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Analysis of Dynamics of Vibratory Machines Applaying Vision Based Measurements

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In this paper the some practical application of measurement vision techniques useful for measurement of dynamics properties of vibration of vibratory machine working under normal operating conditions was shown and practically tested. Developed methods and algorithms were working with the usage of only one camera and was compared with measurements done with classical accelerometer based measuring system. Obtained results can be useful in the implementation of control and diagnostics systems for vibratory machines.

Keywords: Vision measurements, vibration measurements, planar homography mpping, digital image processing

1. Introduction

Potential way for reducing negative impact of vibration machines to the environment is the use of different kinds of control systems. In most cases they require current amplitude vibration measurements. Because of that and what's sometimes also important self–diagnosis of machine requires to monitor the changes in it's dynamic. The attempt to use of vision based measuring vibration amplitudes of vibrating machine working looks to be great possibility for solving this problem. 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.

Two vision techniques with the usage of one high speed digital camera for vibration measurement of vibratory machine were developed. The first method has been based on classical image processing and analysis techniques whilst the latter has been employed discrete epipolar geometry framework. Obtained values of 3D and 2D components of the amplitude of vibration along y axis conform to both qualitative and quantitative

2. Vision based measurements

There were developed two approach of vibration measurements based on vision signals: first so called classical embedded in two–dimensional space and the latter based on homography transformation enabling three–dimensional characteristics of vibration to be obtain [1–5].

For measuring the vibration analysis algorithms developed a classic image processing techniques as a result, have received the geometrical center of gravity image markers at selected points of the structure. In order to calculate the geometric center of gravity analyzed images of objects based on the Image Processing Toolbox developed and implemented procedures for the initial processing and analysis of images in MATLAB programming environment. Developed image analysis algorithm is shown in Fig. 1. As a result of calculated vision data displacements of selected elements of the machine in two directions were evaluated. Obtained displacements represented motion of analyzed objects what corresponded to their amplitude of vibration. Centroids, velocities and acceleration were computed as well. Information about position of centroids of analysed objects was obtained as a result of the image analysis realisation. The image analysis was based on region-oriented segmentation techniques [1–6] and was developed in the form of software tool embedded in MATLAB environment.

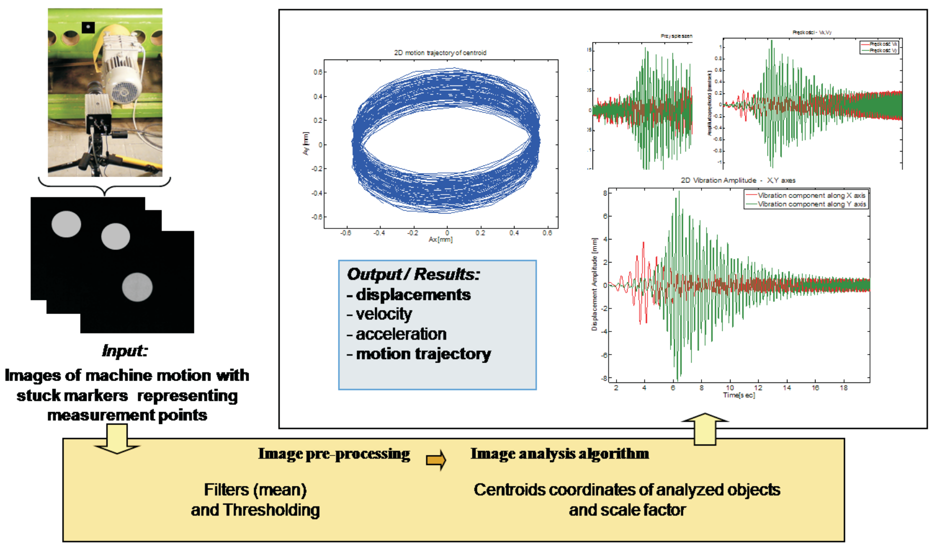


Figure 1 Scheme of developed an algorithm for image analysis. Results of measured vibration characteristics of vibratory machine: i.e: amplitude of vibration and motion trajectory

There were 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 one high speed digital camera (Fig. 2.). In case of epipolar geometry the motion parameters were determined between two consecutive image frames provided by one or more cameras [2–5], [7–9].

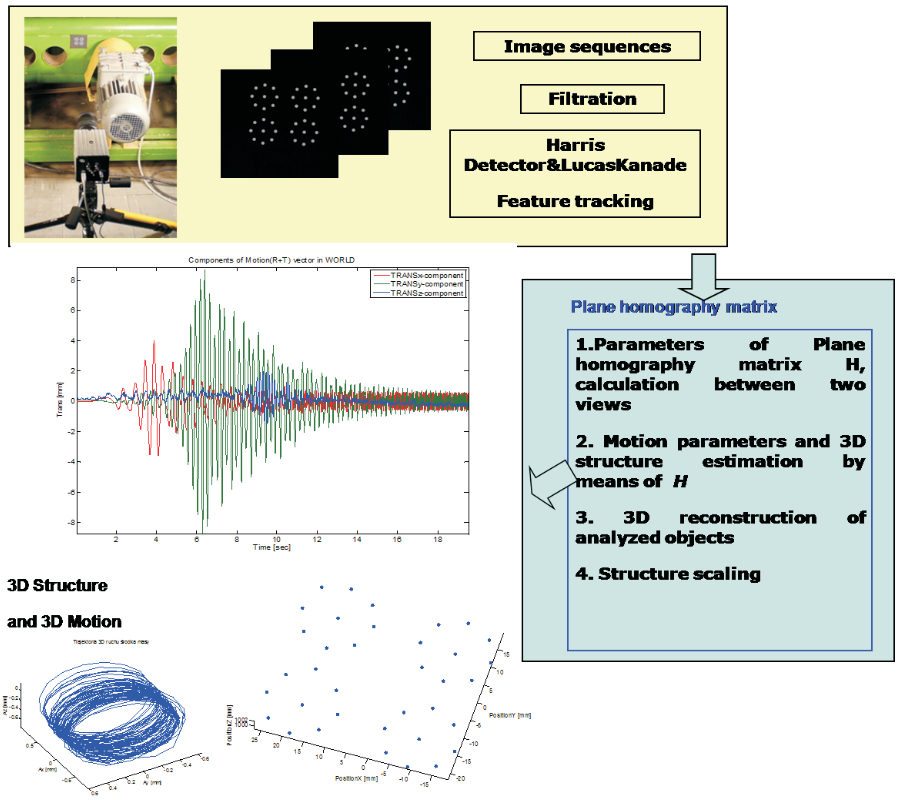
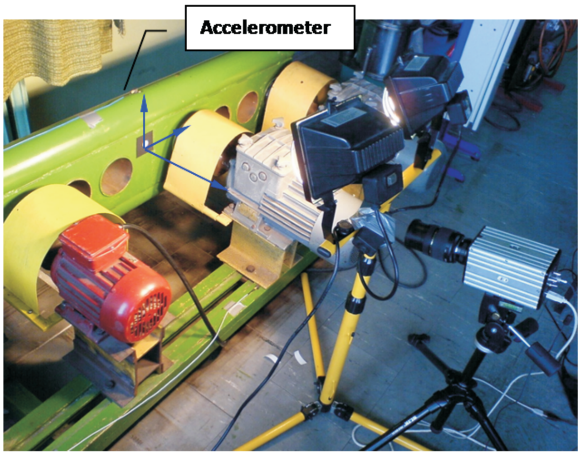


Figure 2 Algorithm of homography based 3D and reconstruction

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, must be determined in the calibration of cameras. Then may be calculated external parameters of the camera and three–dimensional structure and motion of the image scene. Motion parameters (rotation matrix and translation) 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 distributed on one plane then three–dimensional structure and motion is obtained using matrix decomposition plane homography [2–5], [7–9]. The consecutive stages of developed algorithm are presented in [3].

3. Experiment and results

Developed two and three–dimensional vision measuring method was verified during the test on the experimental setup (Fig. 3), [2]. Tested vibratory conveyor was closed for construction (pipe), which was marked by 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 infuence of operational burdens. Sequences of images were taken by digital cameras XStreamXS3.



Vision system: **a digital camera X-Stream XS-3 (200fps), Lens Tamron SPAF 28-75 mm, lighting (halogen 2x500W**

Accelerometer: **One axial Accelerometer PCB 333B30(mounted in the direction of conveyor's Y axis) connected to Teac GX1-1 recorder**

The object of research: **the conveyor vibrating pipe for construction of glued reflex markers representing the measuring points. Excitation body of the conveyor with output converter in the range of 0-25 [Hz].**

Figure 3 Experimental set–up

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. The geometric center of gravity (COG) of the position of objects analyzed as a function of time to lay down the movement of the mass center of device in two directions on the x axis and y. Its trajectory of motion of mass centre under lodging condition can be computed as well (Fig. 6). In the case of three–dimensional passive measurement techniques were estimated motion parameters and structure [3], [7–9]. They allowed the use of triangulation algorithms and scaling scheduled three–dimensional movement measurement points and three-dimensional geometry. The resulting measurement points represented the three components of the amplitude of vibration along the x axis, y, z coordinates a global system for the mass in the middle of the machine (Fig. 6). Calibration of internal and external camera parameters were carried out by using software embedded in the environment MATLAB [10].

Calculated the amplitude of vibration and trajectory of center of gravity of the body of the machine vibration by means of the image analysis algorithms and geometry epipolar using matrix homography shown in Figs 6–8. Obtained by vision system values of 3D and 2D components of the amplitude of vibration along axis y conform to both qualitative and quantitative. The root of mean square error of movement for the y–axis, corresponding to the vertical vibration amplitude equaled 0.0857mm (Fig. 4.)

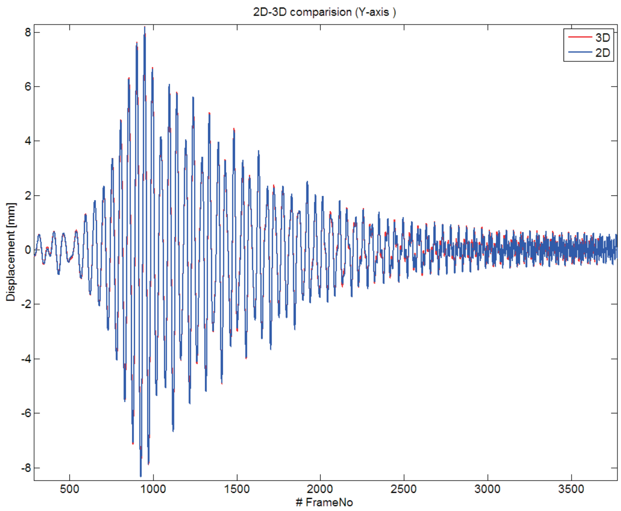
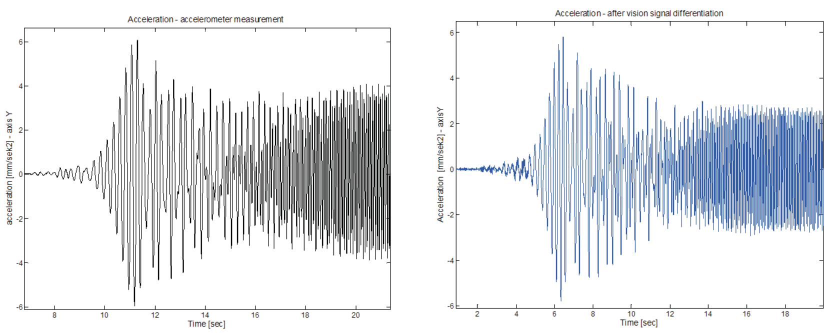


Figure 4 Comparison of the calculated values of 3D and 2D components of the amplitude of vibration along axis y



a) signal from accelerometer   b) 2nd differentiation of vision signal

Figure 5 Value component of the vertical acceleration along the y–axis derived from accelerometer (a) and from the vision system after a double displacement signal differentiation (b)

The results of the measurements were compared with the results of 3D vision measurement using classical accelerometer (Fig. 5) mounted on the upper part of the body machine. A comparison of the vertical acceleration corresponding vibration along the y–axis was made. 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. A *peak–to–peak* signal comparison amounted to 3.5% of relative error.

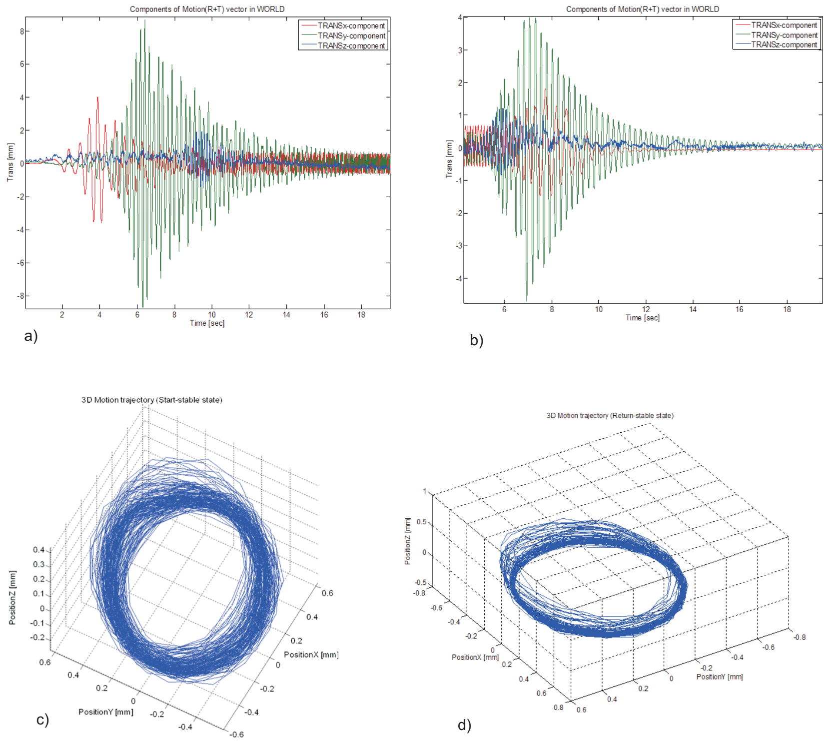


Figure 6 Machine Start–Up (3D Amplitude of Vibrations): Components of vibration amplitude along x, y, z axes (a), Machine Breaking (3D Amplitude of Vibrations): Components of vibration amplitude along x, y, z axes (b), 3D motion trajectory of centroid (c,d)

Components of vibration amplitude along x, y, z axes and 3D motion trajectory of centroid obtained by means applying the planar homography are presented on Figs 6–8. On Fig. 6 examples of machine start–up and breaking are shown. Examples of obtained dynamical characteristics for different resonances are depicted on Figs 6–8.

Obtained results shows resonance frequencies of 2.3 [Hz], 4.2 [Hz] and 7 [Hz]. First one is undesired and in real machine can be even dangerous because of it's direction of vibration. Second one is nominal resonance of machine in vertical direction.

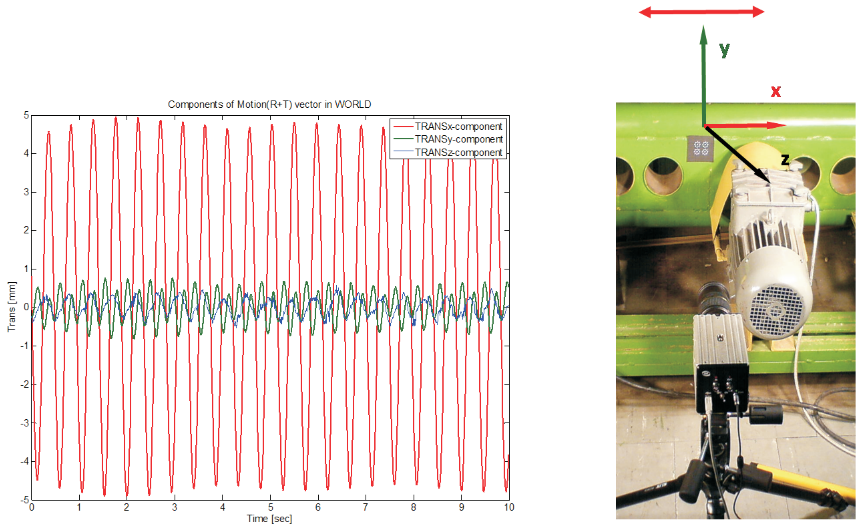


Figure 7 Components of vibration amplitude along x, y, z axes: resonance at 2.3 [Hz]

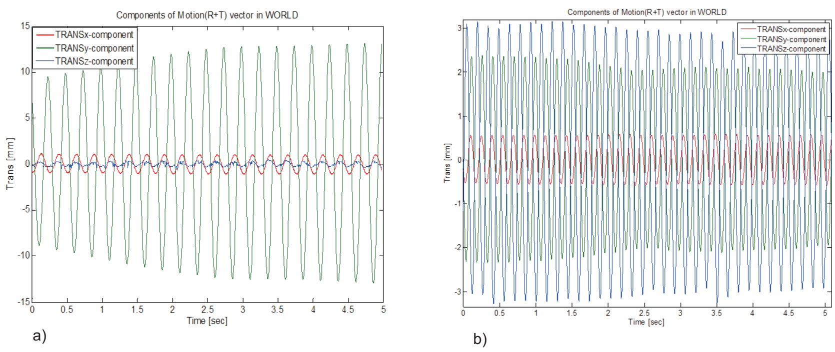


Figure 8 Components of vibration amplitude along x, y, z axes: a) resonance at 4.2 [Hz], b) resonance at 7 [Hz]

Normal working space of over–resonant vibratory machine should be well over this frequency. The third one torsion resonance is also undesired and should be minimized during machine process.

4. Conclusion

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. In most cases they require current amplitude vibration measurements. For this reason and what's also important for self–diagnosis of machine it is important to monitor the change in dynamic. This work concerns the attempt to use the methods for vision based measuring vibration amplitudes of 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.

Two vision techniques with the usage of one high speed digital camera for vibration measurement of vibratory machine were developed. The first method has been based on classical image processing and analysis techniques whilst the latter has been employed discrete epipolar geometry framework. Obtained values of 3D and 2D components of the amplitude of vibration along y–axis conform to both qualitative and quantitative. The root of mean square error of movement for the y–axis, corresponding to the vertical vibration amplitude amounted to 0.0857 [mm]. In the case of second method related to homography transformation a peak–to–peak signal comparison of the vision to the acceleration data in the direction of y–axis amounted to 3.5% of relative error. The main advantage of applying method based on the epipolar geometry is the possibility to estimate of the third component of vibration characteristics along z–axis. For selected points of the structure the developed vision based measurement techniques allow displacement, velocity and acceleration in the 2D or 3D space, motion trajectory and 3D reconstruction of objects to obtain.

Obtained results can be used for dynamical parameters of vibratory machine monitoring and control systems realization. For example calculated components of vibration amplitude of vibratory machine along x, y, z axes reveled unwanted phenomena at resonance frequency equaled to 2.4 [Hz] and 7 [Hz] which should be minimized by machine conrtol system.

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