

THE USE ARTIFICIAL NEURAL NETWORK TO MODELLING OF A CAR POWER TRANSMISSION SYSTEM

ИСПОЛЬЗОВАНИЕ ИСКУССТВЕННОЙ НЕРВНОЙ СЕТИ ДЛЯ МОДЕЛИРОВАНИЯ СИЛОВОЙ ПЕРЕДАЧИ АВТОМОБИЛЯ

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Abstract: It was assessed in the hereby study that the use of artificial neural networks for modelling of the car power transmission system of constant power ratio change proves good in imaging interrelations occurring in the unit. With such a network the work of the whole system with power transmission, vehicle, driver and environment was modelled. Original in this method is the application of neural network to inversion model, which make possible the investigations by determined vehicle speed profile. It was shown that the neural network, trained on the base of measurements results, carried out in the a chassis test vehicle to a synthetic speed profile ECE + EUDC, not only good represents actual relationships but also makes possible prediction of selected work indexes at an arbitrary vehicle speed point.

KEYWORDS: POWER TRANSMISSION SYSTEM, VEHICLE, CONTINUOUSLY VARIABLE TRANSMISSION (CVT), ARTIFICIAL NEURAL NETWORKS

1. INTRODUCTION

Correct work of a power transmission system for the sake of a car motion properties, fuel consumption and emission of harmful substances, requires proper interaction of an engine and a power transmission system [2, 3]. The problem becomes especially significant in the case of automation of the power transmission system and particularly regarding the system of constant gear ratio change between the engine and drive wheels (Continuously Variable Transmission - CVT), examined in the hereby study. Great complexity of the entire power transmission system hinders simple determination of interrelations occurring there. It is necessary, then, to conduct appropriate tests consisting in searching for optimal configuration of the car power unit. It is connected with necessity of testing various variants, whereas required recurrence and explicitness of tests leads to situation that the tests are most often performed at a chassis test bed in conditions strictly defined for the set profile of a car speed [2]. However, conduct of such tests with the use of a car requires construction of a series of costly prototypes which extends time and increases costs of the tests.

For this reason works were launched on modelling of the car power transmission system of constant gear ratio change [2,3] enabling testing of the power transmission system by means of computer techniques. There are many different studies on improvement of calculation techniques of the car power transmission system. However, a new technique emerged in a past few years which enables usage of so called artificial intelligence including evolution algorithms, fuzzy logic and most of all artificial neural networks. It was assessed in the hereby study that the use of artificial neural networks for modelling of the car power transmission system of constant power ratio change proves good in imaging interrelations occurring in the unit [3].

2. ASSUMPTIONS OF THE METHOD

The suggested method is based on assumption that neural, which means with the use of an artificial neural network, modelling of interrelations resulting from work of the car power transmission system is possible. The Feed-forward back propagation neural network is most often used to model strongly nonlinear, multidimensional interrelations and it is more and more usable in classic applications. As it was proved by Duym and Reybrouck [1], the network is especially suitable to model the system where two

kinematic parameters are introduced at the entrance, such as change of X parameter in time and speed of its change dX/dt . Such a way of introducing the input signal gives the entire picture of its change in time.

On assumption that the speed profile completed by a car is the final result of the power transmission system work, it was decided to use a neural network to model the opposite interrelation as distinct from typical use of the network for modelling simple interrelations. Parameters characterising the motion state, the car linear speed signal and its longitudinal acceleration (fig. 1), were assumed as input quantities. Whereas, quantities characterising the power transmission system state, such as throttle inclination, engine rotational speed, used fuel stream or concentration of harmful substances in exhaust fumes later on, were output quantities.

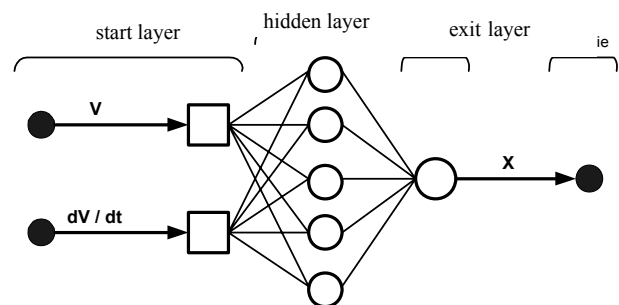


Fig.1. Structure of the used Feed-forward back propagation neural network

It was assumed that owing to reversing of a modelling task it would be possible to acknowledge the course of selected indicators characterising the power transmission system work while performing both synthetic and real speed profiles. In the hereby study the neural model that images work of the power transmission system controlled according to a specified algorithm consists of many neural networks as distinct from work [4]. The task of a single network is to image interrelations between the input and a single output signal, throttle inclination, rotational speed, fuel consumption or emission of harmful substance respectively.

3. TESTS CONDUCT MODE

Correct imaging of the power transmission system work mode with the use of neural networks requires appropriate choice of their

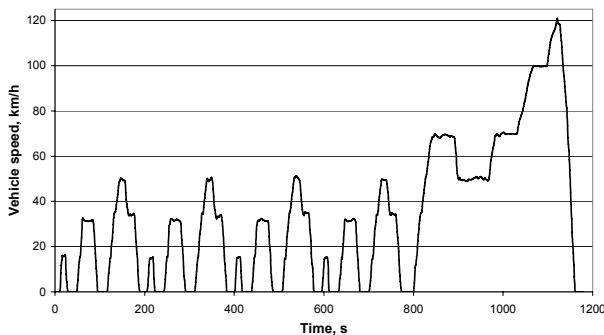
structure and quantities of parameters. Quantities of parameters are defined in so called network teaching (training) process. Measurement results acquired during the author's own tests performed at a chassis test bed according to a synthetic speed profile ECE + EUDC for a test car were used in the process of teaching of the neural network. The car *Fiat Punto II Speed Gear*, equipped with an automatic power transmission system with string continuously variable transmission, was used for the purpose. Basic parameters of the car were presented in table 1.

Table 1. Basic parameters of the examined car and its power transmission system

No	Parameter	Value, description
1.	Total mass of the vehicle	1200 kg
2.	Front area	2,12 m ²
3.	Engine	SI PFI
4.	Power /speed	59 kW / 5000 rpm
5.	Torque / speed	114 N·m / 4000 rpm
6.	Shape factor	0,32
7.	Transmission type	Fuji HyperM6
8.	Wheel radius	0,29 m
9.	CVT ratio interval	0,442 - 2,432
10.	Final drive ratio	4,647
11.	Engine controller	Bosch MPI ME7.3
12.	Engine displacement	1,242 dm ³

Tests were performed according to the Directive 70/220/EEC, amended with successive directives including the Directive 2002/80/EC from October 3, 2002 and the Regulation 83/05/ECE of the European Economic Commission, UN agenda, assumed to be used in Poland. The recorded speed profile acquired during tests at a chassis test bed was presented in figure 2. Results acquired for one of the programmes of controlling the "D" type power transmission system were presented in the hereby study. Presented courses of the speed profile are treated as the neural network input signals.

a)



b)

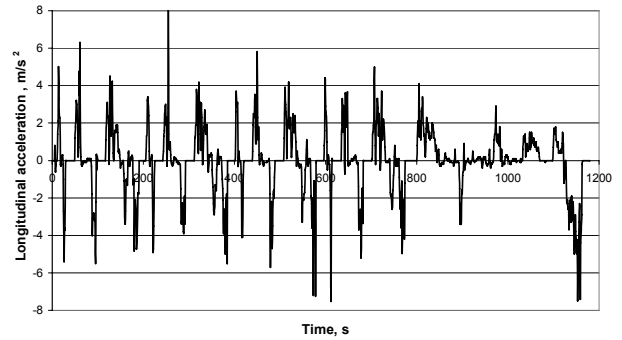


Fig.2. Exemplary profile of a neural network input signals recorded at a chassis test bed for ECE + EUDC course: a) linear speed b) longitudinal acceleration

Data referring to functioning of the power transmission system of constant gear ratio change were gathered for the sake of this speed profile. The gathered data enables determination of characteristics of the power transmission system in the function of the car linear speed and its longitudinal acceleration. Characteristics of engine rotational speed, choke valve draw, speeds of gear's driving and driven wheels, acceleration pedal position, driving force and emission of harmful substances were obtained. Characteristics of throttle inclination, engine rotational speed and fuel stream were analysed in the hereby study. They were selectively presented in figure 3.

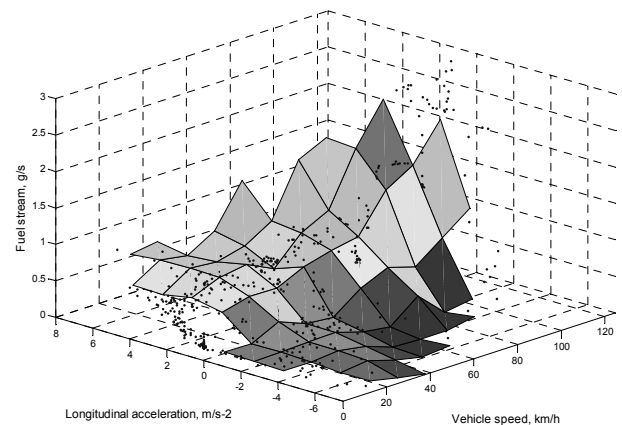


Fig.3. Exemplary characteristic fuel consumption of the power transmission system recorded during tests at a chassis test bed

4. NEURAL MODEL OF A POWER TRANSMISSION SYSTEM

The suggested neural, reverse model of a power transmission system was prepared in *Matlab/Simulink* environment with the use of *Toolbox Natural Network* library. Designed neural networks were trained on the basis of existing measurement data gathered during tests at a chassis test bed with the use of the algorithm of controlling the power transmission system that was defined in advance. Commands *trainlm* and *trainrp* were used for training *Feed-forward back propagation* networks. The function *trainlm* consists in optimisation of an output parameter according to significance and quantities of input parameters, and it was concluded by Levenberg-Marquardt [1]. For comparison purposes the function *trainrp*, concluded by Riedmiller and Braun, was also used. This is a gradient function of optimisation of a network parameters. The artificial *Feed-forward back propagation* neural network is a network of sigmoid function of neuron activation. The error of network training process with different structure and

different training function of the network and for the same parameters of the power transmission system, was presented in table 2. Engine rotational speed was an input parameter assumed in this case for which the error of imaging is sometimes below 1 percent.

Table 2. Training error of Feed-forward back propagation network for engine rotational speed

	Results of calculations				
	trainlm 2x9x1	trainlm 2x9x5x2	trainrp 2x9x1	trainrp 2x9x2x1	trainrp 2x9x5x1
Relative error, %	0.781	2.236	4.279	0.674	0.647

Further calculations were focused on *trainlm* training function for network structure (2x9x1) and *trainrp* function for structure (2x9x5x1). The first network has one hidden layer and the second one has two of them.

The presented relative error was calculated from the following interrelation (1):

$$(1) \Delta x = \frac{\sum_{i=1}^n (x_p - x_s)^2}{\sum_{i=1}^n (x_p)^2}$$

Where x_p – result for existing measurement data, x_s – result of imaging with the use of artificial neural networks.

Value of the above-presented relative error (1) stands for a sum of square of profile approximation errors acquired with the use of a neural network compared to a sum of squares of values measured during course research. Figure 4, where the relative error was compared graphically, enables qualitative evaluation of imaging. However, usability of the model will be examined by verification of input data outside the set used in the training process. As it was proved in the study [3, 4], excellent imaging of the power transmission system parameters during the teaching process does not always prove usability of a certain network structure and teaching function during the network operation.

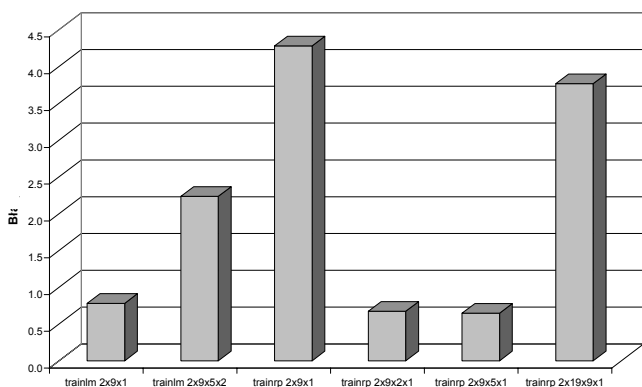


Fig.4. Comparison of an error value for various network structure and various training function

Both excessively expanded as well as wrong teaching function may lead to oscillatory working of the model as a result of its overtraining or faulty adaptation.

5. MODELLING OF THE POWER TRANSMISSION SYSTEM WITH THE USE OF ARTIFICIAL NEURAL NETWORKS

The trained neural network was used for approximation of selected parameters of the power transmission system of constant gear ratio change for arbitrarily assumed speed of a car motion (fig.5).

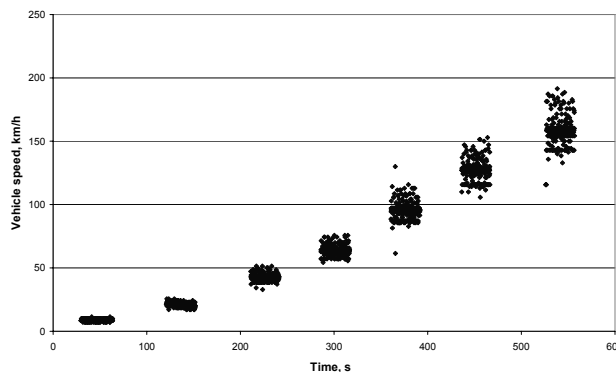


Fig.5. Assumed speeds of a car motion used for verification of a neural power transmission system

Neural model of the power transmission system was verified for a set speed of a car motion, from 20 to 120km/h. Results of the model verification were presented in figure 6. Changes in parameters of the power transmission system, such as throttle inclination and fuel consumption in a function of a car linear speed for existing motion conditions, were presented with a full line. Whereas, points in the form of rectangles and triangles were results of operation of the neural model of the power transmission system. Rectangles stand for *trainlm* training function and triangles result from approximation of the network with *trainrp* function.

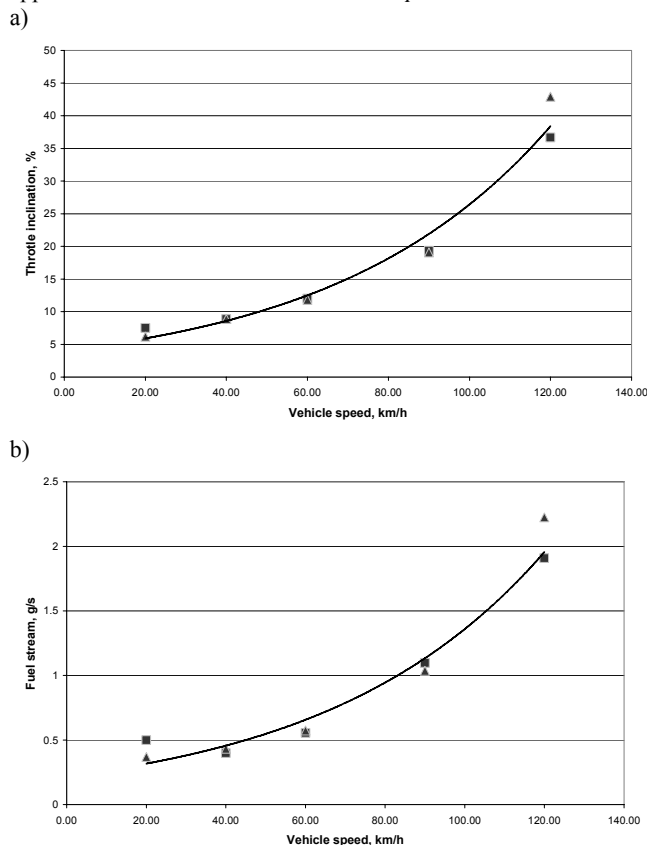


Fig.6. Results of operation of the neural model of the power transmission system: a) throttle inclination, b) fuel stream

Parameters of the power transmission system acquired by means of approximation of the network were compared to a curve of existing motion conditions. Their pooled error was determined with the use of interrelation (1), in this case the error of imaging is below 1.5 percent for all tested parameters. While comparing results of approximation with the use of both training functions according to (1) criterion, it appears that the network of structure (2x9x1) trained with *trainlm* function shows better imaging of the power transmission system.

6. CONCLUSION

The neural reversed model of the power transmission system, as suggested in the hereby study, credibly images characteristic interrelations resulting from work of the examined power transmission system of constant gear ratio change and its controlling algorithm. The method of modelling the power transmission system, presented herein, can be also used for modelling issues referring to harmful substances emission. The method ensures better imaging of the neural model of the power transmission system for the used training function by Levenberg-Marquardt. It was proved that measurement results collected during performing tests at a chassis test bed are sufficient for a successful training of neural networks which constitute the discussed model. The formulated and verified model can be further used for computer tests of working manner of the automated power transmission system at a random, set speed profile (including existing one). A significant advantage of the method is that the knowledge acquired by the neural network stems from existing conditions of the power transmission system work. Moreover, selected parameters of the system can be repeatedly determined and stand or exploitation tests are not necessary. The above-mentioned advantages imply that the suggested method can be especially suitable for assessment of algorithms that control a car power transmission system.

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REFERENCES

Journal articles

- 1 DUYM, S. AND K. REYBROUCK, *Physical Characterization of Nonlinear Shock Absorber Dynamics*, European Journal Mech. Eng., 1998, Vol. 43, No. 4, 181-188
- 2 JANTOS, J. 2001 *Control of the Transmission Ratio Derivative in Passenger Car Powertrain with CVT*, SAE Transactions, Journal of Passenger Cars – Mechanical Systems, SAE, 1277..1284, 2001
- 3 MAMALA, J., J. JANTOS, *Exploitation characteristics of a engine car*, Journal of Kones, 31th International Scientific Conference on Internal Combustion Engines, 2005, 142-148

Conference articles

- 4 LAM SARAH, S. Y., E. SMITH ALICE. *Process Control of Abrasive Flow Machining Using a Static Neural Network Model*, Proceedings of the Artificial Neural Networks in Engineering Conference (ANNIE '98), 1998, St. Louis, ASME Press, New York