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Optical Measurement of Amplitude of Vibration of Machine

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In the paper the application of 2D and 3D vision techniques for amplitude vibration measurements of vibratory machine working under operating conditions was presented. For this purpose method and algorithms were developed of image analysis and discrete epipolar geometry with the usage of one camera. They were implemented in programming environment – MATLAB and tested on experimental set–up.

Keywords: Optical measurement, 2D and 3D vision techniques

1. Introduction

Vibratory machinery implement the technology or transport on the basis of the transmission of vibrations to the body of the machine. A major problem for designers and users of over resonant vibratory machinery represents a very significant increase in the amplitude of vibration resonance during the transition in relation to the state established during start-up and open [1]. Particularly in time comes for long-range resonance transition, and resulting in the outcome, strong vibrations corps may lead to disposal nadawy, damage to the foundation, or support structure (e.g. ceiling) or even to cancel the suspension system elastic machine. The main difficulty associated traditional methods of measurements carried out during the experimental work of these machines is linked to the difficulty in assembling a system of sensors and wiring, and the influence of conventional sensors installed on the behavior of the machine. In traditional techniques for measuring the vibration of machinery, equipment and construction are used transducers such as accelerometers, force transducers, tensometerss. These transducers require their direct attachment to the test items during the course of the experiment. In many cases, it is difficult, even impossible, or undesirable impact on the substance measured object. Another reason is low frequency vibrations encountered in the construction machinery vibration, and especially systems of vibroisolation. Their measure because of the low frequency band is difficult and often almost impossible with standard accelerometers. This makes it necessary to use other tools for measuring Alignment based on the measurement method. In such cases, the system as a visionary tool easy to use, accurate and universal may be a good alternative for measuring the vibration. This work concerns the application of techniques to measure vision vibration amplitudes corps vibrating machinery. The article presents the methodology, algorithms and procedures for two–dimensional and three-dimensional measuring vibrations certain points of construction. Methodology and algorithms developed in the form of software was made in MATLAB environment and tested on the bench.

2. Two–dimensional vision techniques

For measuring the vibration analysis algorithms developed a classic image processing techniques as a result, have received the geometric means of gravity image markers at selected points of the structure. In order to calculate the geometric center of gravity analyzed images of objects in outfit based on the Image Processing Toolbox [2] developed and implemented procedures for the initial processing and analysis of images in MATLAB programming environment. Algorithm developed process of analyzing the image area is shown in Fig. 1.

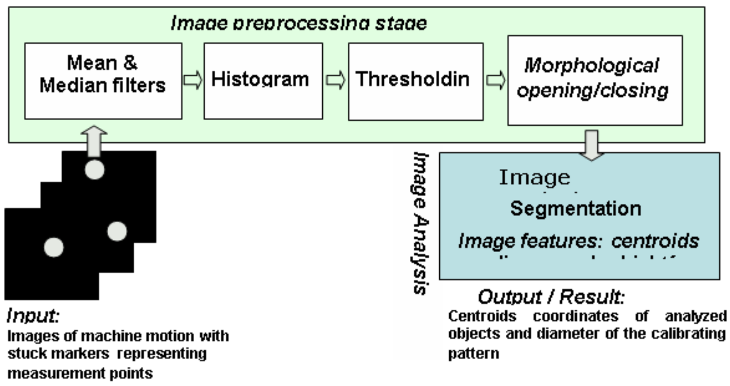


Figure 1 Diagram used in the transition falling developed an algorithm for image analysis

Derived digital image was subjected to the image preprocessing stage in order to improve image quality, reduced interference and stress and enhance the image of the essential elements in the next phase of image analysis. Median filter, if necessary, was used to eliminate the value of pixels significantly different from the average and to remove any local noise ratio and distortion. Digitalized and filtered using selected morphological transition (opening = erosion + dilatation) was the last picture of the initial phase of image processing and was prepared to carry out image analysis. As a result of its implementation obtained information about the position geometric center of gravity of objects analyzed in two axes. Image analysis was conducted on the basis of the area segmentation technique [3], [4], [5], [6], [12] and implemented in MATLAB programming environment.

In connection with the tender procedures have been implemented from the IPT [3] performing segment as a result–oriented field, which features the image obtained in the form of geometric center of gravity locations of objects image (1), (2).

$$m_{pq} = \sum_{i=1}^{n} \sum_{j=1}^{m} i^p j^q x_{ij} \tag{1}$$

[n, m] – the size of the picture

For binary image m_{00} is the surface of an object, and the m_{10}, m_{01} – its center of gravity. Moments of the first row determine the geometric center of gravity of object (2):

$$x_c = \frac{m_{10}}{m_{00}} \qquad y_c = \frac{m_{01}}{m_{00}} \tag{2}$$

The values of coordinates geometric center of gravity in pixels have been expressed in millimeters by developed module calibration. For this purpose, are mounted (glued) on the present object standard calibration in the form of a circle with a known diameter, D_{mm}. With images downloaded the facility, based on an algorithm developed calculated diameter, D_{pix}, a calibration standard image of the formula, (3), [3].

$$\sqrt{\frac{4 * Area}{\pi}} \tag{3}$$

The coefficient of scale W_{mm_pix} indicating the number of pixels per 1 mm analyzed the object was calculated according to (4):

$$W_{mm\_pix} = D_{mm}/D_{pix} \tag{4}$$

3. Three–dimensional vision techniques

In order to measure the amplitude of vibration and three–dimensional structure of vibrating machines are applying advanced techniques of stereo–vision, such as discrete epipolar geometry methods. Developed algorithms and procedures for obtaining the amplitude of vibration of objects analyzed scene (measuring points) along with their three–dimensional structure based on data obtained from a fast digital camera [14]. For geometry, motion epipolar parameters are set between two successive frames image taken from one or more cameras. This represents an internal geometry of two different–looking images of the same 3D scenes. Epipolar geometry only depend on the parameters of internal and external camera and is independent of the three–dimensional structure of scenes [2], [11], [13]. Obtaining the reconstruction of the test object in the true extent of knowledge of the parameters impose internal camera. This means that a matrix of internal camera parameters, K, it must be determined in the calibration of cameras. They may be calculated parameters of the external camera(s) $\{\mathbf{R}, \mathbf{t}\}$ and three–dimensional structure and motion of the picture scene. Motion parameters R and t are estimated by Essential Matrix Factorization. On the basis of using the triangulation algorithm is calculated three–dimensional reconstruction and depth to an appropriate scale.

In the case where the measuring points are on one level (i.e., highlighted patterns of known geometry to flattag measuring, for example, 10 white circles on a black background drawed using flat marker on the design of the test) then three–dimensional structure and motion (**R** parameters of it) is obtained using matrix decomposition plane homography.

Homography plane matrix is the linear representation between the two corresponding flatted points in two images

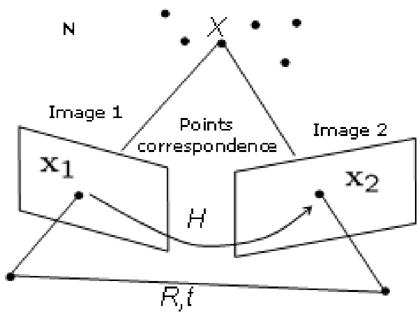


Figure 2 Homography matrix describing the relationship between the projections of points lying on one plane of the normal vector N on the plane imaging cameras 1 and 2

Homography matrix is defined as follows [11]:

$$\mathbf{H} = (\mathbf{R} + \frac{\mathbf{T}}{d}\mathbf{N}^T) \tag{5}$$

where:

$\mathbf{R}, \mathbf{t}$ – motion parameters;

$\mathbf{N}$ – unitary normal vector of the plane π with respect to the first camera frame;

d – distance form the plane π to the optical center of the first camera

Homography matrix describes the relationship between the X_1 and X_2 ($X_2 = RX_1 + t$) and includes information about the test object motion parameters $\{\mathbf{R}, \mathbf{t}\}$ - describing the relative position and orientation of the camera, which get images 1 and 2, and its three-dimensional structure $\{\mathbf{N}\, d\}$ – location of the plane on which the measurement points are the coordinates of the first terms of the camera. Homography matrix also describes the accuracy of the scale of the transformation between the corresponding points on the first and second images.

$$x_2 \sim Hx_1 \tag{6}$$

Relationship (6) is called planar homography mapping induced by plane π.

Four–point algorithm was developed to estimate the homography matrix H and then motion parameters **R, t** between two frames of cameras and structure: **N** and d.

To determine the three–dimensional structure and movement of an object on an appropriate scale developed a method of triangulation and scaling results [2],

[11]. To track features extracted using a module based on the movement of the optical image as a hierarchical decomposition [10], [11], [13]. The various stages of appointment is presented below t [2], [11]:

With the data at least 4 pairs of corresponding points (x1j, x2j) j = 1, 2, ..., n, n $\geq$ 4 meeting the plane bonds epipolar [11]:

$$H = H_L^{/}\sigma_2$$

- Step 1: The calculation of the first approximation of a matrix H:
- Step 2: Normalization matrix H_L:
- Step 3: Decomposing matrix homography to (**R**, **T**) and (**N**, d):

$$H^{\mathbf{T}}H = VDV^{\mathbf{T}}$$

- Step 4: The choice of solution – to impose a condition for a positive depth:

$$(x_i P_i) > 0 \qquad N^T e_3 > 0$$

$$M^j \lambda^j = \left[\hat{x}_2^j R \hat{x}_1^j, \hat{x}_2^j T\right] \begin{bmatrix} \lambda_1^j \\ \gamma \end{bmatrix} = 0$$

- Step 5: Reconstruction of 3D structures – linear triangulation algorithm:

$$AX = 0$$

- Step 6: Scaling: Where:

  H_L^S – vector of size 9x1, consisting of unknown elements of the matrix H_L

  σ_2 – the peculiar matrix H_L

  e_3 – versor axis of the camera system

  λ^i, γ – depth points and the value of the vector translation;

4. Experiment and results

Developed double and three–dimensional vision measuring method was verified during the test for the experimental (Fig. 3). Tested vibratory conveyor was closed for construction (pipe), which was marked by markers made using reflective tags representing the measuring points. Glued tags in the middle of the weight of the machine vibration. Carried out a series of measurements amplitude vibrations corps vibrating machine working under the influence of operational burdens. Sequences of images were taken by digital cameras XStream XS–3 and saved as files in the format *. MRF. Digital camera enables acquisition of images with a frequency over 50 kHz [14].

As a result of the analysis of the image for each frame was calculated coordinates geometric center of gravity images of glued marker expressed after the calibration process in millimeters. Two of the geometric center of gravity of the position of objects analyzed as a function of time to lay down the movement of the cog devices in two directions on the x–axis and y, and their lodging trajectory of traffic measure the mass (Fig. 8a).

a) b)

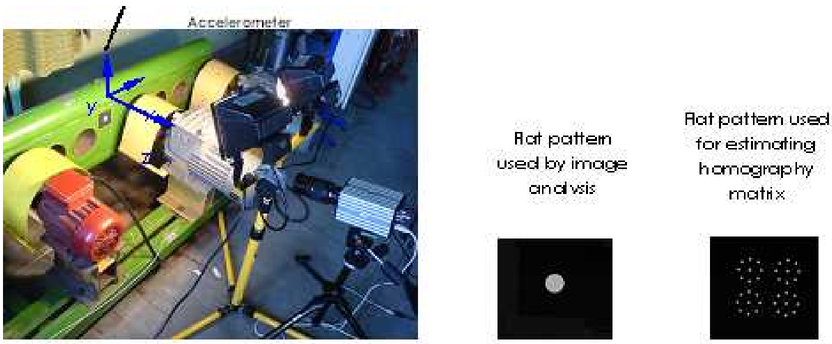


Figure 3 The experimental set–up

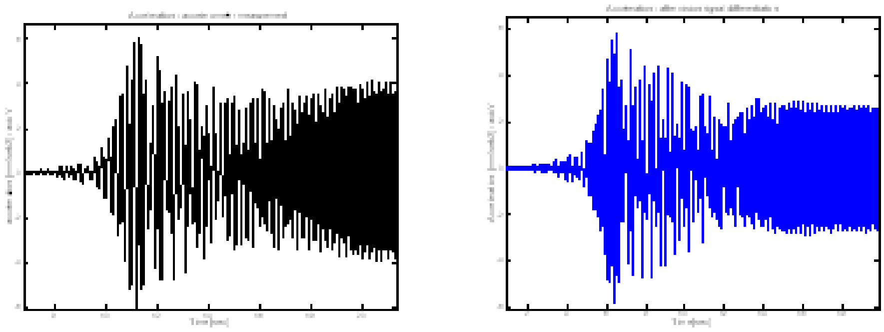
a) Components of positions:

- The visionary: lighting (halogen 2x500W); acquisition of images with a frequency of 200 frames per second using a digital camera XStream XS–3, Lens Tamron SPAF 28-75 mm f / 2.8
- The object of research: the conveyor vibrating pipe for construction of glued reflex reflector flags representing the measuring points. Agitation body of the conveyor with output converter in the range of 0–25 [Hz].
- Software embedded in the environment Matlab

b) Markers used in the video measuring 2D and 3D

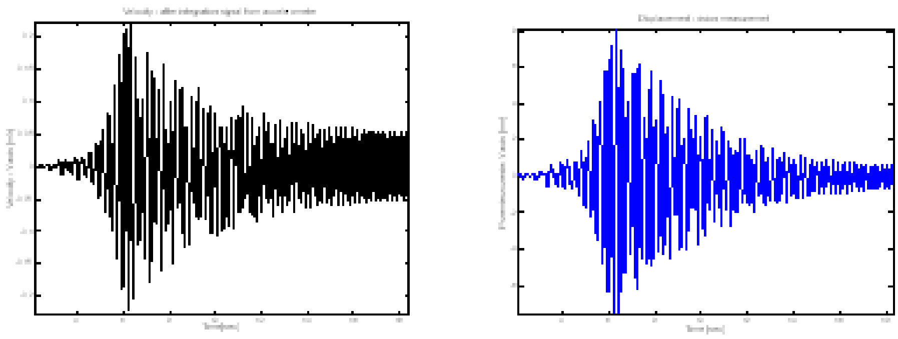
In the case of three–dimensional passive measurement techniques were estimated motion parameters R, T and N structure and d. They allow the use of triangulation algorithms and scaling scheduled three–dimensional movement measurement points and three–dimensional geometry. The resulting traffic measurement points represented the three components of the amplitude of vibration along the x–axis, y, z coordinates a global system for the mass start in the middle of the machine (Fig. 8b). Calibration of internal and external camera parameters were carried out by using software embedded in the environment MATLAB [15]. Calculated the amplitude of vibration and trajectory of traffic center of gravity of the body of the machine vibration by using image analysis algorithms and geometry epipolar using matrix homography shown in Fig. 8. For these two techniques, and compared the calculated values of three–dimensional components of the amplitude of oscillation of the axes x and yi obtained conform to both qualitative and quantitative. For example, the element of main square error of movement for the y–axis, corresponding to the vertical vibration amplitude of 0.1057 [mm].

In addition to the three–dimensional techniques of the third set of vibrations along the axis of (Fig. 7.).



a) signal from accelerometer b) the differential video signal

Figure 4 Value component of the vertical velocity along the y-axis derived from accelerometer a) and from the video after a double movement signal after differentiation b)

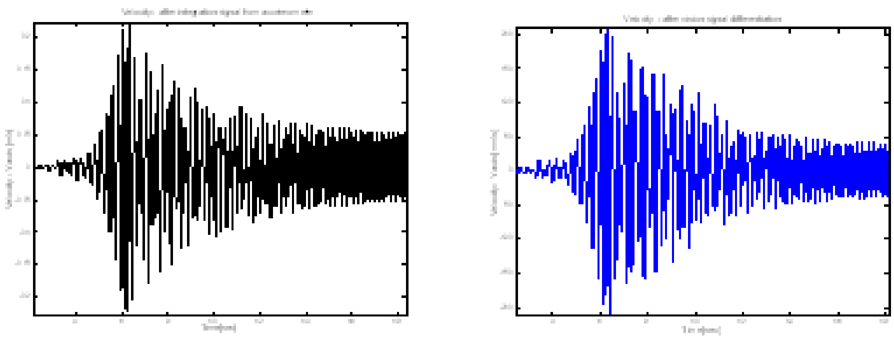


a) integrating of the signal from accelerometer b) signal visionary

Figure 5 Value component of the vertical movement along the y-axis derived from the system of video (b) and integration of signal from accelerometer (a) a) integrating the signal from accelerometer b) the differential video signal

The results of the measurements were compared with the results of vision measurement using classical accelerometer (Figs 4, 5, 6) mounted on the upper part of the body machine. A comparison of the vertical acceleration corresponding vibration along the y–axis was made. To this end, processes of numerical differentiation of signal obtained from vision system and the signal derived from the integration of this from accelerometer was done (Figs 4, 5, 6).

After double differentiation of amplitude of vibration designated by vision system compared its maximum value and values in the steady state with the results of the measurement accelerometer (Fig. 4.).For example vision maximum value (peak–to–peak – PTP) amounted to 11,614 m/s2 acceleration, and the maximum value of acceleration measured accelerometer 12,032 m/s2, which represents approximately 3.5% error.



a) integrating the signal from accelerometer b) the differential video signal

Figure 6 Value component of the vertical speed along the y-axis obtained: after integration signal from accelerometer (a) and after shipment differentiation of signal obtained from the vision data (b)

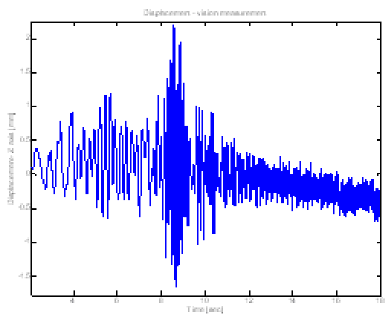
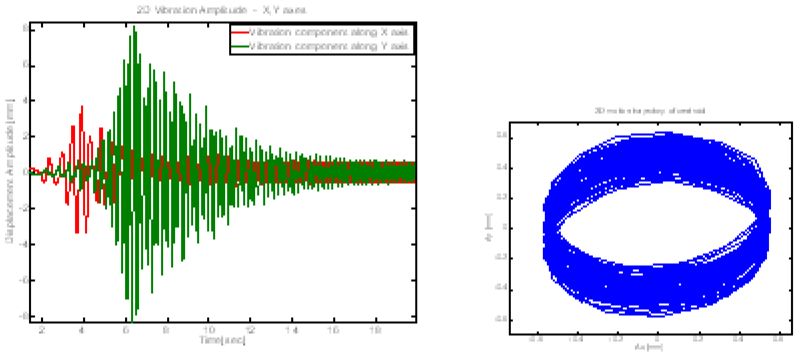


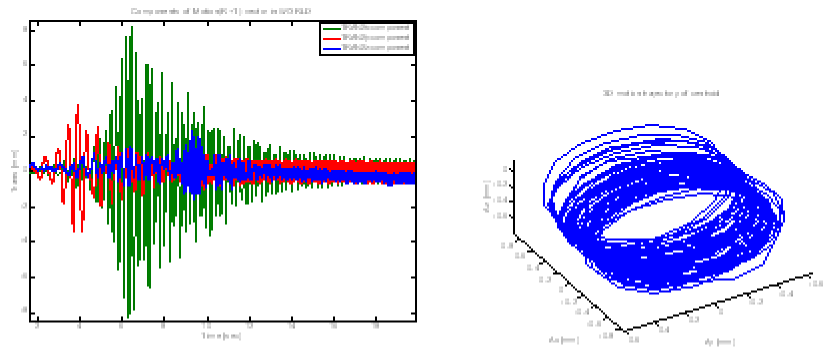
Figure 7 Component movement along the axis of the designated system based on video using homography algorithm

In order to obtain the amplitude of movement of the signal obtained from the measurement accelerometer were it twice time integrated (Fig. 5). In this case, for example, the maximum value of shipments, measured accelerometer was 16.3 mm, while for the measurement of video –15.55 mm. Error for these data did not exceed 4.9%. To highlight the impact of errors in the numerical accuracy of the measurements was calculated passes speed signals "vision" and signals from a accelerometric sensor (Fig. 6). This required differentiation of "video" component of the vertical movement and expedite the integration of the signal from accelerometer. Peak amplitude speed reached: 418.194 mm / s for speed video and 443.5 mm / s for speed after integration of signal from accelerometer. For this set of data error rate 6%. With the analysis shows that a greater influence on the growth of measurement errors in the process of integration brings signal compared with the process of differentiation.

On the difference between the quantitative results affected by the errors associated with differentiation and integration number and route of assembly and wiring of accelerometer. The accuracy of methods vision has been verified and confirmed by other studies [6], [7] [8].



a) Components of vibration amplitude along x,y axes and 2D motion trajectory of centroid



b) Components of vibration amplitude along x,y,z axes and 3D motion trajectory of centroid

Figure 8. Comparison of the 2D/3D amplitude of vibration machines corps calculated with vision methods of measurement: a) a two-dimensional method based on the analysis of image b) Three-dimensional method based on a matrix plane homography

5. Conclusions

One of the potential for reducing the negative impact of vibration machines to the outside world is the use of different kinds of control systems and even solutions fall into the group of mecatronics solutions or even whether intelligent. In many cases, there used algorithms require current amplitude vibration measurements. In addition, changes in the dynamic machine vibration may provide the occurrence causing damage to the consequent increase in harmful impact on the environment. For this reason it is important to monitor the change in dynamic. This work concerns the attempt to use the methods for measuring vision vibration amplitudes corps vibrating machine working. The results obtained can be used in the implementation of control systems eliminating the need for costly and cumbersome to install and operate the system with classical accelerometers wiring and processing signals.

Studies carried out on the one hand, in terms of qualitative and quantitative measurement confirmed the accuracy of both two and three-dimensional video techniques. Indicating the benefits of the method based on the epipolar geometry, because of the vibrations received along a third axis, with the other hand, on the other hand, highlighted the differences between classical and vision measurements.

For selected points within the structure developed algorithms 2D/3D video system provide for the designation: (2D/3D) movement, speed, acceleration (2D/3D) trajectory of movement of the cog (2D/3D) Reconstruction object (3D) Mother orientation

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