ESTIMATION OF OSCILLATORY COMFORT DURING VERTICAL VIBRATIONS USING AN ARTIFICIAL NEURAL NETWORK

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Abstract:

Vertical vibrations in the vehicle can have a negative effect on the oscillatory comfort of the passengers. Vibrations can cause pain in muscles and joints, fatigue, problems with vision and coordination of movements. The ISO 2631 standard provides guidelines for assessing the level of vibration experienced by passengers in a vehicle and provides guidelines for the design and testing of vehicles to ensure the highest possible oscillatory comfort. In this paper, the influence of vertical vibrations on the human body was investigated using the ISO 2631 standard. For the purposes of the experiment, ten healthy subjects participated, five male and five female. Based on experimental results, an artificial neural network was developed to evaluate oscillatory comfort.

Key words: vertical vibrations; oscilatory comfort; passengers; artificial neural network

1. Introduction

Whole-body vibrations represent one of the indicators of the improvement of the human body's kinematic part. Long exposure of the body to vertical vibrations can lead to harmful consequences on the musculoskeletal system [1]. When analyzing vibrations, it is important to fully describe the characteristic values of vibrations. For the human body exposed to vibrations, the following characteristic values are important: the frequency spectrum, amplitude, action factor, and length of exposure to vibrations [2].
Exposure to vibrations has a different impact on the human body, ranging from minor discomfort to decreased work efficiency and health disturbances. Today, there are guidelines in the international standard ISO 2631-1:1997 [3] for defining the tolerance of the human body exposed to whole-body vibrations. The standard ISO 2631-1:1997 is used for assessing exposure to high levels of vibrations and impacts. Vibrations that the human body absorbs can lead to muscle contractions that can cause muscle fatigue, especially at resonant frequencies. Vertical vibrations

in the range of 5 Hz - 10 Hz cause resonance in the thorax - abdominal system (4 Hz - 8 Hz in the chest, 20 Hz - 30 Hz in the head, neck, and shoulders and 60 Hz - 90 Hz in the eyes) [3].
The ISO 2631-1:1997 standard provides acceptable values of human discomfort depending on daily exposure to vibrations, but does not define specific limits. In Table 1, the mentioned values of discomfort are shown.

Acceleration (m/s^2)	Comfort Level
< 0.315	Not uncomfortable
0.315-0.63	A little uncomfortable
0.5-1	Fairly uncomfortable
0.8-1.6	Uncomfortable
1.25-2.5	Very uncomfortable

Table 1. Passenger comfort perception according to ISO 2631 (1997)

Also, the SRPS ISO 2631-1:2014 [4] standard specifies the total value of the average effective rms acceleration, based on which the assessment of the impact on discomfort is carried out according to the formula:

$$a_v = \sqrt{\left(k_x \cdot \ddot{x}_{rms,w}\right)^2 + \left(k_y \cdot \ddot{y}_{rms,w}\right)^2 + \left(k_z \cdot \ddot{z}_{rms,w}\right)^2}\ , \tag{1}$$

where: k_x, k_y, k_z – are correction factors for r.m.s. values of weighted accelerations in the direction of the x, y and z axis,– x, z and z with two poinst above are mean effective value of the weighted acceleration for the directions x, y and z.
The development of new technologies, specifically artificial intelligence, provides the opportunity for a better understanding of human body behavior exposed to vibrations [6]. The term "artificial intelligence" refers to an inanimate system that demonstrates the ability to adapt to new situations. It is based on the behavior of human beings, in order to fully replicate human behavior [5]. Machine learning is a subset of artificial intelligence that deals with building computer systems that can adapt to new situations. This field has been extremely popular in recent years, both in science and industry [9].
In this work, an ANN model was created based on the experimental results. Based on this, it is possible to perform an assessment of comfort in the vehicle.

2. Materials and methods

The research on the impact of vibrations on humans is conducted with two aspects [10], [11]:

- health (fatigue, oscillatory discomfort, appearance of professional improvements),
- mechanical frequency response of the human body (biodynamics).

In literature, the impact of harmonic and stochastic vibrations on humans is most often considered. In these cases, the frequency range is in the range of 1 Hz - 30 Hz. Recent research has shown that humans are also very sensitive to frequencies below 1 Hz [12]. For these research, or measuring the impact of vibrations on humans, vibration exciters, or shakers, are used. They are most commonly realized on the hydraulic principle, as a hydraulic platform with the possibility of exciting in two independent axes (two-axis) or in one linear axis (one-axis).
For this research, a hydro-dynamic shaker, HP-2007, was used. The HP-2007 hydro-dynamic shaker is designed to provide excitation in the frequency range of 0.1 Hz - 31 Hz and amplitude of 0 mm - 50 mm.

In the study, 10 subjects participated (5 males and 5 females). The average values for five healthy male subjects were: 30.8 years of age, 183.6 cm height, 90.2 cm seating height, 93.4 kg weight, and 27.7 BMI. Also in the experiment, five healthy female subjects with average age of 30.4, height of 172.6 cm, seating height 79.2, weight 68.4 kg and BMI 22.9 participated. Both male and female subjects were exposed to random vertical vibrations for one excitation value of 0.45 m/s^2 r.m.s. in the frequency range of 0.1 Hz - 20 Hz. The angle of inclination of the seat was 90°.

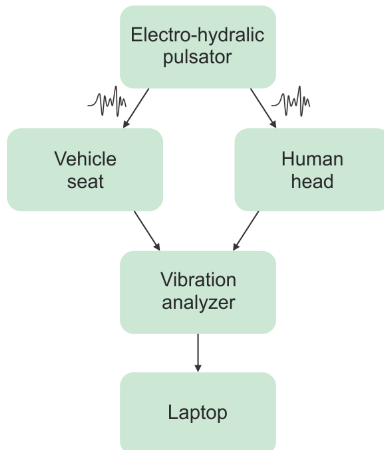

Fig. 1. A laboratory setup of the experiment

After measuring the experimental values of ponderous acceleration on the subjects, a neural network was used for model formation. Neural networks can be described as a relatively new concept used in data analysis. Their wide application can be seen in social and technical sciences as well as many other fields.

In this work, a common artificial neural network was used to determine the oscillatory comfort in a vehicle. The neural network is defined with 50 neurons in the first hidden layer and one neuron in the output layer. The data used for training the network was data obtained experimentally from the subjects. For each subject, the following parameters were given: BMI, height, weight, seat height, age, gender, years and measured r.m.s values.

Figure 2 shows the schema of the artificial neural network used in this work.

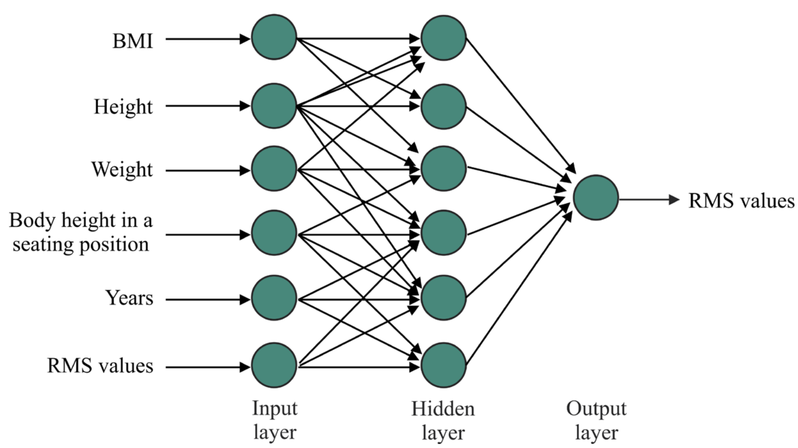

Fig. 2. A scheme of a neural network

The mean absolute error is used as the loss function in the training phase. The minimization of the loss function is done using the Adam optimization algorithm.

3. Results

3.1 Exprerimental results

Based on the ISO 2631 standard, this study carried out an assessment of oscillatory comfort based on the overall effective comfort of the weighted acceleration. Table 2 shows the overall r.m.s. values of weighted acceleration and the assessment of oscillatory comfort under the influence of vertical motion for 5 male test subjects. Minor discomfort is observed for test subjects numbered 2 and 3, while no discomfort was observed in the other test subjects.

ID	r.m.s.	Comfort level
1	0.364	A little uncomfortable
2	0.352	A little uncomfortable
3	0.179	Not uncomfortable
4	0.186	Not uncomfortable
5	0.284	Not uncomfortable

Table 2. R.m.s. weighted acceleration values and oscillatory comfort ratings under the influence of vertical excitation for five male subjects

In table 3, the overall r.m.s. values of the weighted acceleration and the assessment of oscillatory comfort under the influence of vertical vibration are shown for 5 female test subjects.

ID	r.m.s.	Comfort level
1	0.396	A little uncomfortable
2	0.297	Not uncomfortable
3	0.376	A little uncomfortable
4	0.355	A little uncomfortable
5	0.288	Not uncomfortable

Table 3. R.m.s. weighted acceleration values and oscillatory comfort ratings under the influence of vertical excitation for five female subjects

Based on the table 3, it can be concluded that there is a little discomfort observed for the subjects under the serial number 1, 3 and 4, while no discomfort was observed in the other two subjects. From table 2 and 3, differences between male and female subjects can be observed and it can be said that the testing conditions are more suitable for the male population than the female.

3.2 Artificial neural network results

Using artificial neural network and ISO standard 2631, it is possible to train the neural network. The ANN model is trained with 100 training epochs. The coefficient in training, validation and testing was 92.1% for male subjects. The mean square error for the predicted RMS values of male subjects was 0.051. In the female population, the coefficient in training, validation and testing was 91.3%. The mean square error for the predicted RMS values of female subjects was 0.069. It is known that there are differences in the anatomy of both sexes, but it should be noted that the percentage of visceral fat is higher in the female population than in the male population. Special analysis were made for male and female subjects due to the different anthropometric characteristics of both sexes.

In tables 4 and 5, the predicted RMS values of male subject under serial number 5 and female subject under serial number 5 are shown under the action of vertical vibration.

ID	Original	Predicted
R.m.s	0.284	0.269
Comfort level	Not uncomfortable	Not uncomfortable

Table 4. Predicted r.m.s values for male subject number 5

ID	Original	Predicted
R.m.s	0.288	0.298
Comfort level	Not uncomfortable	Not uncomfortable

Table 5. Predicted r.m.s values for female subject number 5

The advantage of applying neural networks can be seen based on these results. With a large amount of experimental data, the designed neural network can provide a good basis for further analysis of vehicle comfort and replace expensive and time-consuming experiments.

4. Conclusions

In this study, the assessment of the vehicle's oscillatory comfort was carried out based on the ISO 2631 standard. Ten test subjects were exposed to random single-axis vertical vibrations. Five healthy male and five healthy female test subjects participated in the experiment. It was determined that there are small differences in the comfort assessment between males and females. The excitation of 0.45 m/s^2 r.m.s. showed greater discomfort among females than among males. The reason for this may be differences in anthropometric characteristics of the test subjects.

The artificial neural network model developed in this study shows the ability for precise biomodeling. The main feature of this model was to take into account the input data of the test subject, namely, height, weight, sitting height, BMI, and years during exposure to whole body vibrations.

The continuation of this research would be in the direction of determining oscillatory comfort in relation to changes in seat inclination angle and changes in excitation values, which will be future research.

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