EVALUATION OF HAND-ARM VIBRATION TRANSMITTED DURING SOIL TILLAGE BASED ON ARDUINO AND MPU9250 MOTION SENSOR

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EVALUATION OF HAND-ARM VIBRATION TRANSMITTED DURING SOIL TILLAGE BASED ON ARDUINO AND MPU9250 MOTION SENSOR

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SUMMARY

Irrespective of the industrial activity it comes from, vibrations act on the human body causing discomfort to the operator, can change its activity or even may have more or less serious effects on its health. In paper is presented the estimating of vibration exposure to agricultural workers during soil processing operations with a pedestrian-controlled tractor BCS 740 in a greenhouse. It should be noted that pedestrian-controlled tractor was equipped with a rotary cultivator which performs a rotary tillage from top to down. The vibration measurement system has been achieved with the development platform “open source” Arduino and of an electronic device IMU type MPU9250 Ivensense. Processing and analysis of measurement data was performed with a program developed in MATLAB. The experimental results obtained show that exposures of workers are below the exposure action value and the risks from hand-arm vibration is reduced to a minimum. The system used in experiments is less expensive compared to other vibration measurement systems.

Key words: vibration exposure, Arduino, operator, greenhouse, IMU sensor

INTRODUCTION

The human body is characterized by a fragility that is also manifested in the case of exposure to vibrational phenomena. This has led to in-depth research into the area of determining and combating the negative effects of vibrations on the human body. At the same time, the limits of human exposure to vibrations were imposed by legislative means depending on the working conditions, (European Directive 2002/44/EC).

Work Safety and Health Guide on Mechanical Vibrations defines two vibration transmission systems in the human body: vibrations transmitted to the hand-arm system and vibrations transmitted to the whole body. In the case of vibrations transmitted to the hand-arm system, the handle of a machine or the surface of a piece to be worked, in contact with the hand, vibrates quickly, and this movement is transmitted to the hand and arm. Workers whose hands are regularly exposed to hand-arm vibrations, may suffer destruction of the tissues of the hands and arms, which causes the symptoms collectively known as hand-arm vibration syndrome. This may result in long-term blood flow disorders in the fingers and disorders of the neurological and locomotor functions of the hand and arm. Vascular, neurological and bone and joint malformations caused by hand-arm vibrations are recognized as occupational diseases in a number of Member States of the European Union.

People from a biological point of view (and not only) are distinct entities and respond differently to environmental aggressions, in relation to their native resistance, with their degree of health, their personality and temperament, etc. On the other hand, we cannot always make experimental determinations *in vivo*. All these findings, highlights the opportunity of biomechanical modelling of the human body subjected to vibration, modelling used in the literature frequently.

Biomechanical models used in the literature are based on models of rheological behaviour. Thus, the first biomechanical model of the human body, used to determine the impedance and frequency response in the vertical direction, was made by Dieckmann in 1957, based on a Kelvin-Voigt model (figure 1), (Truța and Arghir, 2010).

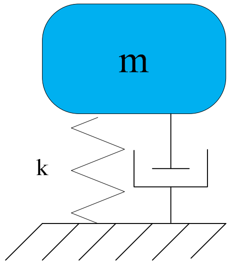


Figure 1. Dieckman biomechanical model (Truța and Arghir, 2010)

Numerous research has been conducted to study the vibrations transmitted to human operators during agricultural works. The vast majority of them investigate the exposure of tractor drivers to vibrations transmitted to the whole body (Boshuizen et. all, 1990, Gomez et. all, 2013, Bovenzi and Betta, 1994). It has been pointed out that long-term exposure to vibrations ranging from 2 to 20 Hz can cause severe diseases such as spinal column degenerative pathologies. Also, has been observed that with changing soil profile and tractor speed, the accelerations resulting from ground input present similar spectral trends (Cuttini et al., 2017). Manetto et. all, 2013 study vibration risk in hand-held harvesters for olives. They found a high level of hand-arm vibrations, in range of 8-20 m s^{-2}, due to hand contact with the handle. Hassan (2013) has conducted a study to determine an optimum operator‟s daily exposure limit in field conditions from the handles of a single-axle tractor. The results of his study show that the magnitude of vibrations during the various activities varies in the range 4.5 - 10.5 m s^{-2} and increases with the increase of the forward speed.

This paper has as main objective to evaluate the influence of vibrations on the hand and arms through the palm and fingers in the soil processing activities based on the smart and low coast instrumental systems. Results show that proposed solution can collect and present data in a mobile environment.

MATERIALS AND METHODS

The experimental work has deployed in the greenhouse with polyethylene film roof, available in UPB campus, Department of Biotechnical Systems. To classify the vibrations according to their degree of discomfort and the risk of injury they produce to workers, measurements were made for hand-arm vibrations in the soil-processing activity with a pedestrian-controlled tractor BCS 740. Pedestrian-controlled tractor was equipped with a rotary cultivator which performs a rotary tillage from top to down. The inertial motion sensor was mounted whit a handle adaptor on pedestrian-controlled tractor handlebars. In figure 2, is presented the assembly used for the experiments, respectively, the basicentric coordinate system.

Figure 2. Experimental measurement of hand-arm vibrations in the soil-processing activity

The vibration transmitted to the hand shall be measured and reported for three directions of an orthogonal coordinate system. The primary quantity used to describe the magnitude of the vibration shall be the root-mean-square (rms) frequency-weighted acceleration expressed in meters per second squared (m s^{-2}). Vibration exposure is dependent on the magnitude of the vibration and on the duration of the exposure. In order to apply the guidance on health effects, the vibration magnitude is represented by the vibration total value a_{hv}:

$$a_{hv} = \sqrt[2]{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \quad (1)$$

where, subscripts, *w* - refers to frequency-weighted acceleration values, and, *x,y,z* – refer to the direction of translational, or rectilinear, vibration.

Daily vibration exposure is derived from the magnitude of the vibration (vibration total value) and the daily exposure duration and can be expressed with:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \quad (2)$$

where, T is total daily duration of exposure to the vibration a_{hv}, respectively, T_0 is the reference duration of 8h (28.800 s).

By using an exposure points system, hand-arm vibration exposure management can be simplified. The number of exposure points, P_E, is defined by:

$$P_E = \left(a_{hv} \big/ 2.5 m/s^2\right)^2 \frac{T}{T_0} \cdot 100 \quad (3)$$

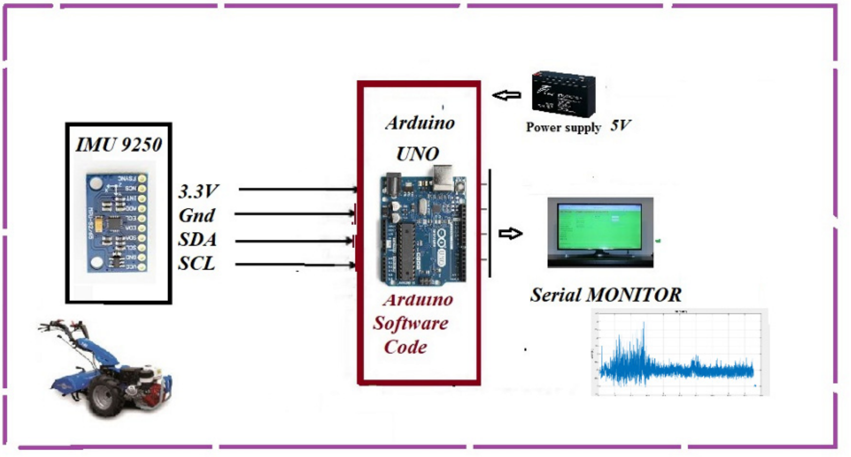


Figure 3. Block diagram of vibration monitoring system

The proposed monitoring system is presented in Figure 3. The main component of hardware section is the **Arduino UNO**, a microcontroller board based on the ATmega368, on miniature computers in a single integrated circuit. The main board can be programmed flexibly to provide specific features regarding requirement function in the intelligent system, such as data handling. In general, Arduino boards have proven to be robust enough to be accurate, simple tasks are not affected by the programming style even at beginner level. Software implementation of our vibration monitoring system uses Arduino software.

Industry of Inertial Motion sensors (IMU) are in a fast growing, mainly because they are miniaturized and require a low power supply. IMU sensors typically contain three orthogonal accelerometers, gyroscopes, and magnetometers, measuring angular velocity, acceleration and magnetic field respectively. A multi-chip module MPU 9250 developed by InvenSense Inc. (that combines a full 9DoF inertial sensor and a Digital Motion Processor in a small 3x3x1mm package), is used as the motion sensor in our research.

Micro-Electro-Mechanical Systems, or MEMS, is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements that are made using the techniques of microfabrication. The MEMS accelerometer can be considered as a mass-spring system. Figure 4 illustrate block diagram of IMU 9250 module. It is composed of movable proof mass with plates that is attached through a mechanical suspension system to a reference frame.

Therefore, the measurement of an accelerometer can be modelled as (Zhi, 2015):

$$R(t) = \hat{v} - g + s_a(t) + n_a(t) \tag{4}$$

where $\hat{v}$ represents the instantaneous linear acceleration, **g** represents gravitational acceleration, $s_a(t)$ and $n_a(t)$ stand for accelerometer bias and noise respectively.

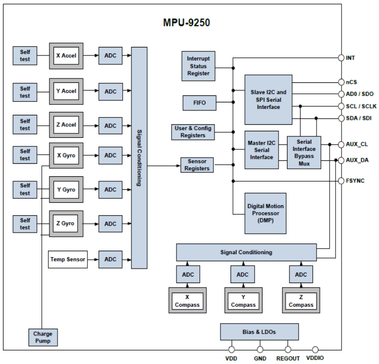


Figure 4. Block Diagram of IMU 9250 module

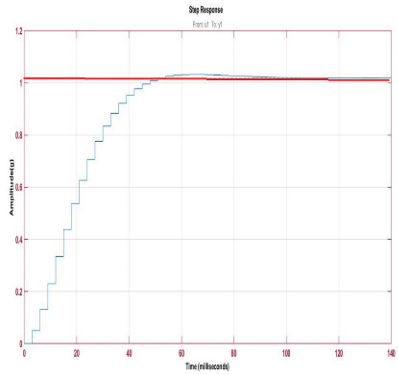


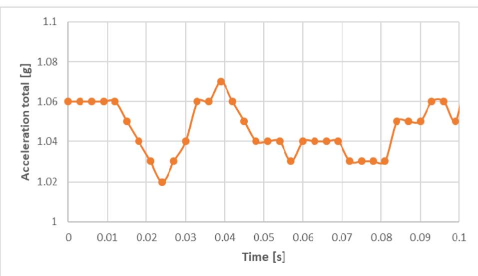
Figure 5. Step response of system

For communication between the Arduino and IMU sensor an I2C protocol communication (f_{SCL}, SCL Clock Frequency, 400kHz) is used. The Arduino microcontroller is connected over USB to a computer to send and receive serial data as human readable ASCII text using serial communication protocol which will be set to 115200 Bd. Data were exported in ASCII format and were loaded in MATLAB for further analyses. Transient response plots in figure 5 provide insight into the basic dynamic properties of the linear ARX model obtaining in MATLAB for purpose measurement system.

RESULTS AND DISCUSSION

To test the use of sensors, we have conducted several series of measurements to check the system and data accuracy. Accelerometers are extremely sensitive to changing the direction of movement and impact forces while gyroscopes are sensitive to temperature changes and suffer from a slow-changing bias (Ipate et al, 2015). The MPU 9250 accelerometer present a temperature drift of ±0.026 %/°C.

An important feature of the accelerometer included in the MPU 9250 is the programmable self-test function supplied by the manufacturer. In figure 6 is presented the total acceleration measured whit IMU 9250 device in calibration test. The accelerometer remains statically near 1 g because there are no other gravitational forces.



Mean	1.048422
Standard Error	0.000336
Median	1.05
Mode	1.05
Standard Deviation	0.010635
Sample Variance	0.000113
Kurtosis	-0.10897
Skewness	0.207851
Range	0.06
Minimum	1.02
Maximum	1.08
Sum	1049.47
Count	1001
Confidence Level(99.0%)	0.000868

Figure 6. The measurement accuracy and drift of IMU 9250 device

Total acceleration scaled data is illustrated in figure 7. Data come from accelerometer sensors in sequence of 16 bits with the range of (±78.48 m s^{-2}) and a sensitivity scale factor of 4096 LSB/g. A translational orientation is given to the system and quantification of fluctuations is observed as a response.

The sample rate of the system is 168 Hz, corresponding to 0.006 seconds between every sequent data. The collected signal transformed from the time domain into the frequency domain, using Fast Fourier Transform (FFT), is shown in figure 8. The acceleration peak values found within the frequency range of 64-65 Hz in FFT diagram is clearly vibration generated by the combustion engine overloaded. Also, hand transmitted vibration along z-axis was found most significant and appeared to be more severe than those in horizontal (y-axis) and lateral (x-axis) directions under the same working conditions.

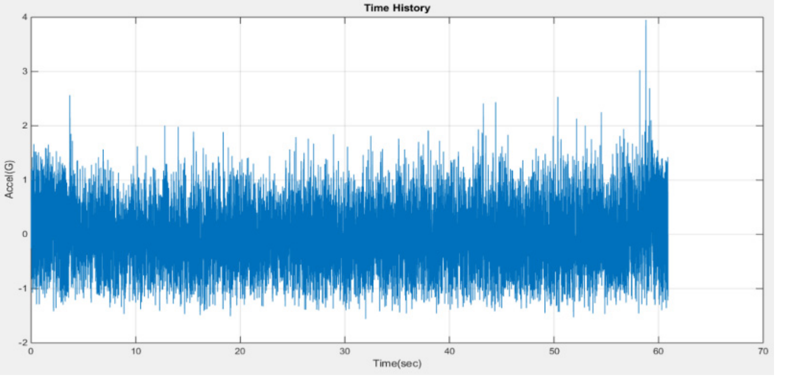


Figure 7. Total acceleration scale data

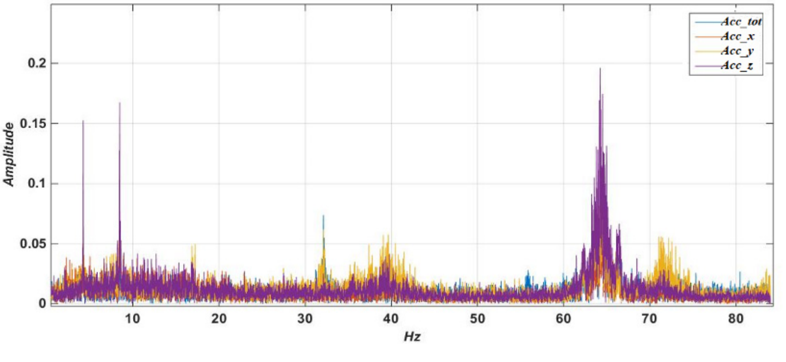


Figure 8. Data of vibrating pedestrian-tractors from accelerometers shown in the frequency domain

To evaluate the risk of exposure vibration transmitted to the hand-arm system in the soil processing activities we compare the daily vibration exposure computed whit relation (3) whit two reference values: exposure action value (EAV) of 2.5 m s^{-2} and exposure limit value (ELV) of 5.0 m s^{-2} established by the European Union (Directive 2002/44/EC) (Gomes and Savionek, 2014).

For a daily exposure duration of T = 2 h, representing an average exposure time for working activity, and a total vibration a_{hv} of 3.512 m s^{-2}, the daily vibration exposure A(8) is 1.774 m s^{-2}, below the vibration exposure action (EAV). In this case, the value of the exposure number is 50, half of the amount corresponding to the score of the limit value for the action of exposure.

If we consider that total daily vibration exposure consists of several operations with different amplitudes of vibrations, then we must consider the individual contribution of each operation. If the vibration total values for exposure times of 1.5 h and 0.5 h (within the same working day) are 3.512 m s^{-2} and 2.783 m s^{-2} respectively, then A (8) is 1.672 m s^{-2}. So, according to relation purposed in ISO 5349-1 (Annex C3) it would take over 18.44 years of exposure to vibration in the soil-processing activity with a pedestrian-controlled tractor BCS 740, so 10% of a population of workers to develop Vibration induced White-Fingers. For hand-arm measurements, ISO 5349 does not set limits for allowed doses.

CONCLUSIONS

Any employer who carries out an activity involving risks from mechanical vibration exposure must implement a number of previous and concomitant steps to carry out the work. An economic and low cost smart vibration monitoring system is proposed and implemented in this paper. It gives a basic idea of how to estimate level risk of vibration exposure and provide a direction of agricultural workers security using Arduino UNO and MATLAB software. Also, it can be said that identifying the symptoms of diseases caused by exposure to vibration is not easy, requiring knowledge, both medical and technical.

We can conclude that the results obtained with the Arduino platform have been satisfactory, it is possible to achieve a reliable data acquisition using low-cost hardware and open source software with utility both in the educational field and in the usual practical engineering activities.

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REFERENCES

Atif, M. and Serdaroglu, S. (2011). A Measurement System for Human Movement Analysis, Chalmers University of Technology, Göteborg, Sweden, Master of Science Thesis.

Bovenzi, M. and Betta, A. (1994). Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress, Applied Ergonomics, Vol. 25, Issue 4, p. 231-241.

Cuttini, M., Brambilla, M., Bisaglia, C. (2017). Whole-body vibration in farming: background document for creating a simplified procedure to determine agricultural tractor vibration confort, Agriculture, ISSN 2077-0472, 7, 84; doi:10.3390/agriculture7100084.

Gomes, H.M. and Savionek, D. (2014). Measurement and evaluation of human exposure to vibration transmitted to hand-arm system during leisure cyclist activity, Braz. J. Biom. Eng., 30(4), pp. 291-300.

Gomez, M.I., Hwang, S., Stark, A.D., May, J.J., Hallman, E.M., Pantea, C.I. (2003). An analysis of self–reported joint pain among New York farmers, Journal of Agricultural Safety and Health 9 (2): 143-157, ISSN: 1074-7583.

Hassan, A.S. (2013). Hand transmitted mechanical vibrations and shocks to operators of single-axle tractor during field operations, Master of Science Disertation.

Hendriek, C. Boshuizen, Paulien, M. Bongers, Carel, T J Hulshof (1990), Self-reported back pain in tractor drivers exposed to whole-body vibration, Internetional Archives of Occupational and Environmental Health 62:109-115.

Hettinger, T. (1956). *Der Einfluss sinusförmiger Schwingungen auf die Skelettmuskulatur*, Int. Z. Angew Physiol, 16, 192-197.

Ipate, G., Voicu, Gh., Dinu, I. (2015). Research on the use of drones in precision agriculture, U.P.B. Sci. Bull., Series D, Vol. 77, Iss. 4, pp. 263-273.

Manetto, G., Cerruto, E. (2013). Vibration risk evaluation in hand-held harvesters for olives, Journal of Agricultural Engineering 2013; volume XLIV(s2):e142, p:705-709.

Truța, A., Arghir, M. (2010). Biomechanical notions of human body in vibrational environment, ISBN 978-606-92133-3-9, Arcadia Media, Cluj-Napoca.

Zhi, R. (2016). A Drift Eliminated Attitude & Position Estimation Algorithm In 3D, The University of Vermont, Master of Science Thesis.

*** Directive 2002/44 / EC of the European Parliament and of the Council from 25 June 2002 on the minimum safety and health requirements for the exposure of workers to the risks arising from physical agents (vibration);

*** Health and Safety Guide to Work on Mechanical Vibrations http://www.inpm.ro/files/publicatii/2013-05.07-ghid.pdf.

*** ISO 2631-1/1997. Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration. Part 1: general requirements.

*** ISO 5349-1/2001. Mechanical vibration: measurement and evaluation of human exposure to hand-transmitted vibration. Part 1: general requirements.

*** ISO 5349-2/2001. Mechanical vibration: measurement and evaluation of human exposure to and-transmitted vibration. Part 2: practical guidance for measurement at the workplace.

*** ISO 8041/2005. Human response to vibration: measuring instrumentation.