

## VIBRATION MEASUREMENT AND ANALYSIS USING IMAGE PROCESSING METHOD

Roya Narimani  
Department of Mechanical Engineering, Sharif  
University of Technology, Tehran, Iran, 11365-9517  
Email: narimani@sharif.edu

Maryam Hoviattalab  
Department of Mechanical Engineering, Sharif  
University of Technology, Tehran, Iran, 11365-9517  
Email: hoviat@sharif.edu

Arash Abadpour  
Department of Mathematics Science, Sharif  
University of Technology, Tehran, Iran,  
Email: abadpour@math.sharif.edu

Azadeh Yadollahi  
Department of Electrical Engineering, Sharif  
University of Technology, Tehran, Iran,  
Email: yadollahi@ee.sharif.edu

### ABSTRACT

A large number of people are exposed to whole body vibration in their occupational life. Measuring vibration is an important tool in rehabilitation and biomechanical fields of research. We have proposed image processing as a new method to record and determine the frequency response of human body. The arranged set up for forced vibration consisted of an AC motor, a variable speed drive unit and a shaking table for producing one directional sinusoidal vibration. Volunteers were asked to stand on the shaking table at a relaxed posture. Two digital camcorders were used to capture the motion of colored pencil-dot markers on the skin of human body (forehead) and on the edge of the shaking table. After color spotting each frame, the binary image results were processed using new circle factor criteria proposed in this work, for fast finding circles based on second order statistics. The extracted points were calibrated using our own extended version of the *direct linear transformation* (DLT) method. Subsequently *Vibration measuring software* has been completely developed in *Borland Delphi 5.0*. Finally obtained displacement function of the body and the shaking table has been used in conjunction with *Matlab 6.5* to prepare a proper algorithm for analyzing human body vibration. We discussed mechanical characteristics of the body by obtaining mechanical impedance and transmissibility from the shaking table to the head as example applications of the conducted *software*. The important point is the fact that all devices used in our developed measurement system are usually available in a biomechanics

laboratory where a *Gait* system is functioning. This gives the opportunity for such laboratory to add vibration measurement to its capabilities without much excessive costs. The system has the advantage of lower noise sensitivity in comparison to accelerometer. The main advantage of this method is working with a simple user-familiar hardware with no external device attached to the subject and also a user-friendly-software

### INTRODUCTION

The human being in the environments of modern technology has to endure stresses of many and varied kinds of vibrations. These vibrations have significant effects in physical and mental health [1, 2]. It has been observed that the stresses imposed by vibration have produced changes in normal functioning of the human body [3, 4]. Whole body vibration can cause severe motion sickness which depends upon the mechanical properties of the human body [5]. An accurate and economic vibration measurement system is a useful tool for researches on human body vibration. In the conventional method of vibration measurement, accelerometers are fixed to the body and the amplitude of vibration is obtained after signal processing [6]. In this method there is a systemic error due to the contact-type of measurements. The error is related to fixing an object to the body surface that interferes with the true vibration of the body. The image-based system of vibration measurements has the benefit of not depending on contact-sensors attached to the stimulated subject. It basically relies on the software development and has a very simple hardware that

can be shared with other image processing studies. The hardware consists of two or more video cameras, an interface to send the images into a computer, a calibration frame apparatus and a synchronization device. The main advantage of this method is working with a simple user-familiar hardware with no external device attached to the subject and also a user-friendly-software.

## NOMENCLATURE

- $\rho$  Illuminated threshold
- $\theta$  Average value of illumination
- $A$  The area including all the points
- $S$  The number of points
- $S_x$  Sum of the x components of points
- $S_y$  Sum of the y components of points
- $S_{x^2}$  Sum of the  $x^2$  components of points
- $S_{y^2}$  Sum of the  $y^2$  components of points
- $\mu_x$  Mass center point in x direction
- $\mu_y$  Mass center point in y direction
- $\gamma_x$  Standard deviation of points in x direction
- $\gamma_y$  Standard deviation of points in y direction
- $\lambda$  Deviation from circular shape
- $I(x, y)$  The image of point  $(x, y)$
- $N$  The set of integers
- $\tilde{I}$  Filtered image
- $f(I)$  Filter function

## APPARATUS

The arranged set-up for producing the whole body vibration was consisted of an ISGEV 380 V, 10 Kw AC electromotor and a variable speed drive unit. A belt-pulley mechanism reduced speed of the crank shaft and a connecting rod in the oil tank under the shaking table converted the rotation to the reciprocating movement of the shaking table, illustrated in figure 1. A screw on the base plate of the shaking table was chosen as the reference marker and a fine white spot was painted on the headband on the forehead of the subject. The images of the motion of these two markers were taken by two digital cameras (Sony DCR-TRU-330EE15) from distance of 60 cm with 200X zoom ratio and speed of 25 fps. The size of captured images were about 1x1cm. The cameras were synchronized by pressing a remote IR control with sending start signal to both cameras at the same time to start capturing images of the reference and the main marker. The images were

saved on a tape and then transferred to the computer via IEEE1394 standard, using Pinnacle Studio DV and saved as MPEG format. A sample file with 6.44 seconds of capture time took about one mega bytes space and included 141 frames.

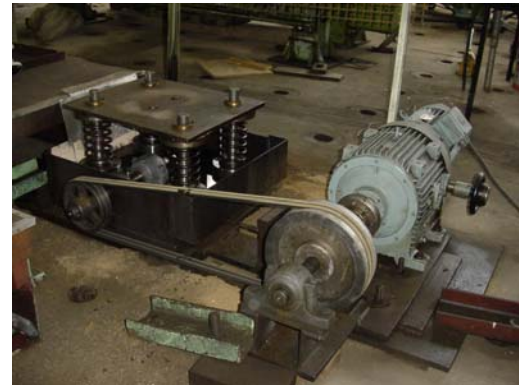


Figure 1. Experimental set-up for whole-body vibration.

## METHODS

The first step in Image processing was to obtain standard intensity definition which has been shown in the flowchart of the program, figure2, as gray-scale.

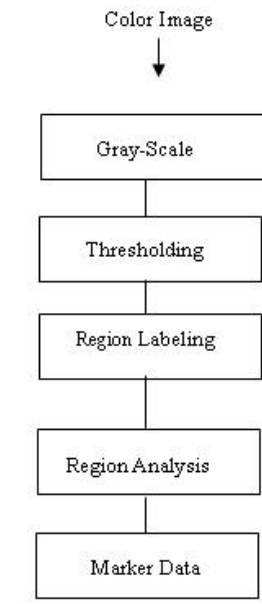


Figure 2. Flow chart for Image Processing.

After this step the image was thresholded, using the well-known double-margin threshold function, as shown in equation (1).

$$f_{\theta,\rho}(x) = \begin{cases} 0 & x \leq \theta - \rho \\ 1 & \theta - \rho < x < \theta + \rho \\ 0 & x \geq \theta + \rho \end{cases} \quad \begin{array}{l} \theta: \text{Center} \\ \rho: \text{Threshold} \end{array} \quad (1)$$

Now, the image was ready for further analysis to find the markers placement. This analysis was performed using statistical morphological parameters of each region in the images. Scanning the image from top-left, the algorithm searched for white points. The neighborhood of each white point was searched for other white points to find the region corresponding to it. Therefore this region was totally removed to increase algorithm performance. During this recursive fill-flood style operation five parameters of  $S$ ,  $S_x$ ,  $S_y$ ,  $S_{x^2}$  and  $S_{y^2}$  were computed consequently [7]. Assuming a new point  $(x,y)$  was found in the recursive loop, the parameters have been updated as the summation of the components in the relevant directions. Having in mind that all parameters were initialized to zero when the process started it was clear that for example  $S_x^2 = \text{Sum of } X^2 (X \text{ belonged to the region})$  and after the whole region was found the following parameters were computed:

$$\begin{cases} A = S \\ \gamma_x = \sqrt{\frac{S_{x^2}}{S} - \frac{(S_x)^2}{S^2}}, \gamma_y = \sqrt{\frac{S_{y^2}}{S} - \frac{(S_y)^2}{S^2}} \\ \mu_x = \frac{S_x}{S}, \mu_y = \frac{S_y}{S} \\ \lambda = \frac{\pi(\gamma_x + \gamma_y)^2}{A} \\ 1 \leq \lambda < \infty \end{cases} \quad (2)$$

New  $(\mu_x, \mu_y)$  in equation (2) was the center of region, and  $\lambda$  was its circularity. For a fine circle,  $\lambda$  was equal to one while larger values of  $\lambda$  showed more deviation. Using a simple threshold on  $\lambda (\lambda \leq 1 + \varepsilon)$ , circles were classified. It must be considered that the criterion  $\lambda$  is a newly derived expression by the authors. To eliminate small circular noise regions the methods used either of the parameters  $\sqrt{\frac{A}{\pi}}$  or  $\gamma_x + \gamma_y$  as the radius of the region. Then putting the threshold on the radius while the threshold on circularity was applied before, the true marker was classified at the point  $(\mu_x, \mu_y)$ .

The important concern for implementing this algorithm was the speed limitation. There we used the standard Delphi

programming language with some precautions. As each image was a 2-D array, the elapsed time increased by power of two as the image was getting larger. In addition, due to the data storage strategy there existed an excessive addition and multiplication for accessing a point as shown in equation (3), also many image processing primitives, were point operative or have approximation point processing [8]. This made the row-by-row storage of the image a good implementation, as this standard completely complied with Windows. Using the "bitblt" family of functions a dataflow(S) and an image (I) were easily mapped using a simple function called long equation (4). Then the image processing algorithms were categorized to three ways or groups; Point operations, Neighborhood and Complicated. Point operations-These algorithms were easily implemented as equation (5). Neighborhood-The pointers to the neighborhood of a pixel were easily computed from the pointers of the central pixel as equation (6), these algorithms were performed as Extended Point Operation in equation (7). Complicated-Algorithms which took access to image pixels in random fashion could not be performed by the two above-mentioned methods and the processes were simulated as successive execution of the long function (without optimization). In fact, using the Tbitmap object, the image was loaded. Then using "Getbitmapbits" the information was extracted as a pointer to the handle of the Tbitmap object (Freeze). After the problem-specific operation was performed on this data-flow, the information was put into bitmap format using the "setbitmapbits" procedure (Refresh). If visualization was necessary in this stage, the image was shown on a Device Context (DC) using "bitblt" category of functions (monitor). Performing these operations in an objective scheme was the main challenge of the developed code.

$$I[x, y] = ((y-1)width + x - 1 + I[0,0]) \quad (3)$$

$$\begin{cases} Long : N^2 \rightarrow N \\ S \xleftarrow{Long} I \\ Long(x, y) = (y-1)width + x - 1 \end{cases} \quad (4)$$

$$\tilde{I}[x, y] = f(I[x, y]) \quad (5)$$

$$e.g.: \begin{cases} Long(x+1, y) = Long(x, y) + 1 \\ Long(x, y-1) = Long(x, y) - width \end{cases} \quad (6)$$

$$\tilde{I}[x, y] = f(I, Long(x, y)) \quad (7)$$

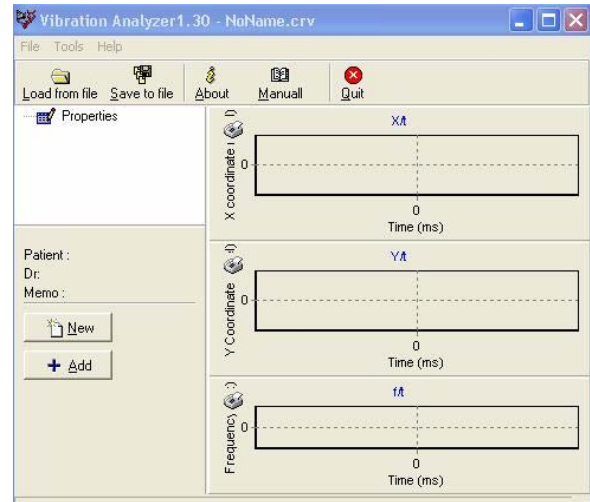
While processing an image, it was crucial to have two parallel version of the image to prevent interferences. The implementation used double data channels for this purpose. To

optimize the sequences of primitives, each image processing algorithm was split into four distinct phases. In this way, the execution speed of the algorithm was increased by an order of magnitude [9]. As the analysis was performed in a 2-D space (horizontal-vertical), the data calibration phases was performed assuming that all points were in the same distance to the lens plane. In this way the projection included only translation and a rotation which were easily compensated using the image of the three points  $[0,0,0]^T$ ,  $I[1,0,0]$  and  $J[0,1,0]$ . This method was a simplification of the Direct Linear Transform (DLT) method [10]. The measurements in different induced frequencies were saved using two internal file formats CRV and compressed CRV (CCV) and also m-file for further processing in Matlab. This information included the arrays  $x$ ,  $y$ ,  $x_0$  and  $y_0$  containing 2-D vibrating motion of the object on the subject and the base.

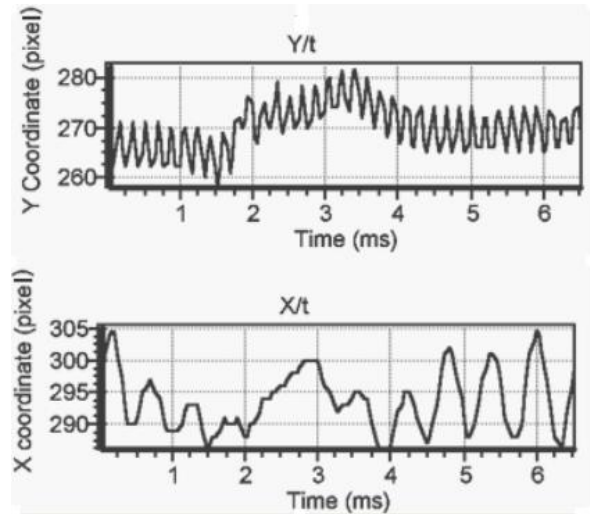
## RESULTS AND DISCUSSION

Several methods of vibration analysis algorithms has been reported in the literature, which vary due to noise-sensitivity [11], limitation on the subject and platform [12] and speed [13]. Some of these algorithms using projections, mass center inspection, and searching for an area were implemented and tested. These algorithms failed when the shape of the marker distorted, so a new statistical method was prepared by the authors. The proposed method does not need the second copy of the image and additional memory spaces, since the parameters are computed as region-growing was performed. The algorithm needs human intervention in tuning two parameters of  $\theta$  and  $\rho$  making it adaptable to severe changes in physical conditions. Due to the interlaced method of image capturing and communication in commercial cameras, when the speed of object motion increases the delay between successive fields, and the low shutter speed distorts the image. Many methods for de-interlacing the image are reported in literatures [14, 15]. We adopted the fast method of low-pass filtering [16] the frames prior to the operation, for the sake of performance to solve the distortion of the marker placements. We used the mass-center of the marker images, adding a filtering stage to the output data inevitably. The proposed method for bypassing the windows event-queue results in a much higher performance, making the method applicable for real-time uses. The markers are much more easily handled in the expressed method compared with an ordinary gait analysis system, based on the easier method of marker-drawing compared with marker-moving. The shape of marker is not very important, compensated by prefer selection of the parameters. The markers must be selected in the way that their dimensions are less than half of the vibration amplitude, furthermore they must be easily distinguishable from the vicinity, and care must be taken that the markers do not cross

the image borders at any time. An enhanced version of the proposed method uses color information for better results. The method measures the error automatically, capturing sudden changes in the “s” value. These abrupt changes show the marker exiting from the frame or miss-tuning of the parameters. This test is vital because no tracking is applicable in this application, because of the odd trajectory of the markers, comparing with gait analysis systems. All the code for the developed program, based on the proposed method, was derived as Vibration Analyzer 1.30 software (figure 3a) .An example output curve has been shown in figure 3b.



(a)



(b)

Figure 3. The developed software; a) Vibration Analyzer 1.30 b) sample data processed with the software (x: horizontal direction, y: vertical direction).

We subsequently used MATLAB 6.5 to obtain the Mechanical Impedance of the whole body and the Vibration Transmissibility from shaking table to the head. These two mechanical properties are example applications of the proposed measuring and analyzing system. The mechanical impedance for a subject has been illustrated in figure 4 which applies to damping characteristic of the body and was shown to be in the same range compared with the previous investigations in the literatures [17]. The results from accelerometer method [6], however shows significant differences due to tissue-accelerometer vibration. Transmission factor from shaking table to the head is shown in figure 5. The peak of resonance was extracted to be 4.4 Hz which featured the natural frequency of head. In the other hand this value was compatible with the predominantly published data for frequency response of the head [18]. As a mechanical factor, the vibration transmissibility is a useful parameter for optimizing the coefficients of shoes or the seats of vehicles to reduce the vibration amplitudes.

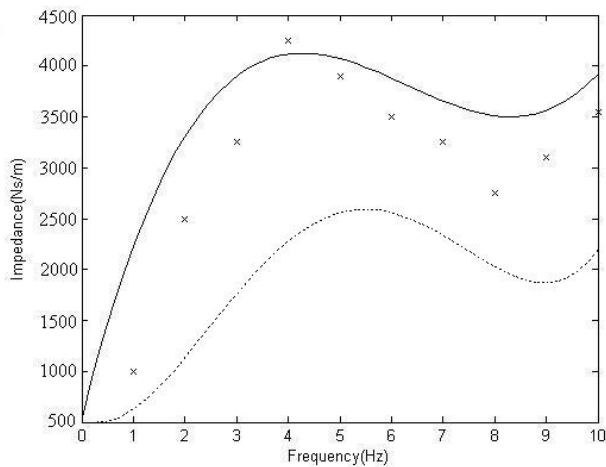


Figure 4. The whole body mechanical impedance for the vertical direction. Result found in this study for a sample subject (—) ; Holmlund et al. (×) [17]; Accelerometer data (...) [6].

The developed system is an applicable alternative for accelerometer systems. Hardware prices are much lower in this system and noise sensitivity is dampened, however the processing time is longer (average 2.5 times more). The designed system uses general purpose hardware but a more sophisticated software. Though the purpose of this study is introducing and devising a new method for measuring human body vibration, with a sufficiently enough number of subjects an extended amount of impedance and transmissibility data would enhance our possibilities to a better understanding the causal connections with respect to injuries, annoyance and performance.

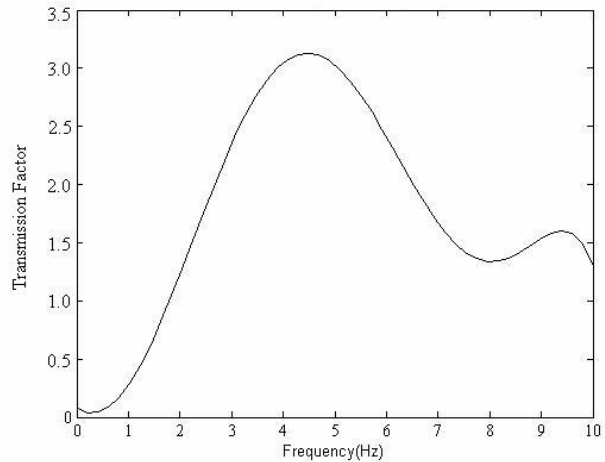


Figure 5. The transmission factor of vertical vibrations from shaking table to the head of a sample subject.

## CONCLUSION

The outcome from this study shows that the developed method is a useful substitution for accelerometer system in studying human body vibration. The proposed system including video capturing devices and Vibration Analyser 1.30 software has been designed by authors for direct measurements of the whole body vibration, using an image processing method. A newly derived expression  $\lambda$  (circularity of the marker region) has been introduced and implemented in the software codes for image processing.

The limitation of using the proposed system is that it requires a gait laboratory environment. The duration of data processing is 2.5 times more than the regular time for video capturing. Nevertheless, it would reveal a more accurate method not only for measuring but also for analyzing human body vibration. The new method does not require body-mounted recording devices, and therefore provides the possibility of real-time measurements and analysis. The system has the advantage of lower noise sensitivity in comparison to accelerometer methods. Furthermore by video capturing more markers on other parts of the body, the mechanical properties of the parts would be studied, in the other hand the number of camcorders would be added excessively. This applicable software provides appropriate "help" instruction for extracting the vibration data step by step. The main advantage of this method is working with a simple user-familiar hardware with no external devices attached to the subject and also a user-friendly-software.

## ACKNOWLEDGMENTS

The support of Research Vice Chancellor and the Biomechanics Lab of Mechanical Department of Sharif University of Technology is gratefully acknowledged.

## REFERENCES

- [1] Mingjun, Xie. , and Zhiyu, H., 1984, "Vibration Analysis of Escalators in The View of Human Comfort," *Survey of Vibration and Noise*, **4**, pp.1-15.
- [2] Donati, P. M., and Bonthoux, C., 1983, "Biodynamic Response of Human Body in the Seated Posture When Subjected to Vertical Vibration," *J of Sound and Vibration*, **3**, pp.22-26.
- [3] Amirouche, F. M. L., 1987, "Biodynamic Analysis of the Human Body Subjected to Vibration," *IEEE Engineering in Medicine and Biology Magazine*, pp. 22-26.
- [4] Newland, D. E., 1989, *Mechanical Vibration Analysis and Computation*, Wiley, NI.
- [5] ISO 2631, 1978 (E) *Guide for the Evaluation of Human Exposure to Whole Body Vibration*.
- [6] Hoviat Talab, M., Narimani, R., and Amiri, F., 2001, "General Purpose Human Body Vibration Measurement System," *Proceedings of fifth Int. Mech. Eng. Conf., ISME*, pp.26-31.
- [7] Wu, A., Bidlack, C., Katkere, A., Fegue, R., and Weymouth, T., 2002, "Vision Based Object Pose Estimation for Mobile Robots," *Proceedings of Darpa Image Understanding Workshop*, pp.59-67.
- [8] Feyrer, S., Zell, A.,2000, "Detection Tracking and Pursuit of Humans with an Autonomous Mobile Robot," *6th International Conference on Intelligent Autonomous Systems (IAS-6)*, Venice, Italy, pp. 710-715.
- [9] Abadpour, A., Tabatabaie Syfi, Sh., 2002, "Development of IDE for Image Processing," B.S. thesis, Electrical Engineering Department, Sharif University of Technology, Tehran.
- [10] Abdel-Aziz, Y.I., Karara, H. M., 1971, "Direct Linear Transformation from Comparator Coordinates into Object Space Coordinates in Close-Range Photogrammetry," *Proceedings of the Symposium on Closed-Range Photogrammetry*, American Society of Photogrammetry, Falls Church, VA., pp. 1-18.
- [11] Fischolz, R. W., Spinnler, K.P., 2002, "Class of Algorithms for Real-Time Sub Pixel Registration," *IEEE Trans. Computers*, **21**, pp. 179-186.
- [12] Kato, H., Billinghamurst, M., 2002, "Marker Tracking and HMD Calibration for a Video-based Augmented Reality conferencing System," *IEEE Virtual Reality Conference Vol.12, Issue 1*, PP.18-26.
- [13] Wang, Y. F., Liang, P., 2003, "3D Shape and Motion Analysis from Image Blur and Smear: Unified Approach" *Proceedings of The Eleventh ACM International Conference on Multimedia*, pp.528-538.
- [14] Guillotel, P., Pigeon, S., 2001, "Progressive versus Interlaced Coding," *Technical Report, Y2/M6*, Universite Catholique de Louvain.
- [15] Skarabot, A., Ramponi, G., Buriola, L., 2001, "FPGA Architecture for a Video Wall Image Processor," *Symposium of Electronic Imaging*, San Jose, California.
- [16] Kovacevic, J., Safranek, R. J., Yeh, E. M., 1997, "Deinterlacing by Successive Approximation," *IEEE Transaction on Image Processing*, **6**, Issue 2, pp.339-344.
- [17] Holmlund, P., Lundstrom, R., Lindberg, L., 2000, "Mechanical Impedance of Human Body in Vertical Direction," *J. of Applied Ergonomics*, **31**, pp. 415-422.
- [18] ISO 5982, 1992, *Human Exposure to Mechanical Vibration and Shock, International Standardization*, Geneva.