Modeling of Human Sensation and Prediction of Passenger Ride Comfort

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Abstract

This article presents a systematic procedure and Artificial Neural Networks (ANN) based tool for passenger ride comfort objectification, to support vehicle developer during the product development process. In this case, the term “comfort objectification” can be clarified as reproduction of subjectively sensed convenience of a passenger through objectively measurable values. Many factors, such as noise, vibration, physical or psychological condition of a passenger generally influence the ride comfort. The main purpose of this project is to develop vehicle assemblies which can sustain customer demand of vibration comfort. The presented methods and tools enable the identification and the evaluation of vehicle dynamic properties from the passenger point of view during vehicle travel in the early stage of the product development process.

To estimate the subjective passenger sensation, the new driver modeling tool based on ANN is developed from the way individual drivers make their assessment. This paper presents a user-friendly interface which allows both experts and users who are short of experience in the ANN field, to create different network architectures depending on given task. By means of this tool, the modeling process can be effectively simplified and shortened. As a result, the objective values captured from experiments are efficiently correlated with the subjective sensation. Consequently, the high performance of comfort prediction can be achieved.

According to the approach of virtual drive train development, in this study, the transmission test bench is primarily used to generate several virtual operating situations. This enables the determination of NVH properties of the future product, such as a transmission, and allows the developer to investigate the effect of vibration like on the degree of ride comfort. By applying objective data from the experiment, a prediction of comfort assessment using the presented tools can be executed. In the long run, costly field tests and cost-intensive prototypes can be partially replaced.

Keywords: Passenger Ride Comfort, Comfort Objectification, Vehicle development, Virtual Drive Train, NVH, Artificial Neural Networks,

1. Introduction

Today's vehicle developers are confronted with rapid innovation, shortened development and product life cycles. They are forced to speed up an optimization of ride comfort to be able to meet rising customer demands in terms of comfortability, quality, economical and ecological aspects. In case of comfort evaluation of road vehicles, the assessment is generally done by test persons using evaluation schemes, as they are commonly used in automotive industries [1,2]. To be able to evaluate the vehicle dynamic properties in early stage of product development process, several studies related to the models for the objectification of passenger ride comfort have been executed [3]. In this article, the approach for objectification of the customer sensation is presented in Section 2. The Tools for modeling of driver sensation and model optimization are demonstrated in Section 3. In Section 4, the experimental investigation to obtain subjective and objective data is presented. Section 5 demonstrates the application of developed methods and experimental results, followed by concluding remarks in Section 6.

2. Ride Comfort Objectification

A generic method to determine and to evaluate the dynamic features of vehicle commonly requires drive tests with passenger as well as real prototypes. Consequently, these lead to time-consuming modification on real vehicle and additional costs. As shown in Figure 1, to be able to support the design process, an approach of comfort objectification based on integrated drive train development [3] at the Karlsruher Institute of Technology is developed. According to the virtual product development, the prediction of passenger subjective comfort assessment can be executed using the objective data. These are both measured and simulated data which can be generated from the numerical simulation as well as experimental investigation. To be able to estimate the comfort rating, the Artificial Neural Networks (ANN) based objectification tool and the user-interface which will be demonstrated in this article are developed.

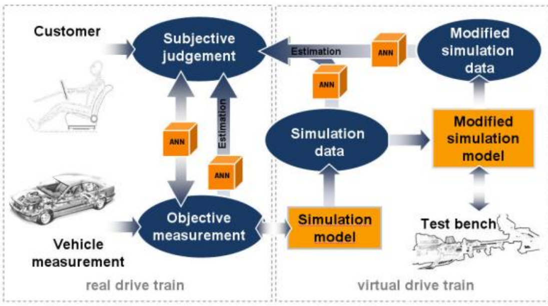


Fig. 1 Approach of comfort objectification based on integrated drive train development [3]

According to the virtual product development, the prediction of customer subjective comfort judgement can be executed using the objective data. These are both measured and simulated data which can be generated from the virtual drive train by using simulation model as well as test bench. To be able to estimate the comfort rating, the Artificial Neural Networks (ANN) based objectification tool and the user-interface which will be demonstrated in this article are developed.

3. Human Sensation Modeling

Similarly to the way a passenger makes his comfort evaluation, an ANN is applied to interconnect input data (human sensation or subjective assessment) with output data (comfort evaluation) by "trained" weighted network connections. This section presents the objectification tool which is developed to predict the individual subjective comfort ratings of average customers.

3.1 Method of Human Sensation Modeling

In this study, Artificial Neural Network (ANN) is applied as a computational model to find a relationship between inputs and outputs as well as to recognize a data pattern. The ANN can be described with a simplified mathematical function *z(w,x)*, which is commonly defined by the nonlinear weight sum according to:

$$z(w,x) = f(\sum_k w_k \cdot x_k) \qquad (1)$$

z denotes the output vector consisting of the data to be approximated. *x* represents the input vector consisting of k input nodes, x_k. *w* denotes the vector of the connection weights wk between the input node x_k and the output node *z*. The type of the function *z* is defined by the applied activation function *f*. This can be either linear or nonlinear function, such as the log-sigmoid function. Due to the capability of the ANN to model the complex nonlinear relationships between the inputs and the outputs [4], the ANN-based methods and tools are developed to find a correlation between the objective data and a subjective comfort assessment from the individual customer point of view. The operating principle of ANN for the current research is illustrated in Figure 2.

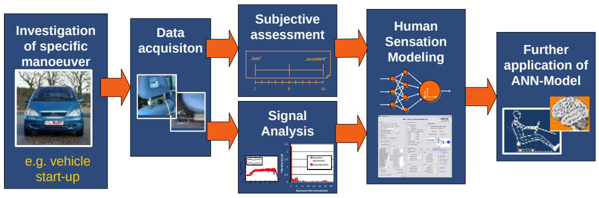


Fig. 2 Methodology for the development of the ANN-based human sensation model [5]

To objectify the human sensation according to each driving maneuver, the comfort-relevant characteristic values as well as the subjective assessment method are to be predefined. After obtaining all data, both sets of objective value representing the input data and the subjective evaluation denoting the target data are combined into a pattern. This is used as a data set for the human sensation modeling.

3.2. User-Interface for Comfort Modeling

To simplify the modeling process, the "Driver Comfort Modeling Tool" presented in Figure 3 enables the modeling of all types of drivers from the way they make evaluations [5]. This is followed by a model optimization to attain a high accuracy of subjective comfort prediction, which generally depends on the topology and training parameters of ANNs [6]. To predict the subjective comfort rating of any driving situation, the "knowledge" of trained ANNs and the generated input data can be used by means of the "Driver Comfort Evaluation Tool". These user-friendly interfaces simplify a modeling and application process by reducing the conventionally time-consuming tasks. In addition, the possible human mistakes occurred during programming can be avoided. The modeling results of the investigation are presented in following section.

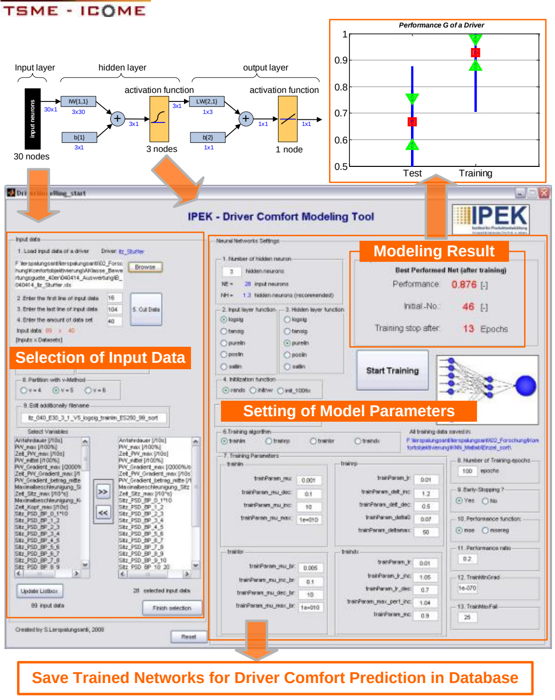


Fig. 3 Driver Comfort Modeling Tool [5]

4. Gear Noise Evaluation

This section presents the modeling results of gear rattle evaluation. By means of the presented ANN-based tools, a non-linear relation of subjective comfort assessment and objective data of each driver can be found and applied to determine the NVH properties of a 5-speed manual transmission in view of gear rattle tendency and its effect on human comfort sensation.

4.1 Gear Rattle Phenomenon

High rotational irregularity of engine torque and consequently causes the excitation in terms of torsional vibration throughout the power train. One of dominant noises from drive train is the gear rattle phenomena from transmission caused by torsional vibration of transmission components that are not under load, which are moving within their functional clearances and knocking against their limits [7]. The gear rattle noise generated by low frequency vibration is perceived as particularly unpleasant, not because of its high airborne sound pressure level, but due to its unpleasant characteristic.

4.2 Experimental Set-up

This experimental set-up was developed on an universal transmission test bench to generate rattle noise in a commercial vehicle transmission by means of the simulation the non-uniform rotational speed pattern of a vehicle internal combustion engine. As shown in Figure 4, the test bench is configured to simulate a front-drive of intermediate-class car. The defined irregular rotational speed patterns can to be generated with oscillating torque excitation [7]. To capture the air borne sound pressure level, an artificial head for binaural recording of gear rattle noise is used. By means of the measurement system for data acquisition and data analysis, the predefined characteristic psychoacoustic values, such as the A-weighted sound pressure level, the loudness or the sharpness are generated. The gear housing vibrations are measured at different positions using piezoelectric accelerometers. In addition, the gear shaft speed, the input and output torque as well as the transmission oil temperature are captured.

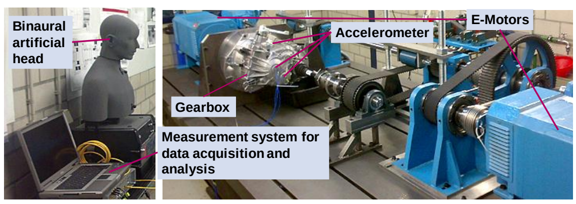


Fig. 4 Experimental investigation of gear rattle on universal transmission test bench [5]

In this study, the subjective assessment has been performed on a basis of the 2-layer-scale developed in such a way that the appearance as well as the evaluation of gear rattle noise from the expert point of view are attained [5]. This allows the allocation of the gear rattle noise appearance as well as the rating of disturbance level. As illustrated in Figure 5, the left box marked as “intolerable” stands for 1 and the right box with rating of 5 means “no disturbance”.

Gear rattle detectable ?	YES				NO
Raiting	1	2	3	4	5
Describtion	INTOLERABLE	STRONGLY ANNOYING	SMALL DISTURBANCE	LIGHT DISTURBANCE	NO DISTURBANCE

Fig. 5 2-layer-Scale for Gear Rattle Evaluation

5. Passenger Comfort Prediction

As shown in Figure 6, an ANN is applied to interconnect input data (objective parameters) with output data (gear rattle evaluation) by “trained” weighted network connections similarly to the way a test person makes his evaluation.

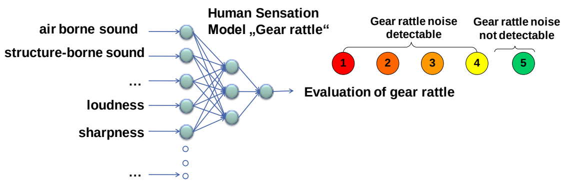
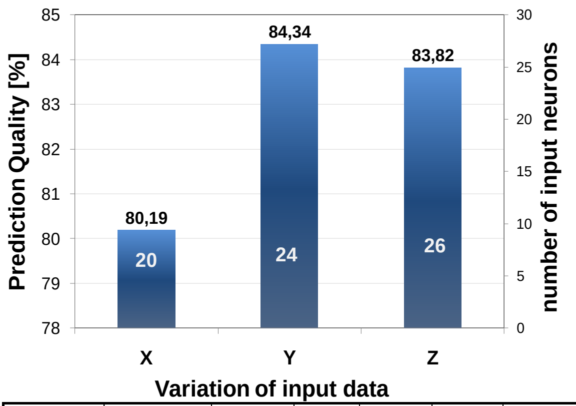


Figure 6. Example of network topology for gear rattle prediction

Commonly, there are several alternatives to set a network structure defining human sensation model. Parameters like network topology, training algorithm or training parameters are to be defined, so that the best performance for the current problem can be achieved. To reach a highest performance possible for each task, the appropriate network setting should be searched. The developed driver comfort modeling tool shown in Figure 3 allows users to build different network structures and find the most appropriate one for the given task. After a process of training, validation and verification, the modeling results consisting of the prediction quality G [6], the sequence of weight initialisation and the number of training epochs are attained.

Figure 7 presents a comparison of prediction performance attained from different network topologies due to different input parameters. In this case, the highest performance is achieved from the trained ANN with objective parameters derived from the A-weighted air borne sound pressure level, the structure-borne sound pressure at different gear housing positions, the captured duration of exposure and the calculated psychoacoustic parameters like the loudness [8] and the sharpness [8].



Alternative	A-weighted air borne sound pressure level (A)	structures borne sound pressure	duration of exposure	loudness	sharpness	roughness
X	x	x	x			
Y	x	x	x	x	x	
Z	x	x	x	x	x	x

Fig. 7 Prediction performance of ANN due to different objective data

In addition, a comparison of prediction performance attained from different training algorithms is shown in Figure 8. The highest prediction performance G of 84.34% is attained from the trained ANN of alternative Y with 26 input neurons, 6 hidden neurons and an output neuron corresponding to a predicted comfort assessment by using the Levenberg Marquardt algorithm.

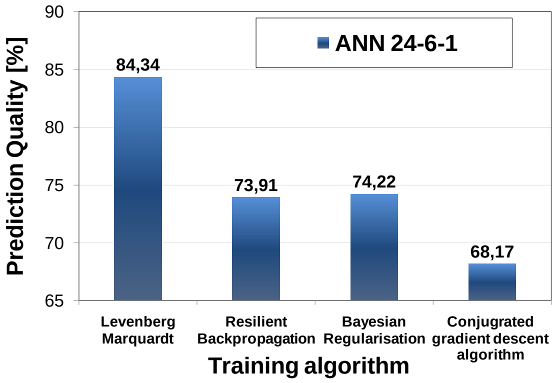


Fig. 8 Prediction performance of ANN due to different training algorithms

Examples in this section present the capability of the objectification tools and the elaborated ANN model to predict the assessment of gear rattle noise generating in different testing conditions. The variation of testing condition is carried out by removing different parts of the tested transmission, which causes different number of possible "rattling gears". Figure 9 demonstrates the comfort ratings resulted from each test with the subjective comfort ratings on the abscissa and the calculated ANN output values on the ordinate. If exact approximation was possible, all points would lie on the first bisecting line.

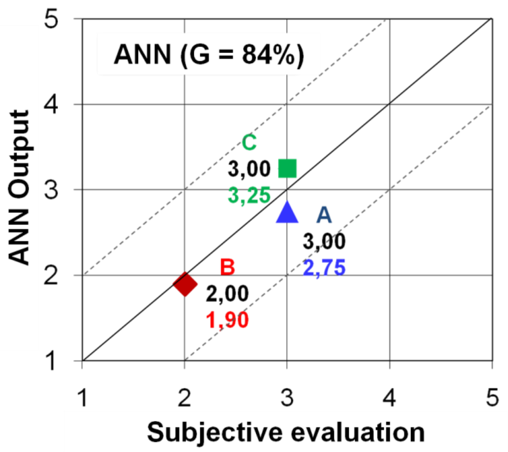


Fig. 9 Application of the driver model to estimate the subjective evaluation

By using the trained ANN with prediction performance G of 84%, a relatively good correlation of the subjective evaluation and the calculated values is achieved. Consequently, the appearance of gear rattle noise of all testing conditions can be predicted. Concerning the disturbance level, the same trends of comfort rating of rattle noises with "small disturbance" from test A and C are attained. On the other hand, the same ANN rated the generated noise from the test B as "strongly annoying". The results indicate that the presented approach can be effectively applied to predict the gear rattle evaluation based on generated data from the test bench.

6. Conclusion

The experimental results indicate that the ANN-based approach can be effectively applied to support the vehicle developemnt. The developed tools as well as the user-friendly interfaces enable the simplification of the passenger ride comfort prediction. Consequently, the attempt to find an appropriate network topology by variation of model parameters can be simplified.

This is carried out on the example of the prediction of the gear rattle noise generated on an transmission test bench. The human sensation modeling is carried out to assess the NVH property of a 5-speed manual transmission in view of gear rattle tendency and its disturbance level perceived by a human. The results of the human sensation modeling indicate that the selection of a suitable topology in views of input neuron type or used training algorithm has a significant effect on the prediction performance. An example of model application is demonstrated based on the investigated tests with different removed parts of the tested transmission. As a result, the good correlation of the subjective rating and the predicted evaluation of all testing conditions is attained. By means of the presented examples, the potential of the developed methodology to support the gear rattle investigation is demonstrated. To improve the NVH behaviour of the entire drive train and to reach a higher customer satisfaction, new concepts emerged from influencing drive train parameters can be examined. This allows the quality gates and process assurance between design, testing and production of new product.

7. Acknowledgement

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8. References

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