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Prediction of reliability of vehicle tire with use of Neuro-fuzzy networks

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ABSTRACT

In this paper, one of the artificial intelligence techniques called networks for prediction of reliability of the tire is neuro-fuzzy network. At first key indices which are effective on reliability of tire are identified and then some rules have been designed and applied for system training with use of experts' views. ANFIS system implements Takagi –Sugno fuzzy system as a system and inference and deduction of the system are mixed and an efficient tool is provided for simulating a nonlinear mapping. In the performed simulations, some 4-input networks are different with membership functions and have been studied in different iterations for prediction and finally the model which had high predictability was selected as optimal model.

Introduction

Smart systems have many applications as one of the modern tools in different fields of sciences for optimization and prediction. These evolutionary achievements in information technology have allowed processing of the information in parallel. Human being has tried to imitate brain mechanism to discover the secrets of creation in order to find this complex architecture of creation leading to development of smart systems.

This major change in human knowledge led to an important achievement in science and scientific methods and has been used as scientific complex tool to solve problems of human beings. This tool has been mostly applied in reliability and many progresses were made in this field.

In this paper which is done with use of one of the advanced techniques in this field i.e. neuro-fuzzy networks, we try to predict reliability of tire in passenger cars. Neuro-fuzzy networks –based models are able to predict variable behavior property and desirably and can predict its future behavior. Our goal is to model a nonlinear prediction for reliability.

With regard to promotion and development of automotive industries and competitive atmosphere in this industry, important issues such as useful life of the car and safety were raised. In this regard, reliability entered automotive industry as an important index which can answer some of the above cases. Reliability is defined as the possibility that a component or system performs its assumed tasks properly under defined conditions and at special time.

Material and methods

Fuzzy deduction system

Fuzzy set theory is a relatively new mathematical theory which was presented by Iranian student, Professor Lotfi Asgarzadeh alias Zadeh, in order to find mathematical models which are compatible with human thinking and deductive manner as well as natural and real models. Word fuzzy means confused and unspecified and is used for description of unreal and unspecified phenomena. A fuzzy system is a system based on fuzzy rules of if-then which images input space on output space with use of fuzzy variables and fuzzy decision making. In summary, starting point of a fuzzy system design is to find a set of if-then rules from knowledge of the experts or the studied knowledge.

Artificial neural network

Main idea of neural networks is human brain. At present, scientists try to have access to information processing by researching function of human brain and algorithm and modeling of its internal mechanism. Main component of these models is information processing unit which simulates function of neural neurons which are called neural neuron.

Although it seems that a neuron is a simple entity, neurons can be connected to each other in a system structure. More than 40 traits of natural neurons have been recorded in information processing. More information about neurons and neural system is presented in detail.

Human brain ⟶ neurons ⟶ ANN

It is a system which has been created by connecting some factors to each other. It is inspired by biological study of neural systems of living creatures especially human being. On the other hand, neural networks try to make the machines which act like human brain. In order to make such machines, some components which act like biological neurons are used. Function of a neural system is as follows: When an input model is defined for it, it should be able to produce an output model (Toloie Eshlaghy, 2008).

Figure 1 shows simple scheme of a neural system model. As figure 1 show, each neural system has been composed of three layers including: input layer, output layer and hidden layer.

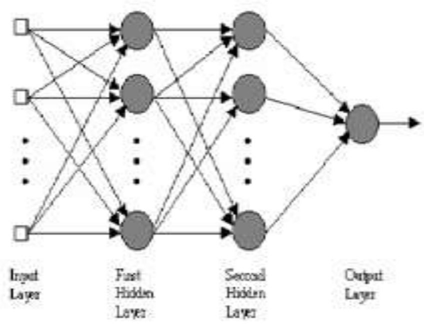

Figure 1: simple scheme of a neural system model

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There are some of these layers on each one of these layers as processing units which are connected to each other. The operations which are performed in each neuron include: 1-neuron gathers all inputs which has reached cell , 2-it deduces threshold value of the neuron from it , 3-it passes a moving function or activity function , 4-outout of neuron is obtained. During some operations, error will be minimized. In order to transfer outputs of each layer to the next layer, moving functions are used. Moving functions include sigmoid, linear and threshold functions. Generally, artificial neural networks are divided into two groups: FEED FORWARD and FEED BACKWARD.

- **Comparative neural networks based adjustable fuzzy systems (ANFIS)**

The most important part of a fuzzy system is proper definition of if-then rules. Different methods such as direct use of human knowledge, clustering method and neural-fuzzy method are used for this purpose. Neural- fuzzy networks method has been converted to very powerful tools which have different applications with reliance on combination of learning power of neural networks and logical function of fuzzy systems. Different structures have been suggested for implementation of a fuzzy system by neural systems of which the most powerful one is ANFIS structure which has been innovated by Jang (Jang, 1995).

○ **ANFIS structure**

ANFIS has good efficiency in education, construction and classification and its advantage is that it allows extraction of fuzzy laws from numerical information or specialized knowledge and makes a rule-basis. In addition, it can adjust complex conversion of human intelligence to fuzzy systems. Main problem of ANFIS prediction model is need for time of structure training and determination of parameters. For simplification, it is assumed that deduction system has two inputs of x and y and an output of f. for a Takagi –Sugno fuzzy model of the first grade, one can mention the sample law set with two laws of if-then:

$$Rule1: if\ x\ is\ A_1\ and\ y\ is\ B_1\ then\ f_1 = p_1x + q_1y + r_1$$
$$Rule2: if\ x\ is\ A_2\ and\ y\ is\ B_2\ then\ f_2 = p_2x + q_2y + r_2$$

Where P_i،q_i ،r_i (i=1, 2), linear parameters are first grade in Tally section of Takagi-Sugno model. The following figure shows scheme of ANFIS structure.

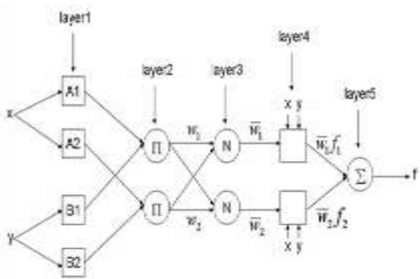

Figure 2- ANFIS structure

ANFIS structure includes five layers:

First layer, input nodes: each node in this layer is equivalent to fuzzy set. Parameters of each node determine membership function equivalent to fuzzy set of that node.

$$O_{1,i} = \mu A_i(x), \qquad for\ i = 1,2$$
$$O_{1,i} = \mu B_i(x), \qquad for\ i = 3,4$$

Where, x and y are non fuzzy inputs to nodes I, A_i and B_i(small, large etc) , language labels which are specified with suitable membership functions of μ A_i and μB_i. Here, Gaussian and bell-shaped structures are used. For example, as bell-shaped membership function is used for mentioning membership function equivalent to fuzzy set, we have:

$$\mu A(x) = \frac{1}{1 + \left| \frac{x - c_i}{a_i} \right|^{2b_i}}$$

Where $\{a_i,b_i,c_i\}$ are parameters set? Parameters of this layer are called Premis Parameters. The following figure represents effect of changes in parameters {a,b,c } in bell-shaped function.

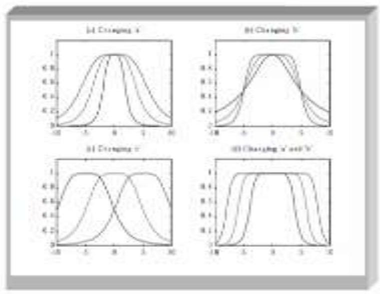

Figure 3-effect of changes of parameters on bell-shaped membership function

The second layer, rule nodes: output of this layer is multiplication of input signals which is equivalent to if part of the rules. In fact, each node of this layer calculates activity degree of a law.

The third layer, middle nodes: i^{th} node of this layer is ratio of i^{th} law activity to sum of activity degrees of all laws. In fact, output of this layer is the normalized form of the previous layer.

The fourth layer, result nodes: function of the fourth node calculates i^{th} distribution layer of the law to total output and is

$$O_{2,i} = w_i = \mu A_i(x) * \mu B_i(y), \quad i = 1,2$$

defined as follows:

$$O_{4,i} = \overline{w}_i f_i = \overline{w}_i(p_i x + q_i y + r_i)$$

$$O_{3,i} = \overline{w}_i = \frac{w_i}{w_1 + w_2}, \quad i = 1,2$$

Where $\{p_i ,q_i , r_i \}$ is comparative parameters of this layer. These parameters will be called result parameters. The fifth layer, output nodes: each node in this layer calculates final output as follows: (number of nodes equals to the number of outputs)

$$O_{5,i} = \sum_i \overline{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}$$

The following figure shows fuzzy logic trend in the first grade Sugno system. As observed, output of each law is final value; therefore, one can calculate final output through weight average of different laws outputs and prevent from time consuming non-fuzzy stage.

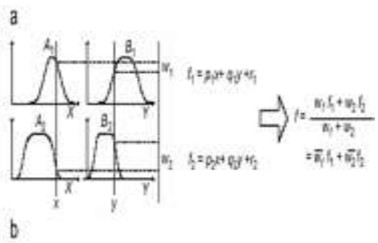

Figure 4-fuzzy logic trend in first grade Sugno system

We have successfully implemented a fuzzy system so that it can have learning ability. Main training method of ANFIS is error back propagation method. In this method, error is distributed toward inputs with use of error descending trend and parameters are corrected. This training method is exactly like error back propagation method used in neural systems.

Variables selection

With studies done on reliability of tire of passenger car, variables effective on this field were identified. These variables include speed, weight applied to each tire, tire air , balance of wheels, adjustment of steering wheel, passed distance etc. In order to identify variables which are of the most importance, the experts were asked to make comment on this field with use of Delphi technique. They include: speed, passed distance, weight applied to each tire, and tire air.

Design an ANFIS system for prediction

Neural systems and neural-fuzzy systems are determined optimally with trial and error. Therefore, in order to have access to optimal model, we designed some different models and compared their predictability with each other. Different models are obtained as result of change of number and type of membership functions which will lead to differences in result of prediction. In this paper, we determine the number of membership functions for design of the model and we should note that there is no specified rule for determination of optimal number of membership functions. Considering low number of membership functions causes to decrease complexity of the model and reduce time spent for learning. Instead, obtained results will be weak results. With increase in the number of membership functions, the more the precision of membership function, the more the complexity of model and time of learning. With regard to the above facts, the number of membership functions has been considered to be 5 for each one of the input variables with regard to views of the experts. Language variables considered for each one of the model inputs are as follows:

Speed: {very low, low, medium, high, very high}

Weight applied to each tire: {very light, light, medium, heavy, very heavy}

Distance passed: {very low, low, medium, high, very high}

Tire air: {very low, low, suitable, high, very high}

Language variables considered for each one of the model outputs are as follows:

Reliability: {very low, low, medium, reliable, very reliable}

Reference for these language variables is as follows:

U={1,3,5,7,9}

Design membership functions

In fuzzy modeling, one of the most important stages is design of membership function. There are different types of membership functions: triangular, trapezoid, bell etc each having special characteristics. In this paper, 3 different models are studied and compared with Gaussian, bell shaped and trapezoid membership functions to select membership function for model leading to better results. The first model which we design for prediction is ANFIS system with four inputs which are introduced under titles of Input 1 to input 4 to the network. For each input, we consider 5 membership functions which are composed of 625 if –then laws of Takagi-Sogno fuzzy system.

System training with the related models

In this section, we observe results of system education with the models mentioned as tables and diagrams which are given as follows.

Learning trend of the system is observed with this model in the following diagram:

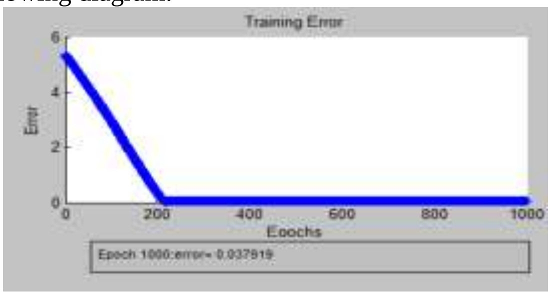

Figure 5- learning trend of the system in the first proposed model

In the second proposed model, bell shaped membership functions were used to observe the obtained results:

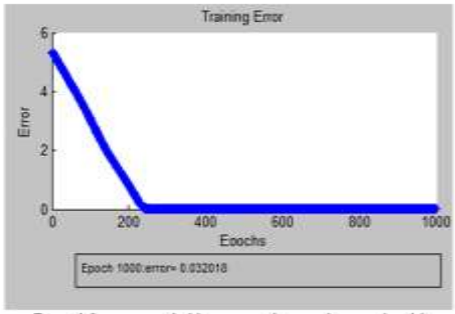

Figure 6 -Learning trend of the system in the second proposed model

In the third proposed model, trapezoid membership functions were used to observe the obtained results:

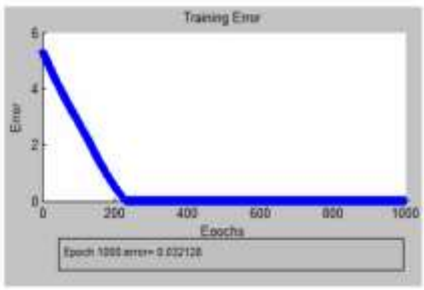

Figure 7 -learning trend of the system in the third proposed model

Results obtained from application of different models of membership functions for inputs are observed and studied well as the above table. By comparing these models, we can find that training error in each system reaches its minimum in iteration 1000 and when the membership functions are bell shaped, error will be the minimum and when the membership functions are Gaussian , it will be the maximum (it is necessary to note that error back propagation algorithm has been used for system training). Therefore, the proposed model is the second model. After completion of system learning, one can observe 3 D representation of output of neuo-fuzzy model against two inputs.

We this diagram, we can observe output of the system against the first and second inputs, first and third inputs , first and fourth inputs , second and third inputs , second and fourth inputs and third and fourth inputs and study their effect on output of the system. The diagram represents 3D image of this system against the first and second inputs.

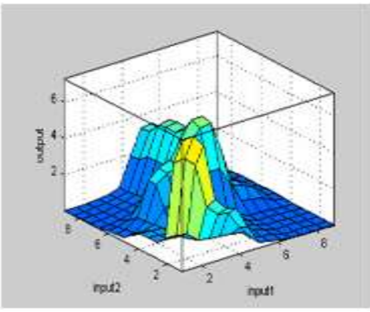

Figure 8 - 3D diagram of neural-fuzzy model output against the first and second input

Issues about validity of the model

In order to study authenticity of the model, two methods were used:

Limit analysis

In order to validate the research model in this method, if our model is logic when all conditions of the inputs are not suitable i.e. at the worst conditions, it will expected that output of the model be unreliable and when the inputs conditions are suitable , it will be expected that it be reliable. In fact, effect of input variables on output variable is studied in two interval ends.

First state: considering the worst conditions when inputs of model include: Very high speed, very long distance passed, tire air (very low or very high), weight applied on very heavy tire. As a result, model output = very unreliable.

Figure 8- When inputs are in the worst conditions.

As shown in the figure, output is 1 which relates to very low reliability.

Second state: considering the best conditions when inputs of model include: Very low speed, very short distance passed, tire air (suitable), weight applied on very light tire. As a result, model output = very reliable

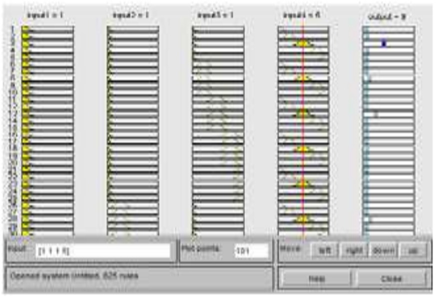

Figure 9- When inputs are in the best conditions.

As shown in the figure, output is 9 which relates to highly reliable verbal variable.

Study of different random conditions results

In reduction method with use of neural system, data is divided into two groups. The first group which is called training data will be used for system training and the second group which relates to test data will be used for testing prediction error and with use of the first group data. For this reason, we consider 30 random states as the model input and one output is predicted by ANFIS for each state and compared with real output and **Prediction error will result**.

If error resulting from prediction is below α, authenticity of the model outputs will be confirmed, otherwise, it will be rejected. α rate depends on sensitivity of analyst to accuracy of the model that is the smaller this value , the more the accuracy of the model. In the said model, α =0.15 has been considered. Results obtained from system test are specified in the following diagram.

In the diagram, the data which is marked with +, real data and the data which is marked with * is data resulting from prediction. As shown in the diagram, results of prediction are very close to reality indicating high reliability of the model. Error of system test is calculated to be 0.12187 which is acceptable.

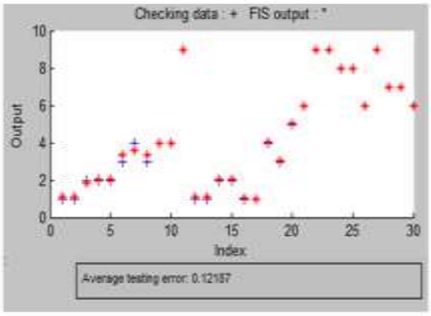

Figure 10 - System test

Conclusion

With regard to the performed analysis, research results include:

Modeling with use of neural –fuzzy systems can have very high flexibility. Modeling with this method is varied and the most important factors effective on this variety are the number of input variables and number of selective membership functions for each input. On the other hand, this variety causes problem in recognition of optimal method, therefore, one can test all kinds of models until the related Hardware can process the model on the one hand and the number of input data is compatible with the number of the input variable on the other hand. But there is optimal medium limit for the number of variables and the number of membership functions for each variable. The next results of this research are generalization of this method for prediction of other parts of vehicle.

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Table 1- table of language variables of model parameters

Numbers fuzzy variable	1	3	5	7	9
Speed	Very low	Low	Medium	high	very high
Weight	Very light	Light	Medium	high	very high
Distance	Very low	Low	Medium	high	very high
Inflation air	Very low	Low	Suitable	high	very high
Reliability	Very Low reliability	Low reliability	Relatively reliable	reliable	Very reliable

Table 2- table of the first model results

Learning error with 1000 iterations	Learning error with 600 iterations	Learning error with 300 iterations	Type of membership function	Number of membership functions for each input	Number of input variables
0.37919	0.3823	0.039473	Gaussian	5	4

Table 3- The second model results

Learning error with 1000 iterations	Learning error with 600 iterations	Learning error with 300 iterations	Type of membership function	Number of membership functions for each input	Number of input variables	Learning error with 1000 iterations
0.032018	0.03230	0.03230	0.03253	Bell	5	4

Table 4- the third model results

Learning error with 1000 iterations	Learning error with 600 iterations	Learning error with 300 iterations	Type of membership function	Number of membership functions for each input	Number of input variables
0.032129	0.032169	0.032199	Trapezoid	5	4