APPLICATION OF NEURAL NETWORKS IN ASSESSING BODY COMFORT DURING DRIVING

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Abstract:

In transportation, comfort is a cornerstone of vehicle quality assessment, significantly impacting drivers and passengers alike. Despite extensive research, a precise method to quantify driving comfort remains elusive. This study addresses this gap by investigating the effects of whole-body vibrations during driving across diverse speeds and road conditions, integrating measured and predicted root mean square (r.m.s.) acceleration values. Real-world road tests provided empirical r.m.s. acceleration data, capturing the dynamic vibrational environment, while an Artificial Neural Network (ANN) model was developed to predict these values with high accuracy. The research involved ten male participants, whose varied anthropometric characteristics ensured a comprehensive analysis of vibration effects. Results demonstrated the ANN model's exceptional precision in forecasting r.m.s. acceleration, offering a robust framework for evaluating whole-body vibration and its influence on comfort. By combining practical road data with advanced predictive modeling, this study introduces an innovative approach to understanding and enhancing driving comfort. This synergy of empirical and computational methods provides fresh insights into optimizing the travel experience across diverse driving scenarios.

Keywords: artificial neural network, comfort, road, vibration

1. Introduction

During car travel, passengers experience whole-body vibration and intermittent shocks, the intensity of which varies based on factors such as road surface, vehicle speed, and the points of contact with the vehicle—namely the floor, automotive seat, and steering wheel. This vibrational exposure, transmitted through these interfaces, directly influences ride comfort, a critical metric in assessing the quality of the travel experience. Over the years, numerous technologies have been engineered to mitigate whole-body vibration, aiming to enhance comfort and reduce its adverse effects [1], [2]. Prolonged exposure to vibrations, particularly within the 0.5–80 Hz frequency range, has been linked to chronic health issues, including low back pain, spinal disorders, abdominal discomfort, and impaired vision [3]. These health concerns underscore the importance of understanding and managing vibration exposure in automotive design.

The human body's sensitivity to whole-body vibration is highly frequency-dependent, with peak perception occurring in the seated vertical direction between 4 and 8 Hz [4]. This range aligns closely with the biomechanical resonance of the body, amplifying the impact on occupants. Research indicates that subjective perceptions of vibration discomfort are intricately tied to the biomechanical responses of the body, reflecting how vibrational energy is absorbed and transmitted through tissues and skeletal structures [5]. The adverse impacts of whole-body vibrations manifest in various health issues, most notably discomfort in the lumbar region and neck. Exposure to extremely low-frequency vibrations (below 0.5 Hz) can induce symptoms akin to motion sickness, often described as "seasickness" [6]. Table 1 presents findings on passenger comfort in urban public transport, evaluated across different vibration intensities as per the ISO 2631 (1997) standard, derived from controlled laboratory experiments. The data clearly indicate that higher vibration levels correspond to a noticeable decline in passenger comfort [7]. These observations highlight the critical need to address vibrational effects to enhance the travel experience and mitigate associated health risks.

Less than 0.315 m/s^2	Not uncomfortable
0.315 m/s^2 to 0.63 m/s^2	A little uncomfortable
0.5 m/s^2 to 1 m/s^2	Fairly uncomfortable
0.8 m/s^2 to 1.6 m/s^2	Uncomfortable
1.25 m/s^2 to 2.5 m/s^2	Very uncomfortable
Greater than 2 m/s^2	Extremely uncomfortabl

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

A study by a group of researchers [8] found that professional drivers exhibit lower sensitivity to vibration levels. This can be attributed to two factors. Firstly, drivers anticipate road irregularities and brace for disturbances affecting their bodies, as increased muscle tone helps suppress the movement of internal organs. Secondly, the steering wheel enables them to regulate both angular movements around the transverse axis and forward-backward translational motions of their bodies. Additionally, the author [9] suggests that in real driving scenarios, passengers tend to perceive comfort at higher vibration intensities compared to controlled laboratory conditions. This difference is likely due to the presence of multiple external stimuli that influence passengers' attention during actual driving. Standard ISO 2631 (1997) [10] prescribes the total value of mean effective weighted accelerations, on the basis of which the impact on discomfort is assessed according to the formula:

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

where:

k_x, k_y, k_z – are correction factors for r.m.s. values of weighted accelerations in the direction of thex, y and z axis,

$\ddot{x}_{rms,w}$, $\ddot{y}_{rms,w}$, $\ddot{z}_{rms,w}$ – are mean effective value of the weighted acceleration for the directions x,y and z, which are determined according to the formulas:

$$\ddot{x}_{rms,w} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \ddot{x}^2{}_{w_i}}, \quad (2)$$

$$\ddot{y}_{rms,w} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \ddot{y}^2{}_{w_i}}, \quad (3)$$

$$\ddot{z}_{rms,w} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \ddot{z}^2{}_{w_i}}, \quad (4)$$

where:

$\ddot{x}_{wi}$, $\ddot{y}_{wi}$, $\ddot{z}_{wi}$ – are i-th sample of weighted accelerations of the user for the directions of the x, y and z axis (m/s^2), N – is number of signal samples of weighted accelerations.

Uncovering hidden patterns and relationships within data has become increasingly efficient with advanced computational methods, offering a modern and innovative approach to solving complex engineering problems. A key focus in this field is the development of algorithms that replicate human-like learning processes. Among these, artificial neural networks (ANNs) stand out as a subset inspired by the structure and functioning of the human brain. These biologically motivated models have shown exceptional capability in predicting nonlinear responses, particularly in applications related to human body dynamics in seated positions. Due to their ability to learn from input-output relationships, artificial neural networks have been extensively applied across various domains [11-15], including biomechanics and vehicle dynamics. In this study, an ANN model was developed based on experimental data to assess the oscillatory comfort of the human body during vehicular motion. As vehicles continue to advance in design and technology, understanding and mitigating vibrational dynamics remains crucial for enhancing ride comfort and ensuring passenger well-being.

2. Methods

2.1 Experimental measurements

The research task in this paper was to evaluate the vibration comfort of a vehicle by measurement of total mean effective value of the weighted acceleration. In this research, RENAULT Megane 3 was used. The measurements were made by driving the car on the two roads, with different conditions:

- the motorway (Kragujevac – Batocina) straight, well maintained smooth road surface without any damage; the car is driven at 60 and 80 km/h,
- the suburban street (in Kragujevac) the road surface is in a poor condition and characterized by a series of pot-holes and bump; the car is driven at 40 and 50 km/h.

a) b)

Figure 1. Roads where measurements were done. a) motorway, b) suburban stree

Each of the measurement sessions durated about 5 minute. All vibration measurements are carried out on the phone Samsung S23 Ultra in the position shown in Fig. 1 with Vibration Meter application.

Figure 2. The position of the smartphone and 3 accelerometer axes

The phone has an accelerometer LSM6DSO. It is a 6-axis IMU (inertial measurement unit) system-in-package featuring a 3-axis digital accelerometer and a 3-axis digital gyroscope, boosting performance at 0.55 mA in high-performance mode and enabling always-on low-power features for an optimal motion experience. Ten male healthy subjects, with mean age 32.4±5.12 years, height 181.05±3.54 cm, weight 90.2±6.02 kg, BMI (Body Mass Index) 26.21±1.86, seating height 87.15±4.11 cm.

2.2. Artificial neural network

In this study, the principle of ANN was used for modeling complex relationships between input and output data. The network consists of an input layer with six parameters, a hidden layer with multiple neural units, and an output layer that provides the predicted r.m.s. vibration values. Each neuron in the layers is connected through synapses, allowing the model to learn complex relationships between input data and output results. The data used for training the network were obtained from experimental measurements conducted on a sample of 10 subjects exposed to vehicle vibrations during driving. Each subject was characterized by a set of parameters, including BMI, height, weight, sitting height, and age. Figure 3 presents the schematic of the ANN architecture used in this study, illustrating its layered structure and the flow of information between layers.

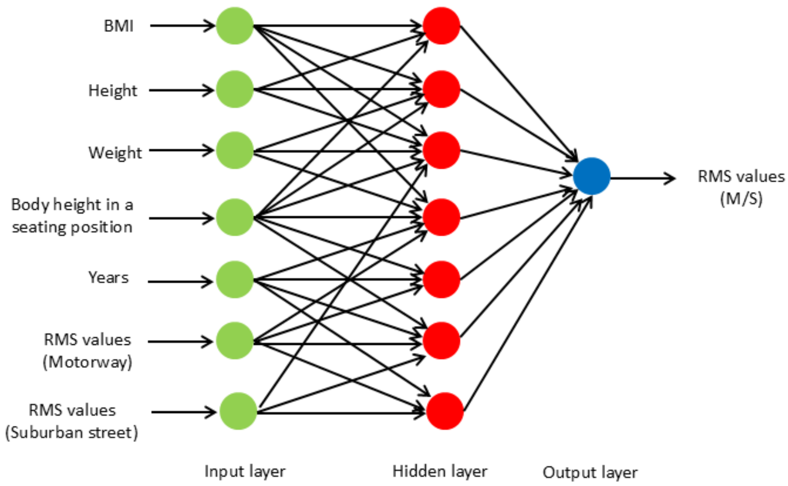

Figure 3. A schematic representation of an artificial neural network

During network training, the mean squared error was also used as the loss function, while the efficient Adam optimization algorithm was applied to minimize the loss function. The model was trained over 100 epochs, with a batch size of 20. The training, validation, and testing accuracy exceeded 91% for both road types.

3. Results

Based on the ISO 2631 standard, an assessment of oscillatory comfort was performed based on the total mean effective value of the weighted acceleration. The ISO 2631 standard prescribes checking the value of the crest factor. The measured peak factor values were in the range of 1.241-2.904, which meets the requirements of the standard (peak factor < 9), so the weighting was done according to the ISO 2631 standard. Table 2 shows the total r.m.s. weighted acceleration values and oscillatory comfort ratings under the whole body vibration for 10 male subjects.

Subject ID	The motorway [km/h]		The suburban street [km/h]	
	60	80	40	50
1	0.682	0.701	0.742	0.751
2	0.721	0.732	0.754	0.767
3	0.715	0.733	0.759	0.778
4	0.741	0.753	0.772	0.783
5	0.738	0.744	0.781	0.799
6	0.752	0.769	0.779	0.806
7	0.769	0.791	0.788	0.811
8	0.751	0.762	0.798	0.824
9	0.761	0.783	0.816	0.834
10	0.774	0.796	0.833	0.847

Table 1. Results of vibration measurement at the seat (r.m.s units [m/s^2])

By analyzing the results from the table, it can be concluded that as the vehicle's speed increases, the r.m.s. values measured at the seat also increase. It is interesting to note how the road quality affects this. Highways yield lower r.m.s. values for similar speed values. This is expected due to the excellent quality of the road surface, which is well maintained and smooth, and the road is relatively in a straight line, with minimum curvatures. Additionally, it can be concluded that as the weight of the test subjects increases (the lightest being subject 10 and the heaviest being subject 1), the r.m.s. values decrease.

The results of the prediction using ANN are presented in Table 2.

Subject ID	The motorway [km/h]		The suburban street [km/h]	
	60	60	40	40
	Experiment	ANN	Experiment	ANN
1	0.682	0.691	0.742	0.749
2	0.721	0.714	0.754	0.761
3	0.715	0.722	0.759	0.767
4	0.741	0.751	0.772	0.783
5	0.738	0.731	0.781	0.771
6	0.752	0.766	0.779	0.764
7	0.769	0.781	0.788	0.799
8	0.751	0.767	0.798	0.806
9	0.761	0.777	0.816	0.822
10	0.774	0.786	0.833	0.843

Table 2. Results of vibration measurement at the seat (r.m.s units [m/s^2])

The developed model of the artificial neural network shows that it has adequate precision in biodynamic modeling, offering a reliable tool for understanding how the human body responds to vibrations. The main feature of the ANN model is its ability to consider height, weight, sitting height, BMI, and age during whole-body vibration exposure, making it a comprehensive approach to studying these effects. The ANN model was tested across various scenarios, revealing that it accurately predicts how different physical characteristics influence an individual's reaction to whole-body vibration. This advancement could lead to improved ergonomic designs in the automotive industry, where passengers are regularly exposed to such conditions, enhancing both comfort and safety.

4. Conclusions

This study demonstrated the effectiveness of using an ANN model to assess the impact of whole-body vibration on driving comfort. The model showed excellent precision in predicting the root mean square acceleration values based on various physical characteristics of the subjects, such as height, weight, sitting height, BMI, and age. The results confirmed that as vehicle speed increases, so do the r.m.s. values, with better road quality resulting in lower vibration values. The model's ability to integrate these factors provides a comprehensive approach to understanding how human bodies react to vehicle vibrations under different conditions. The findings highlight that heavier individuals tend to experience lower r.m.s. values, which is an important consideration for ergonomic design. Furthermore, the ANN model proved to be a reliable tool for predicting human responses to whole-body vibrations, offering valuable insights for improving vehicle comfort. By considering a wide range of factors, this model can contribute to more personalized comfort assessments and better ergonomic practices in the automotive industry. The integration of real-world data and advanced predictive modeling opens up new avenues for optimizing passenger experience and safety. This research not only enhances our understanding of biodynamic responses but also lays the foundation for future studies aimed at improving vehicle design and comfort. Ultimately, the use of ANN in this context provides a powerful tool for addressing vibration-related discomfort, potentially leading to safer and more comfortable driving environments.

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