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CONSTRUCTION

SUMMARY DOCTORAL THESIS
CONTRIBUTIONS REGARDING THE VALIDATION
OF THE BIOMECHANICAL MODELS OF THE
HUMAN ORGANISM SUBJECTED TO THE ACTION
OF MECHANICAL VIBRATIONS

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INTRODUCTION

The general objective of the doctoral thesis is to start research that makes possible new perspectives in the field of vibration measurement in the points of interest of the human body for people who by nature are subject to mechanical vibration and validation of biomechanical models of the human body subject to mechanical vibration. For this purpose, the thesis was structured in 5 chapters and a chapter of final conclusions.

The first chapter examines the evolution of the concept of biomechanical model over time.

Starting from the scheme of biomechanical modeling of the interaction between the human body and the machine with which it works in **the second chapter**, the main dynamic models used are presented..

Chapter 3 reviews the current state of transmission of signals picked up by sensors mounted in areas of interest in the human body. At the end of this chapter, personal contributions are presented regarding the design, design and execution of a device that used the integrated processing platform (Arduino) on which vibration measuring sensors (accelerometers) were positioned, the results can be collected, transmitted and displayed in time. real via GPRS.

Chapter 4 presents a synthesis of biomechanical models associated with the human body from models with 1 degree of freedom to models with 16 degrees of freedom. After a detailed discussion of each biomechanical model, the chapter ends with a table showing the average frequencies found in different components of the human body.

Once the data capture and transmission system was dimensioned, in **Chapter 5**, it was mounted on a subject by making experimental determinations in two concrete situations, namely determinations without the use of vibrating equipment and determinations with the use of two equipment: plate compactor, respectively percussion drill.

Determinations without the use of vibrating equipment were made by mounting the system on the subject and recording data in case the subject descends a ladder and in case the subject moves on a flat surface and moves on rough terrain through a car running at a constant speed. The obtained results were processed and represented graphically.

The graphical representations thus obtained were compared with the results of previous studies in the literature, obtaining a good agreement in the sense that the frequencies found experimentally corresponded to those in biomechanical models of the human body presented in the literature thus obtaining validation of biomechanical models of the organism human subject to the action of mechanical vibrations.

CHAPTER 1. THE MODEL CONCEPT

The concept of the model has appeared since ancient times, being at the beginning an attempt to represent, imitate and explain the environment through cave drawings.

During the development of human civilization, fundamental concepts of elementary mechanics were developed. These concepts were later developed and used in successfully describing the movements of the human body.

The fragility of the human being that manifests itself in the case of exposure to vibratory phenomena has led to in-depth research in the area of determining and combating the negative effects (causing occupational diseases) that vibrations have on the human body. The area of beneficial effects was not neglected either, although the research was smaller.

All these findings highlight the importance of biomechanical modeling of the human body subjected to the action of vibrations. Although it is rarely possible to verify the results obtained on the basis of a model with those we obtain from determinations on the real model, nevertheless simulations can be made on different models to identify the optimal model.

Biomechanical models associated with the human body [30], [92], have undergone successive transformations that have increased the complexity and accuracy of explaining the phenomena and processes that occur in the human body.

When referring to biomechanics, it must provide clarifications to the engineer, to provide him with data that he can understand. The parameters that characterize a biomechanical system will depend on the type of model used. For a real biomechanical system there are two general methods of approach, which lead to the determination of the parameters that characterize the dynamic behavior of the system, namely: the analytical method and the experimental method.

CHAPTER 2. MODELS USED IN DYNAMIC ANALYSIS

2.1. General methods of approach

The models used to assess the dynamic behavior of the human body will be called dynamic models.

The connection between the approach methods as well as between the dynamic models is presented schematically in figure 2.2.

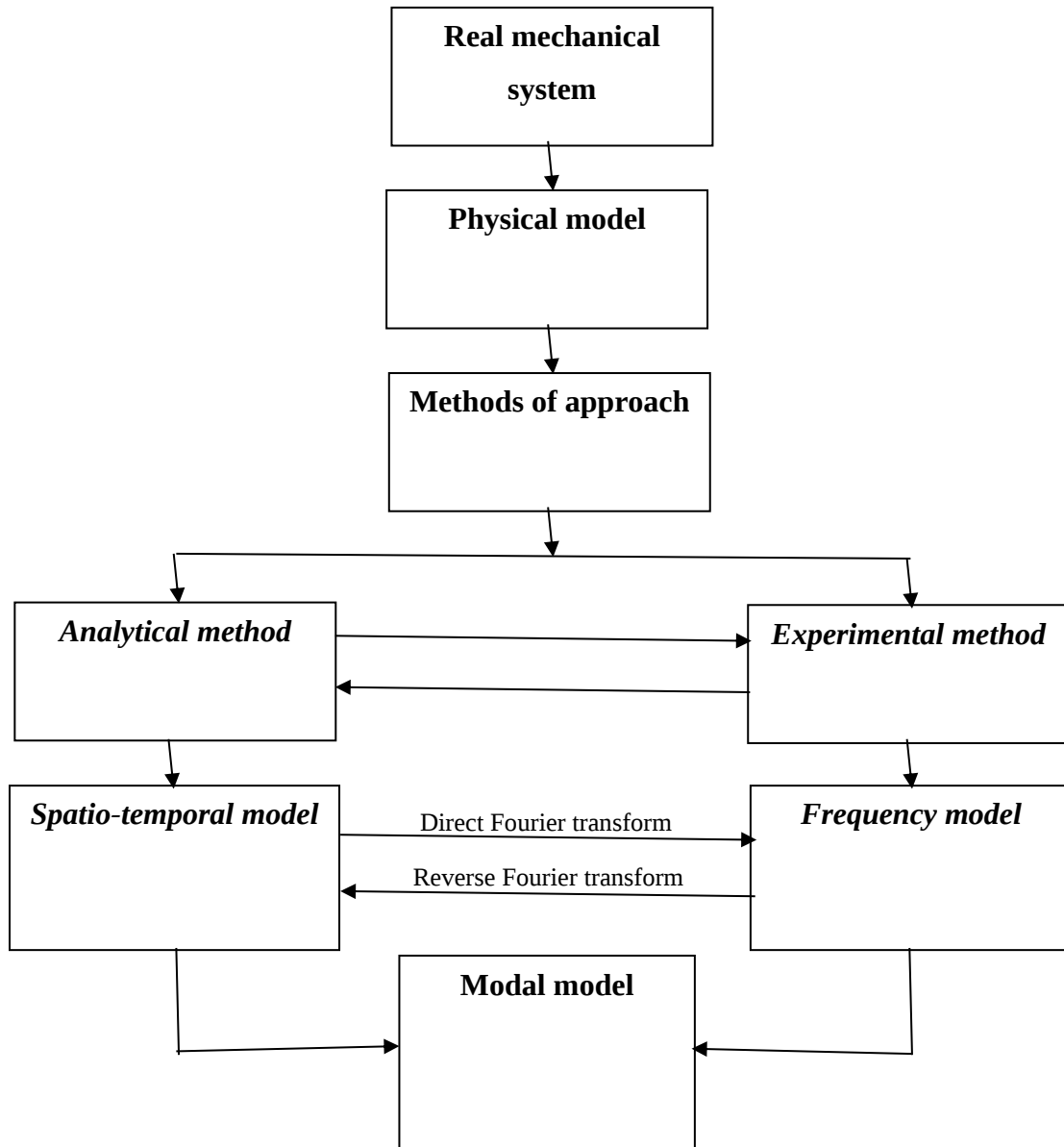


Fig. 2.1. The connection between dynamic models [12],[17],[18]

CHAPTER 3. CURRENT STATE OF THE TRANSMISSION OF SIGNALS RECEIVED BY SENSORS MOUNTED IN THE AREAS OF INTEREST OF THE HUMAN

3.1. Introduction

The analysis and processing of biosignals was first used in medicine for:

1. The study of human gait;
2. E.C.G. – the study of the activity of the heart;
3. E.E.G. - study of brain activity, etc.

The possibility of acquiring biomedical signals, allows the extraction of the necessary information leading to the interpretation of the biological phenomenon and respectively to the establishment of a correct diagnosis.

In this sense, electronic instrumentation and computers have been used in the investigation of biological and physiological systems such as:

- electrical activity of the cardiovascular system;
- electrical activity of the brain;
- electrical activity of the neuromuscular system;
- pressure variation in the cardiovascular system;
- the human gait.

The first step in investigating the physiological system involves the use of sensors and the appropriate instrumentation to transform the variation of a quantity of interest into a measurable electrical signal.

The signal thus obtained may contain, in addition to information of clinical relevance, a lot of noise being difficult, even impossible sometimes to analyze visually by the human observer.

Also, the variability of a certain signal from one patient to another and the subjective analysis performed by doctors or analysts can make it difficult to understand or evaluate the phenomenon.

These factors have created the need not only for proper instrumentation but also for methods of objective analysis using hardware and / or software implemented processing algorithms.

The electrical activity is collected by electrodes, amplified, converted analog / digital and purchased by a computer (EKG, EMG, EEG).

Non-electrical activity is transformed into electrical activity (using transducers), converted analog / numerically and acquired by a computer (respiratory activity, temperature, pulse).

3.2. Acquisition of biomedical signals

There are three known methods of acquiring biomedical signals used in medicine [13], [123]: some for the study of humanoid gait and others for measuring heart activity, brain activity.

- image processing by cameras - for gait study;
- capturing information with sensors mounted on a flat surface of known dimensions - for gait study;
- capturing information with the help of portable sensors mounted in a device in different areas of interest of the patient - study of gait and measurement of heart activity.

3.3. Personal contributions

Analyzing the existing results at national / international level and partially presented in the previous chapters, it is proposed to use a device for acquisition and processing of vibratory signals [123], {124}, [125], [14], [13], [16] to can transmit this data.

The collected data can be accessed / viewed through a web platform, designed by me.

CONCLUSIONS

1. Analyzing the existing results on a national / international level and partially presented in the previous chapters, it is proposed to use a device for acquiring and processing vibrating signals, **a device designed and executed by me**, which can transmit these data through:

- GSM / GPRS – 2G / 3G / 4G; Bluetooth; Wi-Fi; 802.15.4 and ZigBee.

The collected data can be accessed / viewed through a web platform.

2. We have taken into account the experience gained in coordinating the maintenance and serviceability of machines and equipment presented in the following figures and we have developed a web platform for the acquisition and transmission of data retrieved in real time through accelerometers from subjects in real time.

This information portal is useful in emergencies because it allows more users to access information about patients status and locations.

The portal has three user groups:

1. Emergency department staff connect to the portal to get information about patients being transported to their hospital;
2. Those in charge of operations connect to the portal to see the list of patients affected by disasters;
3. Specialist doctors, often located in remote institutions, may be called upon to give treatment instructions to doctors on the spot..

3. Starting with the new Smart watches, I thought of designing a plastic case that would have the same shape as the Smart watch case but other sizes to be suitable for embedding acceleration sensors in it and to mount the entire device with a belt in the areas of interest as in the previous figures.

The execution plan of the Smart watch case was shown in fig. 3.8.

4. Thus, a device was **designed and executed** that used the integrated processing platform (Arduino) on which vibration measuring sensors (accelerometers) were positioned, the results being able to be collected, transmitted and displayed in real time via GPRS. of assets with GPS / GLONASS, GSM connectivity and standalone battery, is able to collect GPS coordinates and transmit them via GSM / GPRS to VPS in order to perform permanent storage of data in a MySQL database or view them in time real in a web page directly on your laptop.

The data obtained can be viewed on any mobile phone running Android +4.2 and on any laptop running Windows, OS X via a Python script.

Given the need for the data to be analyzed, the entire device has been designed and the components that ensure the capture and transmission of this data have been dimensioned..

5. Once the data capture and transmission system was dimensioned, it was mounted on a subject and experimental determinations were made in two concrete situations, namely determinations without the use of vibrating equipment and determinations with the use of two equipments: compactor plate, respectively percussion drill.

CHAPTER 4. METHODS USED IN ASSESSING THE EFFECT OF VIBRATION ON THE HUMAN ORGANISM

CONCLUSIONS

The human body is a very sophisticated dynamic system whose mechanical properties vary from one moment to another and from one individual to another. In recent decades, many mathematical models have been developed based on various field measurements to describe the biodynamic responses of human beings. According to different modeling techniques, these models can be grouped as concentrated parameter models, finite element (FE) models, and multibody models..

Models with concentrated parameters consider the human body as several concentrated masses interconnected by springs and dampers. This type of model is simple to analyze and easy to validate through experiments.

A study was conducted on biodynamic models of human subjects exposed to vertical vibrations.

Models with concentrated parameters in the literature were also analyzed and validated in the synthesis of various experimental data. The following conclusions can be drawn from the analysis and validation:

1. Models with concentrated parameters are limited to one-dimensional analysis. Therefore, the human body is considered to be standing upright, without support, regardless of the position of the hands, while the legs are supported and vibrate. These mathematical models include linear and nonlinear systems with varying degrees of complexity depending on the purpose of the analysis.

2. From the analysis of biomechanical models: with a degree of freedom Dieckmann (1957) (Coermann, 1962), two degrees of freedom (Wei and Griffin, 1998), (Allen, 1978), (Muksian and Nash, 1976), with three degrees of freedom (Suggs et al., 1969), (Allen, 1978), (Cho-Chung Liang, Chi-Feng Chiang, 2006 and Suggs C.W., Abrams C.F., Stikeleather L.F., 1969), (A. Picu 2009), with four degrees of freedom (Wan and Schimmels, 1995), (1998, Liu, Shi), (Boileau and Rakheja, 1998), Wagner and Liu (2000), with six degrees of freedom (Muksian and Nash, 1974), with seven degrees Freedom (Patil et al., 1977), (Cho-Chung Liang, Chi-Feng Chiang, 2005 and Patil, M.K., Palanichamy, M.S., Ghista, D.N., 1977), (Abbas et al., 2010), (Sengkang et al., 2013), with nine degrees of two-dimensional freedom (Harsha et al., 2014), with eleven degrees of freedom (Qassem et al., 1994; Qassem and Othman, 1996), results in important frequencies of human body segments presented in table 18., page 110, [82] namely:

Head - 2,06 Hz; chest - 1,2 Hz; trunk - 1,21 Hz, forearm - 1,17 Hz, arm - 3,39 Hz, thigh - 4,7 Hz, foot - 0,93 Hz.

3. The analysis of the results of the biodynamic models presented in [100] shows that it will be used in the validation of biodynamic models with the results of experimental measurements, the important frequencies of human body segments are those in the table below, table 4.1., [82].

Table 4.1. Important frequencies of the human body [82]

Name segment of the human body	Frequency [Hz]
Head	2,06
Chest	1,20
Trunk	1,21
Forearm	1,17
Arm	3,39
Thigh	4,7
Foot	0,93

CHAPTER 5. EXPERIMENTAL DETERMINATIONS OF THE PROPER FREQUENCIES OF THE COMPONENT ANATOMICAL PARTS OF THE HUMAN BODY SUBJECT TO VIBRATIONS

5.1. Introduction

The general objective of the doctoral thesis is to start research that makes possible new perspectives in the field of vibration measurement in the points of interest of the human body for people who by nature are subject to mechanical vibration, transmission and monitoring of this data in real time via GPRS.

Thus, a device model was conceived and designed that used the integrated processing platform (Arduino) on which vibration measurement sensors (accelerometers) were positioned, the results being able to be collected, transmitted and displayed in real time via GPRS, [121], [122], [123], [124].

Once the data capture and transmission system was dimensioned, it was mounted on a subject and experimental determinations were made in two concrete situations, namely determinations without the use of vibrating equipment and determinations with the use of two equipments: compactor plate, respectively percussion drill.

The determinations for the situation in which a vibration working equipment is used were made with the use of two equipments: compactor plate, respectively percussion drill. Similarly, the determinations were made by mounting the system on the subject and recording the data when the subject uses a compactor plate or a percussion drill with defined technical characteristics. The obtained results were processed and represented graphically.

The graphical representations thus obtained were compared with the results of previous studies in the literature and a good concordance was obtained in the sense that the frequencies found experimentally corresponded to those in the biomechanical models of the human body in the literature thus obtaining validation of biomechanical models of the human body. subjected to the action of mechanical vibrations.

5.3. Data aquisition system mounted on the subject

The following image (fig. 5.4.) Shows the location of the components of the data acquisition system on the subject as well as its diagram.

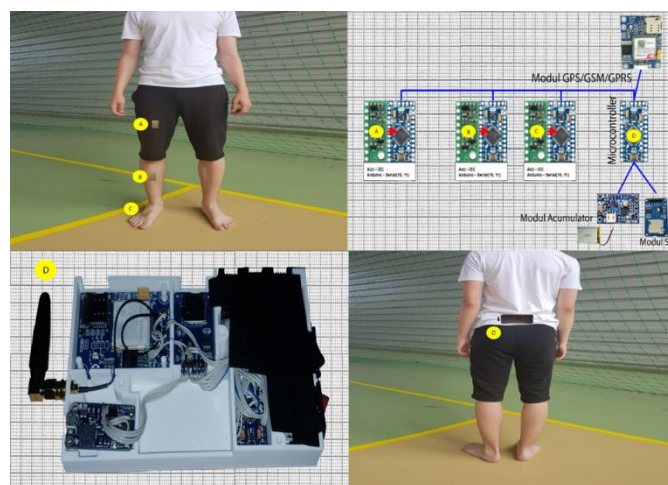


Fig. 5.1. Data acquisition system [124]

5.4. Experimental determinations

Two sets of determinations were performed, namely:

1. determinations without the use of vibrating equipment;
2. determinations with the use of two pieces of equipment:
 - a) compactor plate;
 - b) percussion drill.

In both cases, acceleration measurements were performed on the three axes: Ox, Oy and Oz, obtaining the following types of diagrams:

1. Acceleration - time:
 - a. On the Ox axis; On the Oy axis; On the Oz axis;
 - b. A diagram in which the three measurements overlap.
2. Fast Fourier Transform FFT - frequency, presenting in the thesis only a diagram in which the three measurements are superimposed.
3. Power spectral density - frequency:
 - a. On the Ox axis; On the Oy axis; On the Oz axis;
 - b. A diagram in which the three measurements overlap

In the case of set A, the data acquisitions were made in the following situations:

- a) steady descent down a stone staircase;
- b) moving at a constant speed on straight ground;
- c) constant speed travel on rough terrain;
- d) driving on the ground in a motor vehicle;
- e) traveling in rough terrain in a car.

In the case of set A, data were collected from:

- a) thigh;
- b) leg;
- c) foot.

In the case of driving, data were collected from:

- a) right forearm;
- b) right arm;
- c) left forearm;
- d) left arm;
- e) thigh;
- f) leg;
- g) foot.

Determining the power spectral density - depending on the frequency:

- a) On the Ox axis; On the Oy axis; On the Oz axis;
- b) A diagram in which the three measurements overlap.

In the case of set B, data acquisitions were made for:

- a) right forearm;
- b) right arm;
- c) left forearm;
- d) left arm;
- e) percussion drill handle.

Determining the power spectral density - depending on the frequency.

- a) On the Ox axis; On the Oy axis; On the Oz axis;
- b) A diagram in which the three measurements overlap.

The above diagrams are presented below.

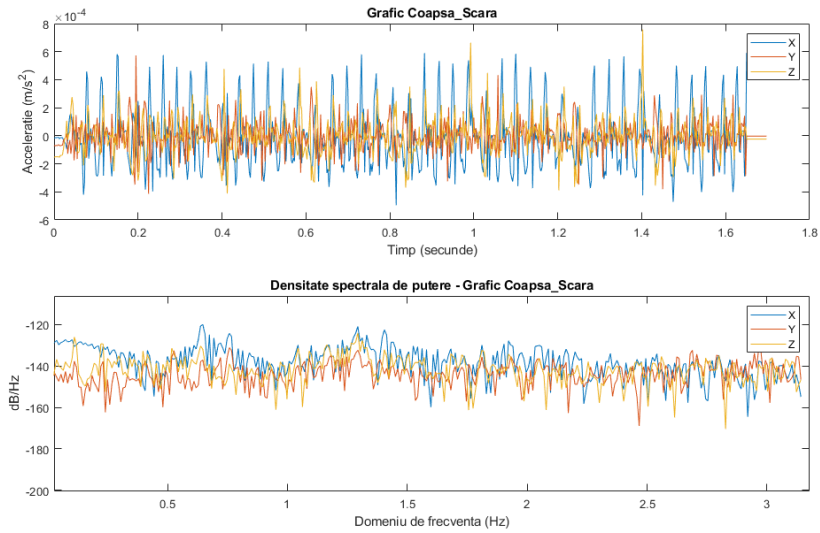


Fig. 5.2. Spectral power density thigh descent scale the three axes

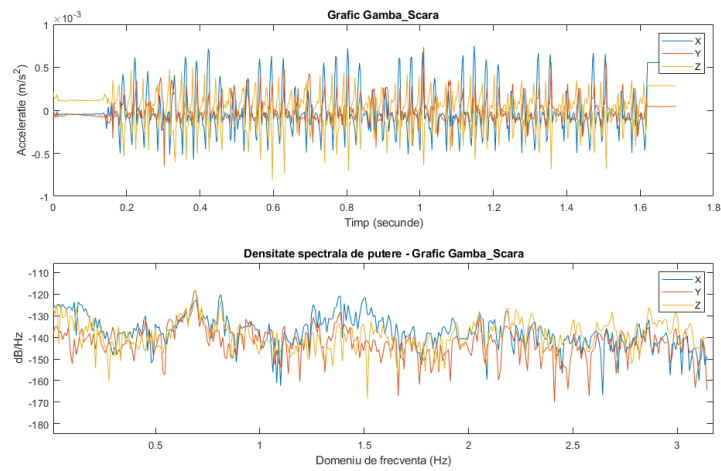


Fig. 5.3. Spectral power density leg descent scale the three axes

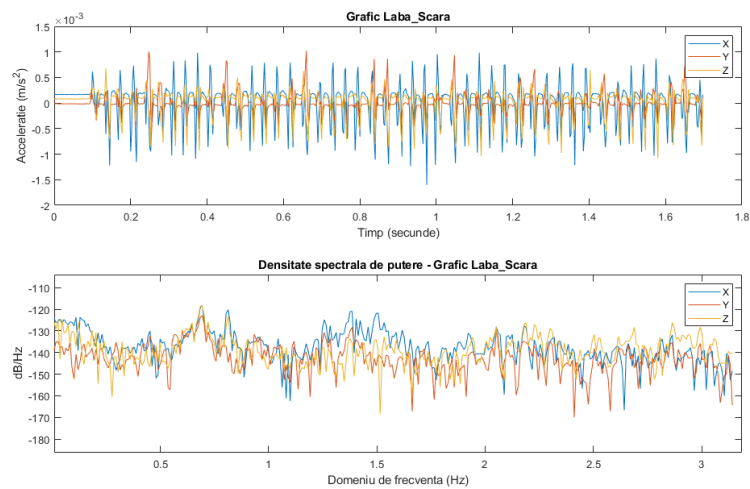


Fig. 5.4. Power spectral density foot downhill scale the three axes

From the analysis of the graphs without the use of vibrations, the frequencies of 0.97 Hz, 1.23 Hz, 1.78 Hz, 2.08 Hz and 2.43 Hz were obtained, for the descent from the scale.

5.5. Purchase percussion drill data

The system was mounted on the subject (fig. 5.8., 5.9., 5.10., 5.11.) And the recorded data were collected (fig. 5.12., 5.13.) When it handles a percussion drill in the following situations.:

- Accelerometer mounted on the handle of the equipment with / without FFT;
- Left and right arm with / without FFT;
- Forearm left and right hand with / without FFT.

Technical characteristics percussion drill:

- Model: Bosch GBH 2-26 DFR; Motor power: 800W; Drill diameter: 6mm;
- Speed: 1300 RPM; Drill length: 10cm.



Fig. 5.5. Purchase system mounted for percussion drill data collection - side view



Fig. 5.6. Purchase system mounted for percussion drill data collection - side view



Fig. 5.7. Purchase system mounted for percussion drill data collection - front view



Fig. 5.8. Mounted acquisition system for percussion drill data collection - rear view

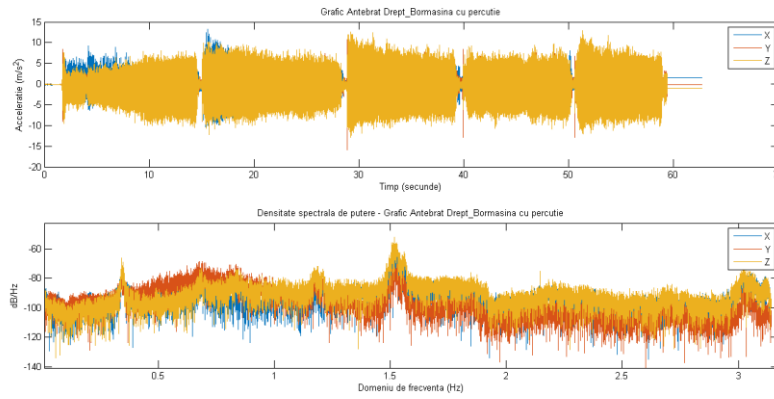


Fig. 5.9. Acceleration measured by the sensor on the three axes, spectral power density forearm as a percussion drill with percussion on the three axes

From the analysis of the graphics of the percussion drill, the frequencies of 0.34 Hz, 0.73 Hz, 0.98 Hz, 1.16 Hz, 1.24 Hz, 1.47 Hz, 1.53 Hz, 2.07 Hz, 2.23 Hz, 2.83 Hz and 3.12 Hz were obtained for a male subject with age. 15 years old, with a height of 175 cm and a weight of 65 kg. Some frequencies correspond to studies in young subjects in [1] as well as in [19].

5.6. Vibration plate data acquisition

The system was mounted on the subject (fig. 5.14., 5.15.) And the recorded data were collected (fig. 5.16., 5.17., 5.18.) When it handles a vibrating plate in the following situations:

- Accelerometer mounted on the handle of the equipment with / without FFT;
- Left and right arm with / without FFT;
- Forearm left and right hand with / without FFT.

Technical characteristics of the vibrating plate:

- Model: Wacker Neuson VP1340AW; Engine power: 3900 RPM; Speed: 3600 RPM.



Fig. 5.10. Mounting system mounted for vibrating plate data collection - front view



Fig. 5.11. Mounting system mounted for vibrating plate data collection - side view

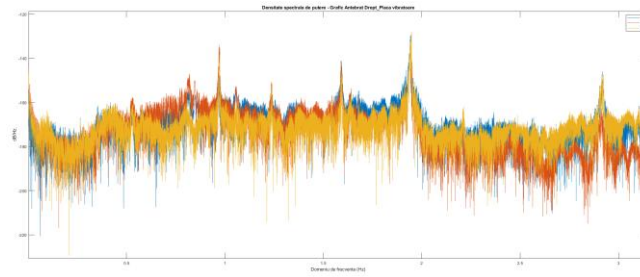


Fig. 5.12. Power spectral density vibrating plate forearm as the three axes

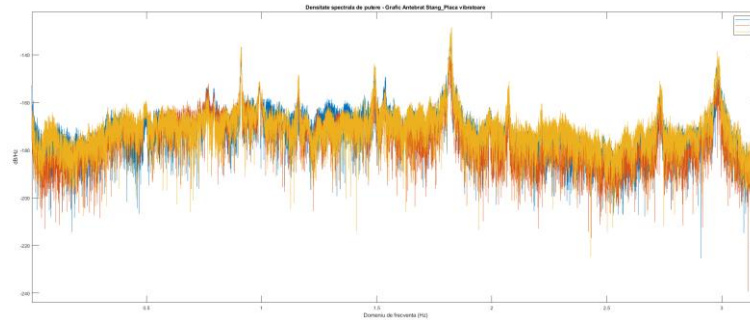


Fig. 5.13. Power spectral density vibrating plate forearm as the three axes

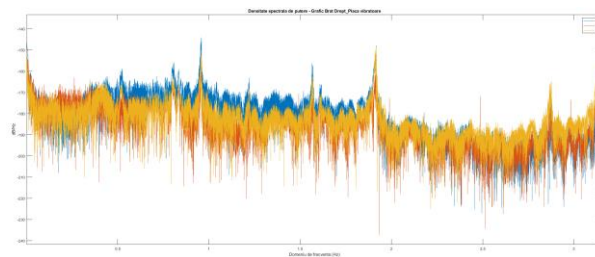


Fig. 5.14. Power spectral plate vibrating plate arm density along the three axes

CONCLUSIONS

From the analysis of the diagrams presented in Chapter 5 it results

1. *Constant speed descent on a stone staircase*

From the analysis of the graphs without the use of vibrations, the frequencies of 0.97 Hz, 1.23 Hz, 1.78 Hz, 2.08 Hz and 2.43 Hz were obtained, for the descent from the scale.

2. *Travel at a constant speed on straight ground*

From the analysis of the graphs without the use of vibrations, the frequencies of 1.53 Hz, 2.74 Hz, 4.23 Hz and 4.37 Hz were obtained for descending the scale and the frequencies of 1.51 Hz, 3.24 Hz and 5.23 Hz when walking on a straight road for a male subject with 15 years old, with a height of 175 cm and a weight of 65 kg. Some frequencies correspond to the studies performed on young subjects in [1] and shown in the graphs below as well as in [19].

3. *Driving on rough terrain in a car*

From the analysis of the graphs without the use of vibrations, the frequencies of 0.64Hz, 9.3Hz, 1.21 Hz, 1.82 Hz, 2.3 Hz, 2.31 Hz and 2.47 Hz were obtained, for traveling with a car on a rough road for a male subject aged 15 years, with a height of 175cm and a weight of 65kg. Some frequencies correspond to studies performed on young subjects in [1] and shown as well as in [19].

4. *Using a percussion drill*

From the analysis of the graphics of the percussion drill, the frequencies of 0.34 Hz, 0.73 Hz, 0.98 Hz, 1.16 Hz, 1.24 Hz, 1.47 Hz, 1.53 Hz, 2.07 Hz, 2.23 Hz, 2.83 Hz and 3.12 Hz were obtained for a male subject with age. 15 years old, with a height of 175 cm and a weight of 65 kg. Some frequencies correspond to studies in young subjects in [1] as well as in [19].

5. *Using a vibrating plate*

From the analysis of the vibration plate graphs, the frequencies of 0.27 Hz, 0.48 Hz, 0.98 Hz, 1.16 Hz, 1.22 Hz, 1.27 Hz, 1.33 Hz, 1.65 Hz, 2.03 Hz, 2.2 Hz, 2.43 Hz, 2.89 Hz and 3.32 Hz were obtained for a male subject aged 15 years, with a height of 175 cm and a weight of 65 kg. Some frequencies correspond to studies in young subjects in [1] as well as in [19].

The frequencies thus obtained were compared with the results of previous studies in the literature and a good agreement was obtained in the sense that the frequencies found experimentally corresponded to those in biomechanical models of the human body in the literature, especially those presented in Table 4.7 [2] thus obtaining the validation of biomechanical models of the human body subjected to the action of mechanical vibrations.

FINAL CONCLUSIONS

1. Analyzing the existing results at national / international level and partially presented in the previous chapters, it is proposed to use a device for acquiring and processing vibrating signals, a device designed and executed by me, [14] which can transmit these data through:

➤ GSM / GPRS – 2G / 3G / 4G; Bluetooth; Wi-Fi; 802.15.4 and ZigBee.

The collected data can be accessed / viewed through a web platform.

3. Starting with the new Smart watches, I thought of designing a plastic case that would have the same shape as the Smart watch case but other sizes to be suitable for embedding acceleration sensors in it and to mount the entire device with a belt in the areas of interest as in the previous figures.

The execution plan of the Smart watch case was shown in fig. 3.8.

4. Thus, a device was **designed and executed** that used the integrated processing platform (Arduino) on which vibration measuring sensors (accelerometers) were positioned, the results being able to be collected, transmitted and displayed in real time via GPRS.

GPS / GLONASS asset tracking device, GSM connectivity and standalone battery, is able to collect GPS coordinates and transmit them via GSM / GPRS to VPS in order to perform permanent data storage in a MySQL database or view in real time in a web page directly on your laptop.

The data obtained can be viewed on any mobile phone running Android +4.2 and on any laptop running Windows, OS X via a Python script.

5. Given the need for the data to be analyzed, the whole device has been designed and the components that ensure the capture and transmission of this data have been dimensioned. The acquisition and processing of experimental data using LabView was also used.

6. Once the data capture and transmission system was dimensioned, it was mounted on a subject and experimental determinations were made in two concrete situations, namely determinations without the use of vibrating equipment and determinations with the use of two equipments: compactor plate, respectively percussion drill.

A study was conducted on biodynamic models of human subjects exposed to vertical vibrations.

7. Models with concentrated parameters in the literature were also analyzed and validated in the synthesis of various experimental data. The following conclusions can be drawn from the analysis and validation:

Models with concentrated parameters are limited to one-dimensional analysis. Therefore, the human body is considered to be standing upright, without support, regardless of the position of the

hands, while the legs are supported and vibrate. These mathematical models include linear and nonlinear systems with varying degrees of complexity depending on the purpose of the analysis.

From the analysis of biomechanical models: with a degree of freedom Dieckmann (1957) (Coermann, 1962), two degrees of freedom (Wei and Griffin, 1998), (Allen, 1978), (Muksian and Nash, 1976), with three degrees of freedom (Suggs et al., 1969), (Allen, 1978), (Cho-Chung Liang, Chi-Feng Chiang, 2006 and Suggs C.W., Abrams C.F., Stikeleather L.F., 1969), (A. Picu 2009), with four degrees of freedom (Wan and Schimmels, 1995), (1998, Liu, Shi), (Boileau and Rakheja, 1998), Wagner and Liu (2000), with six degrees of freedom (Muksian and Nash, 1974), with seven degrees Freedom (Patil et al., 1977), (Cho-Chung Liang, Chi-Feng Chiang, 2005 and Patil, M.K., Palanichamy, M.S., Ghista, D.N., 1977), (Abbas et al., 2010), (Sengkang et al., 2013), with nine degrees of two-dimensional freedom (Harsha et al., 2014), with eleven degrees of freedom (Qassem et al., 1994; Qassem and Othman, 1996), results in important frequencies of human body segments presented in table 4.7., page 110, [100] namely:

Head - 2,06 Hz; chest - 1,2 Hz; trunk - 1,21 Hz, forearm - 1,17 Hz, arm - 3,39 Hz, thigh - 4,7 Hz, foot - 0,93 Hz.

8. Once the data capture and transmission system was dimensioned, from the device conceived, designed and executed by me and presented in **Chapter 3**, it was mounted on a subject and experimental determinations were made in two concrete situations, namely:

- determinations without the use of vibrating equipment;
- determinations with the use of two equipments: compactor plate, respectively percussion drill.

Determinations without the use of vibrating equipment were made by mounting the system on the subject and recording the data in case the subject descends a ladder and in case the subject moves on a flat surface. The obtained results were processed and represented graphically [16], [124], [125].

In both cases, acceleration measurements were performed on the three axes: Ox, Oy and Oz, obtaining the following types of diagrams.:

1. Acceleration - time:
 - a. On the Ox axis; On the Oy axis; On the Oz axis;
 - b. A diagram in which the three measurements overlap.
2. Fast Fourier Transform FFT - frequency, presenting in the thesis only a diagram in which the three measurements are superimposed.
3. Power-frequency spectral density:
 - a. On the Ox axis; On the Oy axis; On the Oz axis;
 - b. A diagram in which the three measurements overlap.

In the case of set A, the data acquisitions were made in the following situations:

- a) steady descent on a stone ladder, steady speed on flat ground, steady speed on rough terrain, straight road in a car, rough terrain in a car.

In the case of set A, data were collected from:

- a) thigh, calf, foot.

In the case of driving, data were collected from:

- a) right forearm; right arm; left forearm; left arm; thigh; leg; foot.

Determining the power spectral density - depending on the frequency:

- a) On the Ox axis, On the Oy axis, On the Oz axis;
- b) A diagram in which the three measurements overlap.

In the case of set B, data acquisitions were made for:

- a) right forearm; right arm; left forearm; left arm;
- b) percussion drill handle

Determining the power spectral density - depending on the frequency.

- a) On the Ox axis; On the Oy axis; On the Oz axis;
- b) A diagram in which the three measurements overlap.

From the analysis of the diagrams presented in Chapter 5 it results:

a. Constant speed descent on a stone staircase

From the analysis of the graphs without the use of vibrations, the frequencies of 0.97 Hz, 1.23 Hz, 1.78 Hz, 2.08 Hz and 2.43 Hz were obtained, for the descent from the scale.

b. Travel at a constant speed on straight ground

From the analysis of the graphs without the use of vibrations, the frequencies of 1.53 Hz, 2.74 Hz, 4.23 Hz and 4.37 Hz were obtained for descending the scale and the frequencies of 1.51 Hz, 3.24 Hz and 5.23 Hz when walking on a straight road for a male subject with 15 years old, with a height of 175 cm and a weight of 65 kg. Some frequencies correspond to the studies performed on young subjects in [1] and shown in the graphs below as well as in [19].

c. Driving on rough terrain in a car

From the analysis of the graphs without the use of vibrations, the frequencies of 0.64Hz, 9.3Hz, 1.21 Hz, 1.82 Hz, 2.3 Hz, 2.31 Hz and 2.47 Hz were obtained, for traveling with a car on a rough road for a male subject aged 15 years, with a height of 175cm and a weight of 65kg. Some frequencies correspond to studies performed on young subjects in [1] and shown as well as in [19].

d. Using a percussion drill

From the analysis of the graphics of the percussion drill, the frequencies of 0.34 Hz, 0.73 Hz, 0.98 Hz, 1.16 Hz, 1.24 Hz, 1.47 Hz, 1.53 Hz, 2.07 Hz, 2.23 Hz, 2.83 Hz and 3.12 Hz were obtained for a male subject with age. 15 years old, with a height of 175 cm and a weight of 65 kg. Some frequencies correspond to studies in young subjects in [1] as well as in [19].

e. Using a vibrating plate

From the analysis of the vibration plate graphs, the frequencies of 0.27 Hz, 0.48 Hz, 0.98 Hz, 1.16 Hz, 1.22 Hz, 1.27 Hz, 1.33 Hz, 1.65 Hz, 2.03 Hz, 2.2 Hz, 2.43 Hz, 2.89 Hz and 3.32 Hz were obtained for a male subject aged 15 years, with a height of 175 cm and a weight of 65 kg. Some frequencies correspond to studies in young subjects in [1] as well as in [19].

9. The frequencies thus obtained were compared with the results of previous studies in the literature and a good agreement was obtained in the sense that the frequencies found experimentally corresponded to those in biomechanical models of the human body in the literature, especially those presented in Table 4.7 [2] thus obtaining the validation of biomechanical models of the human body subjected to the action of mechanical vibrations.

PERSONAL CONTRIBUTIONS

Analyzing the existing results at national / international level and partially presented in the previous chapters, it is proposed to use a purchasing device and the processing of vibratory signals that can transmit this data through:

- GSM / GPRS – 2G / 3G / 4G;Bluetooth;Wi-Fi;802.15.4 and ZigBee.

The collected data can be accessed / viewed through a web platform.

The records allow real-time visualization of the medical data of the patients being treated and the review of the patients' classification to ensure that they have been targeted correctly..

2. A beta version of the human monitoring web platform presented int (fig. 3.4.), (Fig. 3.5.), (Fig. 3.6.)

3. Starting with the new Smart watches, a plastic case has been designed that has the same shape as the Smart watch case but other sizes to be suitable to incorporate the acceleration sensors and to mount the entire device with a strap in the areas of interest as in the previous figures.

The execution plan of the Smart watch case is presented in (fig. 3.8.).

4. A device was designed and designed using the integrated processing platform (Arduino) on which vibration measurement sensors (accelerometers) were positioned, the results can be collected, transmitted and displayed in real time via GPRS.

GPS / GLONASS asset tracking device, GSM connectivity and standalone battery, is able to collect GPS coordinates and transmit them via GSM / GPRS to VPS in order to perform permanent data storage in a MySQL database or view in real time in a web page directly on your laptop.

The application was developed using the Arduino MEGA 2560 acquisition device and / or RaspBerry Pi and / or IOIO Board which are presented in (fig. 3.12.) .

5. The operating instructions for this device were written in Python.

The data obtained can be viewed on any mobile phone running Android +4.2 and on any laptop running Windows, OS X via a Python script.

Given the need for the data to be analyzed, the whole device has been designed and the components that ensure the capture and transmission of this data have been dimensioned. The acquisition and processing of experimental data using LabView was also used.

6. Once the data capture and transmission system was dimensioned, it was mounted on a subject and experimental determinations were made in two concrete situations, namely determinations without the use of vibrating equipment and determinations with the use of two equipments: compactor plate, respectively percussion drill.

FUTURE RESEARCH DIRECTIONS

The doctoral thesis outlines some future research directions in the field of the influence of vibratory phenomena on the human body, namely:

1. Design and elaboration of parameterized biomechanical models, so that it can render as real as possible the behavior of the human body under the action of vibrations, models from which to result as particular cases the biomechanical models already appeared and studied in the literature presented in the thesis.
2. Further use of the device conceived, designed and made in the thesis, in order to create a digital database on experimentally measured values in other subjects under the same conditions made in the thesis as well as in other more unfavorable conditions.
3. Validation of other new biomechanical models that will appear in the literature in the meantime after the defense of the thesis.
4. Extending the analysis of biomechanical models by introducing nonlinear elements and their validation or non-validation through the collection and processing of experimentally collected signals.

SELECTIVE BIBLIOGRAPHY

- [1] Abbas W, Abouelatta OB, El-Azab M, Elsaidy M, Megahed AA, "Optimization of Biodynamic Seated Human Models Using Genetic Algorithms", **Scientific Research 2: 710-719, 2010.**
- [10] Balcu I., "*Vibrații ale sistemelor mecanice*", **Ed. Lux Libris, Brașov, 1996**
- [12] Baușic Florin, „*Dinamica mașinilor de construcții. Vol.1. Bazele modelării*”, **Ed. Matrix Rom, ISBN 973-685-229-6, București, 2001**
- [13] Baușic Florin, Toader Daniel, Baușic Alexandra, „*Cercetari privind transmiterea semnalelor captate de senzori montați în zone de interes ale organismului uman*”, **Sinuc 2017 – sectia I – I.14**
- [14] Baușic Florin, Toader Daniel, Baușic Alexandra, „*Metodă și dispozitiv pentru monitorizarea în timp real a corpului uman supus acțiunii vibrațiilor*”, **Sinteze de Mecanica Teoretica si Aplicata, Volumul 9 (2018), Nr. 3, pag. 197-200, ISSN 2068-6331, Matrix Rom**
- [15] Baușic Florin, Toader Daniel, Baușic Alexandra, Toader Eliza, „*Contribuții privind analiza modelelor biomecanice ale organismului uman supus acțiunii vibrațiilor*”, **Sinteze de Mecanica Teoretica si Aplicata, Volumul 8 (anul 2017), Nr. 3, pag. 179 - 184, ISSN 2068-6331, Matrix Rom**
- [16] Baușic Florin, Toader Daniel, Baușic Alexandra, Băcanu Sorana, „*Contribuții privind analiza vibrațiilor induse organismului uman în timpul procesului de lucru*”, **Sinteze de Mecanica Teoretica si Aplicata, Volumul 10 (anul 2020), Nr. 1, pag , 57-60, ISSN 2068-6331, Matrix Rom**
- [17] Baușic Fl., Diaconu Cr., "*Dinamica Masinilor*", **Ed Conspress, Bucuresti, 2000**
- [18] Baușic Fl., Pavel Cr., Diaconu Cr., "*Mecanica teoretica. Vibratiile sistemelor mecanice cu un grad de libertate*", **Ed Matrix Rom, Bucuresti, 2007**
- [19] Bedford A., Fowler W., "*Engineering mechanics. Dynamics.*", **Addison-Wesley 1999**
- [21] Biriș Anamaria, Claudiu Alin GLIGOR, Mariana ARGHIR, „*Studiul experimental al acțiunii vibrațiilor mașinilor-unelte portabile asupra sistemului uman mână-braț*”, **a VII-a conferinta nationala multidisciplinara, Sebes, 2013**
- [26] Bratu P., "*Vibrațiile sistemelor elastice*", **Ed. Tehnică, București, 2000**
- [27] Bratu P., Dragan N., "*Vibrații mecanice. Aplicații*", **Ed. IMPLUS, București, 1988**
- [28] Bratu, P., "*Vibrații mecnice. Teorie și aplicații tehnice*", **ISBN 973-98409-5-7, Editura Impuls, București, 1998**
- [30] Budescu E., "*Biomecanică generală*", **Iași, 2013**
- [31] Buzdugan Gh., Fetcu L., Rades M., "*Vibrații mecanice*", **Ed. Didactică și Pedagogică, București, 1982**
- [32] Buzdugan Gh., Fetcu L., Rades M., "*Vibrațiile sistemelor mecanice*", **Ed. Academiei, București, 1979**
- [39] Constantinescu, A., Pavel, C., "*Vibrații mecanice*", **Editura Matrix Rom, București, 2009, ISBN 978-973-755-468-0**
- [40] Cosmescu Alexandru, "*Analiza efectului vibrațiilor asupra sistemului braț-antebraț –mâna*", **Disertatie, Bucuresti, 2013.**
- [42] Daniela Tarnita, "*Wearable sensors used for human gait analysis*", **Rom. J. Morphol Embryol 2016 m 57(2):373-382**
- [48] Gao Tia, Dan Greenspan, Matt Welsh, Radford R. Juang, Alex Alm, "*Vital Sign Monitoring and Patient Tracking Over a wireless network*", **In proceedings of the 27th Annual International Conference of the IEEE EMBS Shanghai, September 2005.**
- [55] Iliescu, A., "*Biomecanica exercițiilor fizice*", **Editura C.N.E.F.S, București, 1968, pag. 9-14**
- [66] Legendi, A., Baușic, F., Pavel, C., "*Analiza transmisibilității vibrațiilor utilizate în scop terapeutic-metoda de investigație a structurii osoase*", **SIMEC 2007, 31 martie 2007, Editura Conspress Bucuresti, ISBN 973-7797-83-3, pag. 133-136**
- [82] Mondal Purnendu, "*Investigation of the dynamic interaction between the human body and car seat using a unique simulation technique*", **Ph.D. Thesis-University of East London,School of Architecture, Computing and Engineering, May 2020**
- [90] Panaitescu-Liess, R, "*Analiza răspunsului dinamic al organismului uman în interacțiune cu fenomenele vibratorii*", **Referat 2 în cadrul doctoratului, Buc, 2012**

- [91] Panaitescu-Liess, R., "*Modelarea biomecanică a organismului uman sub acțiunea vibrațiilor*", **Teza de doctorat, 2013**
- [92] Panaitescu-Liess, R., "*Modele biomecanice asociate organismului uman. Stadiul actual al cercetărilor*", **Raport de cercetare, februarie 2012**
- [97] Picu A., "*Modelarea biomecanică neliniară a dinamicii corpului uman sub acțiunea vibrațiilor transmise*", **Teza de doctorat, 2010**
- [98] Picu, A.A., "*Modelarea biomecanică neliniară a dinamicii corpului uman sub acțiunea vibrațiilor transmise*", **Teza de doctorat, 2010**
- [100] Plosceanu B., Craifaleanu A., Untaroiu C., "*Vibrațiile sistemelor cu un grad de libertate*", **Ed. Bren, București, 2001**
- [103] Predoi M., "*Vibrații mecanice. Modele si aplicatii în Matlab*", **Ed Matrix Rom, Bucuresti 2011**
- [104] Predoi Mihai, "*Vibrații mecanice. Modele si aplicatii în Matlab*", **Ed Matrix Rom, Bucuresti 2011**
- [121] Toader Daniel-Alexandru, „*Cercetări teoretice și experimentale parțiale privind validarea modelelor biomecanice ale organismului uman supus acțiunii vibrațiilor mecanice*”, **Raport de cercetare științifică nr. 3, Bucuresti, 2019**
- [122] Toader Daniel-Alexandru, „*Metode utilizate în aprecierea efectului vibrațiilor asupra organismului uman*”, **Raport de cercetare științifică nr. 2, Bucuresti, 2019**
- [123] Toader Daniel-Alexandru, „*Stadiul actual privind transmiterea semnalelor captate de senzorii montați în zonele de interes ale organismului uman*”, **Raport de cercetare științifică nr. 1, Bucuresti, 2017**
- [124] Toader Daniel-Alexandru, Alexandra BAUȘIC, Florin BAUȘIC, „*Analiza experimentală a vibrațiilor induse organismului uman*”, **Sinteze de Mecanica Teoretica si Aplicata, Volumul 11 (anul 2020), Nr. 2, pag. 109-112, ISSN 2068-6331, Matrix Rom**
- [125] Toader Daniel-Alexandru, Dogaru Marina, Ursache Robert, Baușic Florin, „*Partial experimental contributions of the validation of biomechanical models of the human body subjected to the action of mechanical vibrations*”, **Mathematical Modelling in Civil Engineering, Vol.16 - No. 4: 25-33-2021, Doi: 10.2478/mcee-2021-0018**
- [140] http://iso.org/iso/standards_development/technical_committees