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Adaptive network for fuzzy inference system, internal combustion engine, engine testing

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AN ADAPTIVE NEURAL NETWORK FOR DIESEL ENGINES TESTING

An adaptive neural network for fuzzy inference system (ANFIS) for testing internal combustion engines (ICE) is presented. The proposed ANFIS automatically obtains fuzzy rules for controlling ICE at the testing. Number of layers and theirs neurons was designed. The ANFIS was developed using MathWorks MatLab. Experimental results indicated that ANFIS has satisfactory precision for engine testing.

ADAPTACYJNYCH SIECI NEURONOWYCH DO BADANIA SILNIKÓW DIESLA

Artykuł przedstawia zastosowanie rozmytej sieci neuronowej do badania silników spalinowych. Sieć ta w trakcie badania silnika spalinowego w sposób automatyczny generuje przyporządkowane mu rozmyte reguły wnioskowania. Liczba warstw oraz odpowiadająca im liczba neuronów w każdej warstwie została dobrana w sposób eksperymentalny. Siec została zaimplementowana w oparciu o pakiet Matlab. Przeprowadzone eksperymenty wykazały zadowalającą efektywność działania sieci.

1. INTRODUCTION

Expansion of production of automobiles, tractors and theirs growing role at modern society's satisfaction of needs brings to persistent upgrade of engines.

Rated engine power, efficiency, toxicity and other properties such as reliability and operating life is assessed from engine test at the stand. At the present time all new produced engines is testing at the stand. The essence, volume and number of tests are defined by their purpose. Engine testing is regulated by state standard specifications.

Tests are the final stage of difficult process of creation and modernization of internal combustion engines. So, all new created, modernized and serial internal combustion engines are putted to various kinds of tests.

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Tests allow to estimate quality of the engine and to compare its indicators to indicators of other engines. Also tests allow to define technical, economic, ecological and other indicators of the engine and to establish conformity of these indicators to standards and specifications. Tests reveal features of the engine. Comparison of test results for various types of engines allows to estimate efficiency of design features, quality of manufacturing or engine technical condition.

Nowadays engine tests represent the difficult and labor-consuming technological process a little different from an experimental research. Therefore the automated test systems for ICEs are created.

At studying of the engine and construction of its mathematical model, there is a problem of reception of the law of functioning of object in whole or its some parts. More often the model cannot be constructed on the basis of known laws and the kind of the law of functioning of object is unknown. In such cases the decision of this problem can be the choosing the significant input and target characteristics and carrying out of a series of experiments, for data organization about object functioning in special cases.

For the decision of the given problem a hybrid neuro-fuzzy network for adjustment of fuzzy system may be used.

An engine testing program includes to itself the description of ICE working parameters. The goal of engine automated testing system (EATS) consists in supporting the preset parameters of engine testing.

EATS involves a knowledge base for engine testing, which consists of fuzzy rules. The ANFIS produces fuzzy rules for specified quantity of input and output parameters. For obtaining a knowledge base it is necessary to learn an ANFIS. At the learning process the ANFIS will obtain fuzzy rules for knowledge base. Then fuzzy rules can be use to engine control at the testing.

2. ANFIS FOR ICEs TESTING

2.1. An input and output parameters definition for engine testing

Input parameters have presented at test program as changing of their values by time:

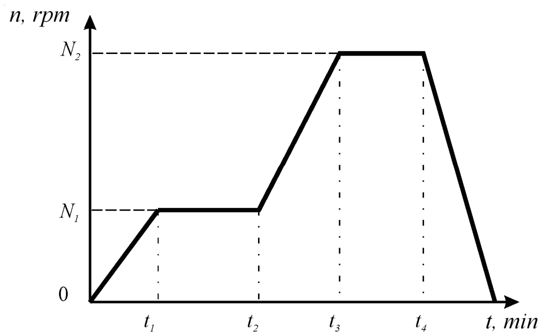

Fig. 1. First input parameter

Input variables are specified as:

- engine speed, n, rpm;
- torque, M_H, N-m;
- fuel expenditure at hour, G_T, kg/hour.

The engine testing program is specified by national standards. At Russian Federation this standard is called GOST 15995-80 “The tractor and combine diesel engines. Stand testing methods”. This standard orders to test engine at steady-state conditions. The fuel expenditure must be choosing as small as possible. The engine testing time with concrete values of each parameter are specified at testing program.

The all testing parameters changing by time can be presented as a table:

Tab. 1. Input parameters changing by time

№	**Testing time, min.**	**n, rpm**	**M_H, N-m**	**G_T, kg/hour**
1	Start engine			
2	0-15	600	73	18,6
3	15-30	800	90	19,5
4	30-45	1000	110	24
5	45-60	1200	123	30
6	60-75	1400	125,8	35
7	75-90	1600	123	41
8	90-105	1800	115	46
9	105-120	2000	112,5	50
10	120-135	2200	110,8	53,5
11	135-150	2400	110	57,5
12	150-165	2450	110	59,2
13	165-180	600	73	18,6
14	Stop engine			

The control action for diesel engine is moving of fuel booster pump’s rack – *h*, mm. By changing *h*, the EATS supports preset engine’s working regime.

2.2. First layer of ANFIS

For receiving a learning sample it is necessary to test a real engine. The results of KamAZ 740-30-260 diesel engine testing are showed at Tab. 2.

Tab. 2. The results of KamAZ 740-30-260 diesel engine testing

First input parameter	Second input parameter	Third input parameter	Output parameter
600	73	18,60	0
935	101	23,10	5
1155	120	29,50	10
1355	126	35,90	15
1555	125	41,80	20
1760	118	46,90	25
1960	113	50,80	30
2165	111	54,20	35
2340	110	57,10	40
2425	110	58,90	45
2450	110	59,40	50

There is may not be the all possible values of each parameter. Therefore the each parameter must have its changing range (Tab. 3).

Tab. 3. Range of parameters

№	Parameter	Range
1.	Fuel booster pump’s rack, h	0-50 mm
2.	Engine speed, n	600-2450 rpm
3.	Torque, M_H	73-126 N-m
4.	Fuel expenditure, G_T	18,6-59,4 kg/hour

For each input parameter fuzzy sets must be specified. A big quantity of fuzzy sets improves control action precision. But more quantity of fuzzy sets increases a size of knowledge base. A big size knowledge base needs a more quantity of computer resources.

For engine speed – 3 membership functions; for torque – 2 membership functions; for fuel expenditure – 4 membership functions are specified (Fig. 2).

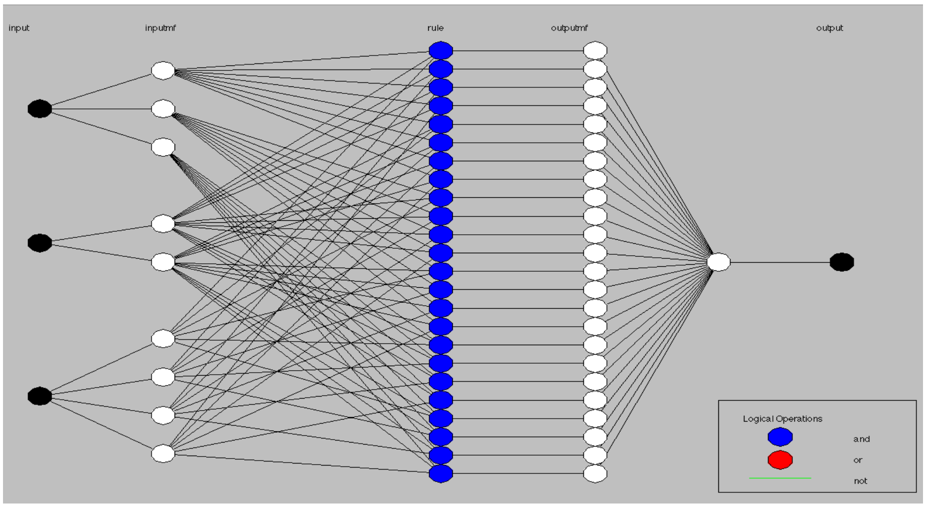

Fig. 2. First, second and third layers of ANFIS

The each neuron of the first layer determines the degree of belong to fuzzy set for input parameters. Any membership function of fuzzy set may be realized using the elemental neural structure (Fig. 3).

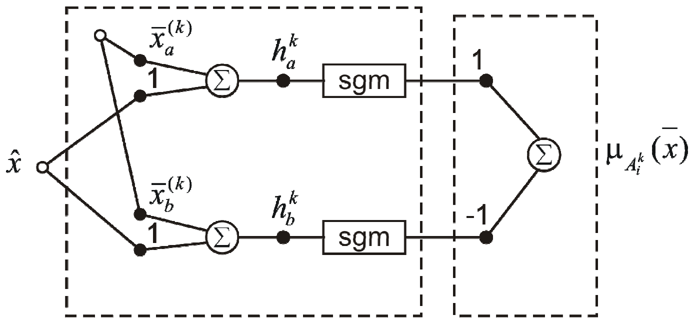

Fig. 3. Neural structure for neurons of first layer

This structure evaluates the degree of belong for preset value of parameter:

$$\mu_{A^k}(x) = f_a^{(k)}(x) - f_b^{(k)}(x), \tag{1}$$

where

$$f_a^{(k)}(x) = \frac{1}{1+\exp[-h_a^{(k)}(x+\bar{x}_a^{(k)})]}, \tag{2}$$

$$f_b^{(k)}(x) = \frac{1}{1+\exp[-h_b^{(k)}(x+\overline{x}_b^{(k)})]}. \quad (3)$$

The weights of links ($\overline{x}_a^k$, $\overline{x}_b^k$, $h_a^{(k)}$, $h_b^{(k)}$) describes the location and curvature of two membership functions (Fig. 3).

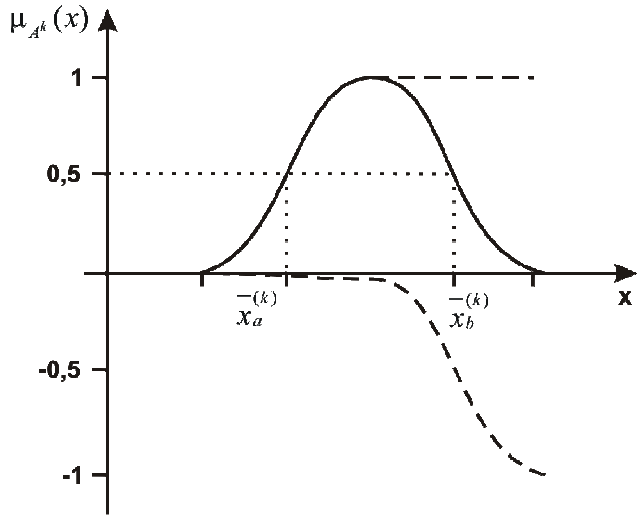

Fig. 3. Two membership functions and result of their subtraction

Before injection each parameter must be normalized (Tab. 4).

Tab. 4. Normalized parameters

First input parameter	**Second input parameter**	**Third input parameter**	**Output parameter**
0,24	0,58	0,31	0
0,38	0,80	0,39	0,1
0,47	0,95	0,50	0,2
0,55	1,00	0,60	0,3
0,63	0,99	0,70	0,4
0,72	0,94	0,79	0,5
0,8	0,90	0,86	0,6
0,88	0,88	0,91	0,7
0,96	0,87	0,96	0,8
0,99	0,87	0,99	0,9
1	0,87	1	1

3. CONCLUSIONS

The divergence between experimental and rated graphs is explained by learning sample what has been chosen for ANFIS learning. For input ANFIS parameters are chosen:

- engine speed;
- torque;
- fuel expenditure at hour.

For output ANFIS parameter is chosen the moving of fuel booster pump's rank. The control action ratio error for engine speed is 4%. This error meets the requirements of GOST 15995-80. ANFIS learning at another learning sample will increase the precision of control action.

4. REFERENCES

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