}} = B^{-1} = \left(\Theta^T R_{\Delta x}^{-1}\Theta\right)^{-1} \text{ ,} \tag{6}$$

where $R_{\Delta x} = \sigma_{\Delta x}^2 \cdot I_k$ – is the correlation matrix of measurement errors Δ_{xi}; $\sigma_{\Delta x}^2$ – is the error dispersion of the x_i coordinate measurement; I_k – is the unitary matrix of the $K \times K$ size; $\Psi_{\hat{\beta}}$ – is the correlation matrix of the movement parameter vector estimation.

That is why; the formulas (5) and (6) are used to determine the estimation of movement parameters of products and equipment in real time. The calculation of the movement measurement errors on the basis of errors correlation matrix and their comparison to the known methods is shown in Fig. 1. The estimations are calculated for time moments $j\delta_{д}$, $j = N_{oc},...,K$, each of them is preceded by the estimation time $T_{oc} = (N_{oc} - 1)\delta_{д}$. It is found by means of the numerical modeling and the experimental research, that the measurement precision of the current coordinates and product movement parameters for the accumulated sequence of video images increases in 3, 7…6, 7 times, for the measurements in real time in 2,1…3,7 times .



a) b)

Fig. 1. The theoretical precision calculation of the current coordinates determination and object movement parameters in accordance with the developed methods (a) and their comparison (b) to the method of numerical differentiation; 1- is the current coordinate, the numerical differentiation: 2- is the current coordinate, the developed method; 3- is the velocity, the numerical differentiation; 4- is the velocity, the developed method; 5- is the acceleration, the developed method

The results of parameter movement determination are used in to control the technological standards when producing the products made of natural stone. These results are also used for the compensation of video image dynamic errors which are caused by the product movement at the digital camera. It allows increasing the precision and velocity of the equipment which measures the products directly at the production process. As a result, the quality of products made of natural stone is increased.

Conclusions

The new methods of algorithmic error compensation of video image with the measurement information about geometric values are developed. These methods provide the precision increase of the determination of geometric parameters and movement of products made of natural stone of 1,5…6,3 times compared to the existing means of measurements.The measurement results of the mentioned values can be used to control the technological process of mining enterprises, and to increase the quality of products made of natural stone.

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