ESTIMATION OF THE AIR-FUEL MIXTURE RATIO, BASED ON THE SIGNAL FROM THE OPTICAL FIBRE INTERFERENCE SENSOR, USING ARTIFICIAL NEURON NETWORK

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Abstract

There are a lot of definitions for the „intelligence", however according to the Prof. Jan Strelau the intelligence can only be attributed to a human. Thus, programs or devices thought out by a man can only imitate intelligence. The phras - artificial neuron networks describes programs or electronic devices running mathematical models of pseudo parallel data processing, consisting of many interconnected neurons imitating actions of biological structures of a brain. The neuron networks are used, amongst other things, for the sound and picture recognition, for the predicting, objects classification, data analysis, matching and optimisation.

This work describes construction of an artificial neuron network in use. The design and operation principles of a fibre optics interference side - hole sensor are presented for the pressure measurement inside the engine combustion chamber and the data range used during a „teaching" process of an artificial neuron network. The gas pressure in the engine combustion chamber carries a lot of information which can be used to characterize the working cycle process. Knowing the pressure curve it is possible to estimate the air-fuel mixture ratio, detect lack of mixture ignition in the cylinder, explosive knocking combustion, unevenness of the following engine working cycles and even estimate the combustion chamber walls' temperature. Construction of a sensor ensures high pressure sensitivity with a low temperature sensitivity. The measuring head has been placed in the threaded opening made in the engine cylinder head.

The paper presents results for two examples of the air-fuel mixture ratio estimations using already developed network. In the first example the measurement data, used during the network educating process, has deliberately been changed at random by 3%. In the second case, the original measurement data has been used. This allowed the initial assessment of the measurement noise influence on the mixture content estimation using fibre optics pressure sensor, in the combustion chamber, combined with the artificial neuron networks. The mixture content estimation results, together with the data obtained during measurements using wide range oxygen sensor, which are presented on the diagram, allowed the conclusions to be formulated.

Keywords: *transport, fibre optics sensor, neuron networks*

1. Introduction

There are a lot of definitions of the „intelligence". According to the Prof. Jan Strelau the intelligence is a theoretical creation referring to relatively constant internal conditions of a human, determining effectiveness of the actions requiring learning processes. These conditions are formed as a result of interaction between genotype, environment and man's own activity. According to this definition the intelligence is attributed to a man. Other definitions attribute the intelligence also to animals, and insects, at the same time excluding electronic devices, together with computers, as not processing data for their own needs. Thus in the article there will be an „artificial intelligence" and „artificial neuron networks" phrases used as imitating biological, natural counterparts.

The phrase - artificial neuron networks describes programs or electronic devices running mathematical models of pseudo parallel data processing, consisting of many interconnected neurons imitating actions of biological brain structures. Neuron networks are used, amongst other things, for the sound and picture recognition, for the predicting, objects classification, data analysis and optimisation.

In order to verify the possibilities of using artificial neuron network for the evaluation of the air-fuel mixture ratio of a spark ignition engine, the data from the test engine has been registered. The engine used, was a four cylinder C20LE engine installed on the test bench of Lublin Technical University. Pressure measurement, inside one of the cylinders, has been taken using side - hole fibre optics interference sensor and piezzoquartz sensor. At the same time, the indications of a wide scale oxygen sensor were registered. The crank shaft revolutions of an unloaded engine working rpm was 2000 rev./min.

2. Structure of an artificial neuron network

Individual interconnected neurons form neuron network. Depending on the number and type of connection, new kinds of networks are created, the most important ones being, the monodirectional, recurrent and cellular networks [9, 7]. Multilayered structure diagram of the monodirectional artificial neuron network is presented in Figure 1. Such network was used during the experiment presented. The signals flow within the network takes place from the entry to the exit. The neurons are grouped in layers, and connections concern only the neurons in the adjacent layers. Each connection has allocated degree of significance (weight), which determines how strong or week is the connection's impact on the neuron. During the network teaching process the weights of individual connections undergo changes.

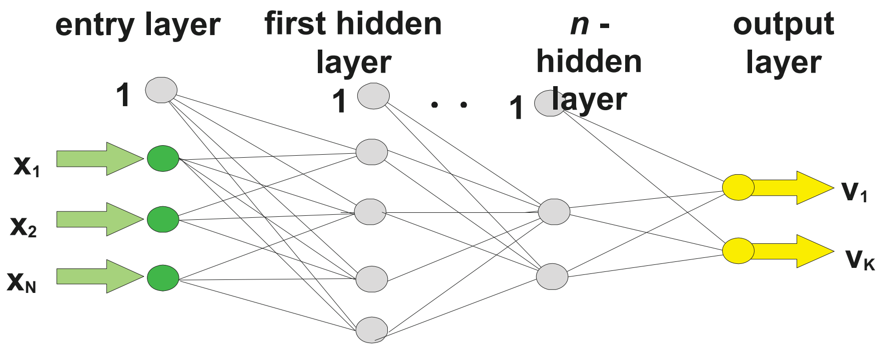

Fig. 1. Multilayered, monodirectional artificial neuron network diagram

3. Network teaching process

There are two groups of teaching process methods known, described as a method „with a teacher" or „without a teacher". First one assumes that the expected value at the network output (exit) is known. The „network teaching" process relies on systematic, slight changes of the relevance levels of the connections between the neurons - change of the „weight" of those connections. The operation is being repeated until the expected value of an output error is obtained. During the learning process, the teaching samples' vectors are being used, for which the expected network values are known.

The „without a teacher" teaching method relies on a selection of weights using a principle of competition between the neurons - so called „Winner Takes All" method or Hebb method. First method relies on using a group of neurons that compete with each other, and input values being entered on their entries. The winning neuron is the one whose output value is the highest. This neuron takes on an output state of „1", while the remaining neurons - the state „0". Only the weights of a „winner" neuron are updated.

The Hebb method relies on changing the weight of a neuron proportionally to the product of its entry and exit (input and output) signals and can also be applied during teaching using so called „with a teacher" method.

4. Fibre optics, interference pressure sensor in the combustion chamber

The gas pressure in the engine combustion chamber carries a lot of information which can be used to characterize the working cycle process. Knowing the pressure curve it is possible to estimate the air-fuel mixture ratio, detect lack of mixture ignition in the cylinder, explosive knocking combustion, unevenness of the following engine working cycles and even estimate the combustion chamber walls' temperature [1, 2, 5, 8].

Despite many advantages, at present, there isn't a serial produced engine control system using pressure sensor to obtain information about a working cycle process. This is due to a low resistance of the sensors to high temperature of gasses in the combustion chamber (reaching even 3000 degrees centigrade), high pressure, attaining even about 12 MPa in case of highly supercharged engines, and the difficulties with fitting of the sensor to an engine.

The author used a sensor head, for measuring combustion pressure, which had a fibre optics of high pressure sensitivity inside. The fibre used was of a side - hole type. Construction of a sensor ensures high pressure sensitivity with a low temperature sensitivity [4, 3]. The measuring head has been placed in the threaded opening made in the engine cylinder head (Fig. 2).

Fig. 2. Measuring head: a - general view, b - measuring head installed in the engine cylinder head

Inside the ribbed arms of a sensor head there is a steal protective capillary containing optical fibre. The internal construction of a head is pictured on the Fig 3. Total internal capacity of a head, together with a pressure supplying tube is 1.189 cm^3, which represents 1.86% of the engine combustion chamber capacity. Thus it can be assumed that, its existence does not substantially disturb the working cycle process. Hot fuel mixture, acting under the pressure inside the combustion chamber, enters the head through the opening shown on the Fig 2 a and next it moves up the channel leading to the part of a head containing measuring optical fibre.

In the case of the sensor being described, the phenomenon of a differential interference in the partially coherent light, has been used [6]. The value of a relative displacement of a LP_{01}^{X} and LP_{01}^{Y} fibre optics modules, stimulated in the optical fibre depends directly and is proportional to the pressure acting on the measuring section of the optical fibre.

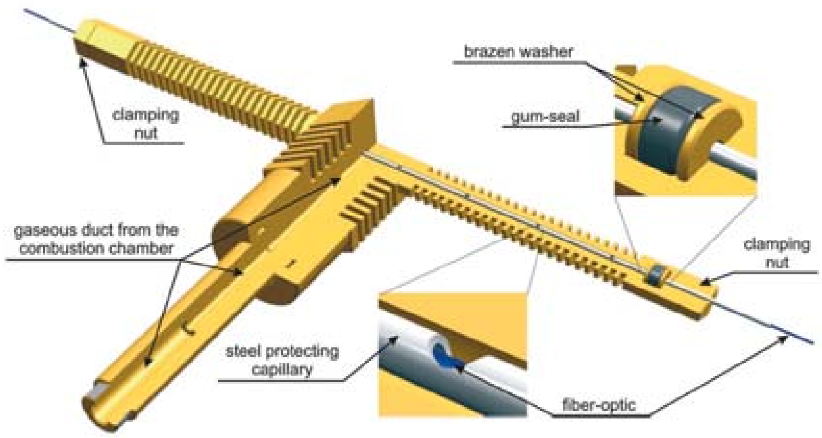

Fig. 3. Internal construction of a measuring head

5. Estimation of the air - fuel mixture ratio

Evaluation of the excess air coefficient of the air-fuel mixture was conducted using pressure signal from the combustion chamber of a four cylinder spark ignition C20LE, installed on the test bench of Lublin Technical University. Pressure measurement was done in one of the cylinders. The results obtained were processed in order to obtain teaching samples' vectors, which were used during a teaching process of an artificial neuron network. To this end there has been an individual program devised, simulating operation of such a network, presented on the Fig 4. Each teaching samples' vector contained four values of a pressure in the engine combustion chamber, adequately to the angle of the crank shaft revolution and equal to: 180°, 380°, 400° and 460°, maximum pressure value of the working cycle and RPM, ignition advancement angle and time of the ignition from a previous working cycle (Fig. 5). Data was obtained under stabilised engine working conditions.

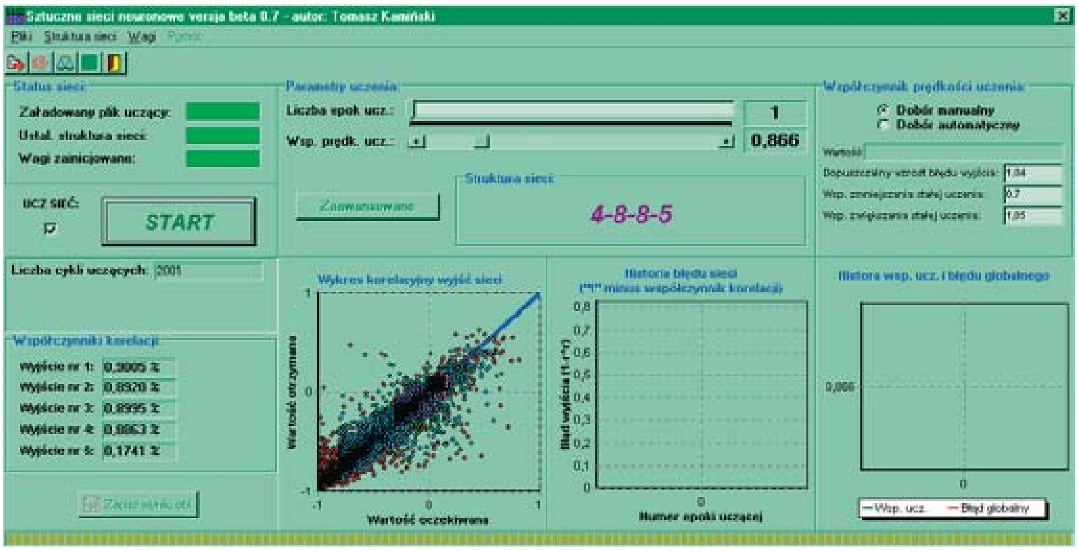

Fig. 4. Program Artificial neuron networks

The network structure accepted contained entry layer, two hidden layers with eight neurons each, and one output neuron. Adaptive selection of a teaching speed coefficient was used, similar to that in MatLab program. At the network input there were teaching samples' vectors, standardised to 1, presented, whose value was deliberately changed randomly by 3%. Output data was compared with mixture content coefficient values, standardised to 1, obtained during laboratory measurements. The network teaching process relied on correcting (weight) relevance coefficient of each of the network connections, according to a back propagation error method [9]. The number of teaching cycles was 212 thousand.

Following completion of a network teaching process, an attempt was made to estimate mixture content. The sample vectors, which were not used in the teaching process, were entered in the network input, while the digital values obtained at the output were compared with the values measured using wide range oxygen sensor. The results obtained are presented in a form of a diagram (Fig. 6).

The diagram contains two determination coefficients: R_1^2 and R_2^2. The first one was calculated for the data marked on the diagram with triangles, obtaining value $R_1^2 = 0.94$.
Subsequently the network was subjected to the repeated training process using the next group of teaching data, with the removed measurement result most distant from the curve, for which r = 1.

Having completed the network teaching process, the input neurons were fed with, as in the previous case, data vectors, which were not used in the teaching process. The network output produced data, which were marked on the diagram with the circles (Fig. 6).

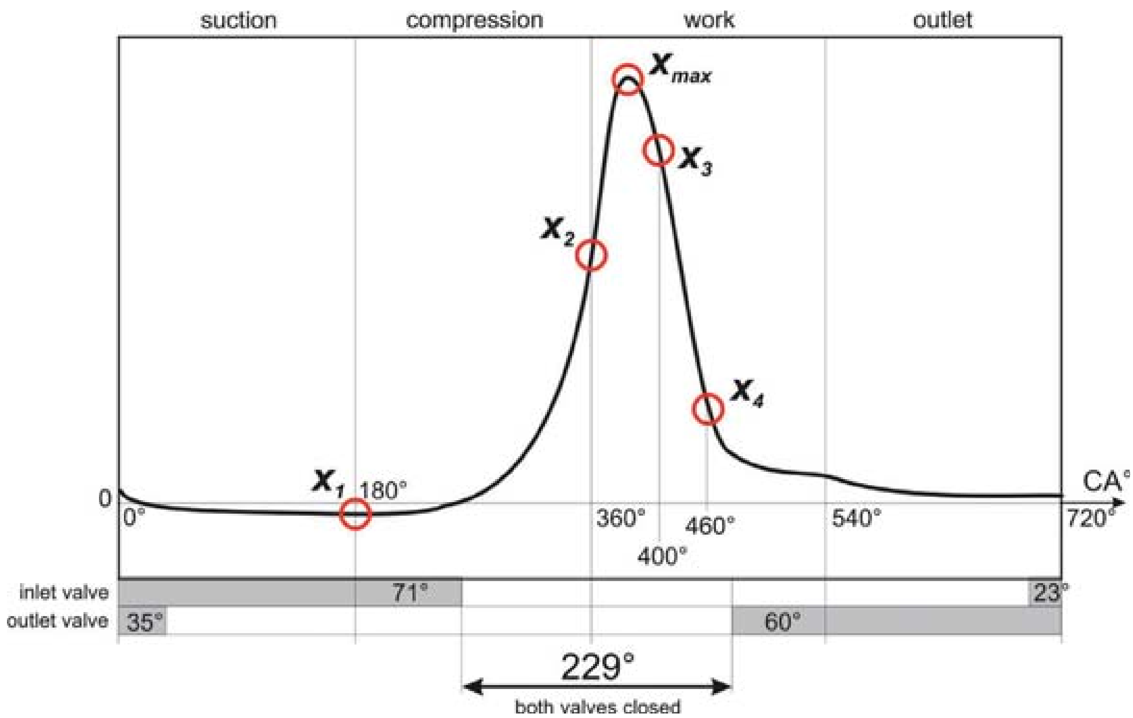

Fig. 5. Pressure diagram of the C20LE engine combustion chamber with the marked points which were used for building network teaching samples' vectors

The determination coefficient for that data is $R_2^2 = 0.99$. In case of a first set of network input data vectors it was established, that in one of the measurements (point on the diagram significantly distant from the regression curve) the measurement error took place.

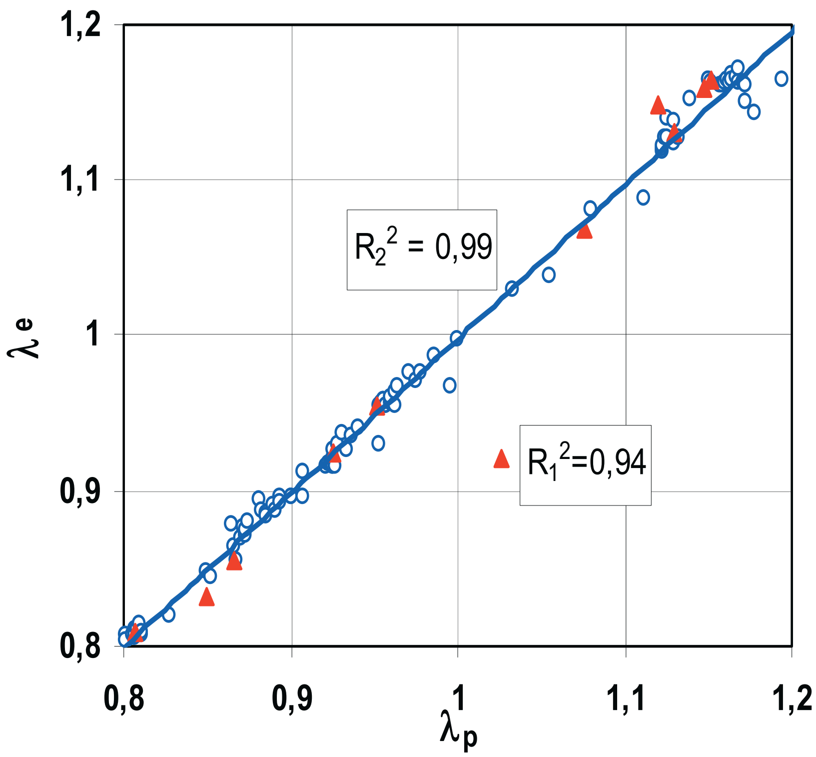

Fig. 6. Excess oxygen coefficient values diagram obtained during evaluation using artificial neuron network as a function of the excess oxygen coefficient value received during laboratory measurements

6. Summary

The artificial neuron networks, as a „black box" type of models" are being used by the scientists in the cases when building the model of an open form is impossible or its laboriousness would be too great in the case discussed. The artificial neuron networks are used for the data analysis, when the task relies on finding relations between the data, as associating memory, for classification and objects recognition, for the predictions, when the task relies on predicting model output data. The artificial neuron networks are also used for filtering signals, creating associated memories, allowing to store the information encoded that way and also in the optimisation processes.

The use of artificial neuron network combined with the interference pressure sensor of a side - hole type, allowed to estimate the air-fuel mixture content of the C20LE engine. The value of the determination coefficient obtained was high, $R^2 = 0.99$. The measurement data however was registered with a hot engine, stabilised RPM and loads as well as stable coolant temperature. The deterioration of the determination coefficient is expected in case of variable engine working conditions.

To evaluate the excess oxygen coefficient it is possible also to use genetic algorithms, being an alternative to SSN.

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