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ANN & It's Application To IC Engine

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Abstract: **- The scope of this paper is to make a brief induction to Artificial Neural Networks (ANNs) for people who have no previous knowledge of them. We first make a brief introduction to models of networks, for then describing in general terms ANNs. As an application, we explain the backpropagation algorithm and its application to IC engines, since it is widely used and many other algorithms are derived from it. The on-line resources are highly recommended for extending this brief induction.**

***Index Terms*--ANN, Back Propagation, Algorithm, Training, Nodes**

1 INTRODUCTION

One efficient way of solving complex problems is following the lemma "*divide and conquer*".A complex system may be decomposed into simpler elements, in order to be able to understand it. Also simple elements may be gathered to produce a complex system. Networks are one approach for achieving this. There are a large number of different types of networks, but they all are characterized by the following components: a set of nodes, and connections between nodes. The nodes can be seen as computational units. They receive inputs, and process them to obtain an output. This processing might be very simple (such as summing the inputs), or quite complex (a node might contain another network...)

The connections determine the information flow between nodes. They can be unidirectional, when the information flows only in one sense, and bidirectional, when the information flows in either sense. The interactions of nodes though the connections lead to a global behaviour of the network, which cannot be observed in the elements of the network. This means that the abilities of the network supercede the ones of its elements, making networks a very powerful tool.

Networks are used to model a wide range of phenomena in physics, computer science, biochemistry, ethology, mathematics, sociology, economics, telecommunications, and many other areas. This is because many systems can be seen as a network: proteins, computers, communities, etc.

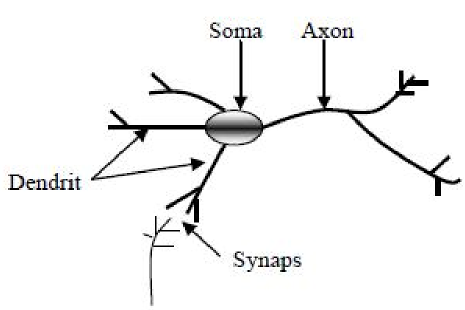


Figure 1. Concept & Components of Neuron

2 ARTIFICIAL NEURAL NETWORKS

The original inspiration for the term *Artificial Neural Network* came from examination of central nervous systems and their neurons, axons, dendrites and synapses which constitute the processing elements of biological neural networks investigated by neuroscience. In an artificial neural network, simple artificial nodes, variously called "neurons", "neurodes", "processing elements" (PEs) or "units", are connected together to form a network of nodes mimicking the biological neural networks — hence the term "*Artificial Neural Network*".

ANN are non-linear data driven self adaptive approach as opposed to the traditional model based methods. They are powerful tools for modleling, especially when the underlying data relationship is unknown. ANNs can identify and learn correlated patterns between input daya sets and corresponding target values. After training, ANNs can be used to predict the outcome of new independent input data. ANNs imitate the learning process of the human brain and can process problems involving non-linear and complex data even in the data are imprecise and noisy. Thus they are ideally suited for the modelling of engineering data which areknown to be complex, and often non-linear. A very important feature of these networks is their adaptive nature, where "learning by example" replaces "programming" in solving problems. This feature makes such computational models very appealing in application domains where one has little or incomplete understanding of the problem to be solved but where training data is readily available.

3 CHARACTERISTICS OF ANN

1. The ANNs show mapping capabilities, i.e. they are able to map input patterns according to the output patterns associated with the inputs.
2. They always learn from previous examples. This makes it possible to "train" the ANNs with known values from previous examples of a problem before they are subjected to the test for their "inference" capability for the unknown instances of the problem. Therefore, they are able to identify new objects which are previously untrained.
3. ANNs are able to recall full patterns from incomplete, partial or noisy patterns. This makes this system robust and tolerant to the faults.
4. ANNs posses the ability to process the information with high speed as well as in a parallel mode and in a distributed manner.

3.1 Basics of Artificial Neural Networks:

This type of network sees the nodes as "artificial neurons". An artificial neuron is a computational model inspired in the natural neurons. Natural neurons receive signals through synapses located on the dendrites or membrane of the neuron. When the signals received are strong enough (surpass a certain threshold), the neuron is activated and emits a signal though the axon. This signal might be sent to another synapse, and might activate other neurons.The complexity of real neurons is highly abstracted when modelling artificial neurons. These basically consist of inputs (like synapses), which are multiplied by weights (strength of the respective signals), and then computed by a mathematical function which determines the activation of the neuron. Another function (which may be the identity) computes the output of the artificial neuron (sometimes in dependance of a certain threshold). ANNs combine artificial neurons in order to process information.

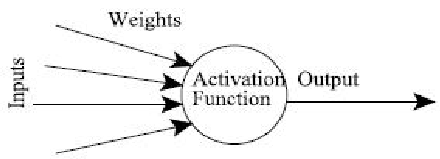


Figure2. An Artificial Neuron

The higher a weight of an artificial neuron is, the stronger the input which is multiplied by it will be. Depending on the weights, the computation of the neuron will be different. By adjusting the weights of an artificial neuron we can obtain the output we want for specific inputs. But when we have an ANN of hundreds or thousands of neurons, it would be quite complicated to find by hand all the necessary weights. But we can find algorithms which can adjust the weights of the ANN in order to obtain the desired output from the network. This process of adjusting the weights is called learning or training.The number of types of ANNs and their uses is very high. Since the first neural model by McCulloch and Pitts (1943) there have been developed hundreds of different models considered as ANNs. The differences in them might be the functions, the accepted values, the topology, the learning algorithms, etc. Also there are many hybrid models where each neuron has more properties than the ones we are reviewing here. Because of matters of space, we will present only an ANN which learns using the backpropagation algorithm (Rumelhart and McClelland, 1986) for learning the appropriate weights, since it is one of the most common models used in ANNs, and many others are based on it.

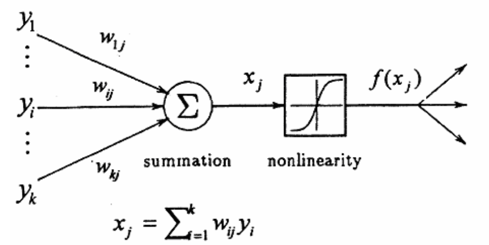


Figure3. A single neuron

3.2 Neural Networks Architectures:

An ANN is defined as a data processing system consisting of a large number of simple highly inter connected processing elements (artificial neurons) in an architecture inspired by the structure of the cerebral cortex of the brain. There are several types of architecture of NNs.However; the two most widely used NNs are discussed below:

3.3Feed forward networks:

In a feed forward network, information flows in one direction along connecting pathways, from the input layer via the hidden layers to the final output layer. There is no feedback (loops) i.e., the output of any layer does not affect that same or preceding layer.

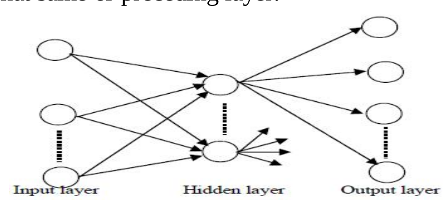


Figure 4. A multi-layer feed forward neural network

4 RECURRENT NETWORKS

These networks differ from feed forward network architectures in the sense that there is at least one feedback loop. Thus, in these networks, for example, there could exist one layer with feedback connections as shown in figure below. There could also be neurons with self-feedback links, i.e. the output of a neuron is fed back into itself as input.

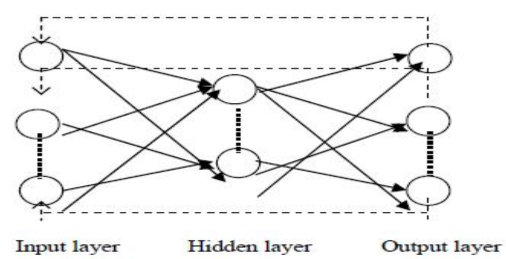


Figure 5. Recurrent Networks

5 LEARNING/TRAINING METHODS

5.1 Supervised learning:

In this, every input pattern that is used to train the network is associated with an output pattern, which is the target or the desired pattern. A teacher is assumed to be present during pattern, the learning process, when a comparison is made between the network's computed output and the correct expected output, to determine the error. The error can then be used to change network parameters, which result in an improvement in performance.

5.2 Unsupervised learning:

In this learning method, the target output is not presented to the network. It is as if there is no teacher to present the desired patterns and hence, the system learns of its own by discovering and adapting to structural features in the input patterns.

5.3 Reinforced learning:

In this method, a teacher though available, does not present the expected answer but only indicates if the computed output is correct or incorrect. The information provided helps the network in its learning process. A reward is given for a correct answer computed and a penalty for a wrong answer. But, reinforced learning is not one of the popular forms of Learning.

6 DEVELOPMENT OF ANN MODEL

The various steps in developing a neural network model are:

6.1 Variable selection:

The input variables important for modeling variable(s) under study are selected by suitable variable selection procedures.

6.2 Formation of training, testing and validation sets:

The data set is divided into three distinct sets called training, testing and validation sets. The training set is the largest set and is used by neural network to learn patterns present in the data. The testing set is used to evaluate the generalization ability of a supposedly trained network. A final check on the performance of the trained network is made using validation set.

6.3 Neural network architecture:

Neural network architecture defines its structure including number of hidden layers, number of hidden nodes and number of output nodes etc.

•Number of hidden layers: The hidden layer(s) provide the network with its ability to generalize. In theory, a neural network with one hidden layer with a sufficient number of hidden neurons is capable of approximating any continuous function. In practice, neural network with one and occasionally two hidden layers are widely used and have to perform very well.

•Number of output nodes: Neural networks with multiple outputs, especially if these outputs are widely spaced, will produce inferior results as compared to a network with a single output.

•**Activation function:**

Activation functions are mathematical formulae that determine the output of a processing node. Each unit takes its net input and applies an activation function to it. Non linear functions have been used as activation functions such as logistic, tan etc.The purpose of the transfer function is to prevent output from reaching very large value which can 'paralyze' neural networks and thereby inhibit training. Transfer functions such as sigmoid are commonly used because they are nonlinear and continuously differentiable which are desirable for network learning.

6.4 Evaluation criteria:

The most common error function minimized in neural networks is the sum of squared errors. Other error functions offered by different software include least absolute deviations, least fourth powers, asymmetric least squares and percentage differences.

6.5 Neural Network Training:

Training a neural network to learn patterns in the data involves iteratively presenting it with examples of the correct known answers. The objective of training is to find the set of weights between the neurons that determine the global minimum of error function. This involves decision regarding the number of iteration i.e., when to stop training a neural network and the selection of learning rate (a constant of proportionality which determines the size of the weight adjustments made at each iteration) and momentum values (how past weight changes affect current weight changes).Several software on neural networks have been developed, to cite a few:-

Commercial Software

Statistica Neural Network, TNs2Server, DataEngine, Know Man Basic Suite, Partek, Saxon, ECANSE-Environment for Computer Aided Neural Software Engineering, Neuroshell, Neurogen, Matlab: Neural Network Toolbar.

Freeware Software

Net II, Spider Nets Neural Network Library, NeuDC, and Binary Hopfield Net with free Java source, Neural shell, Planet, Valentino Computational Neuroscience Work bench, Neural Simulation language version-SL, Brain neural network Simulator.

7 APPLICATIONS TO MECHANICAL ENGINEERING

Modelling Of Normalised Structural Steels Mechanical Properties

The prediction possibility of the material mechanical properties is valuable for manufacturers and constructors. It allows preserving the customers' quality requirements. Prediction of mechanical properties brings also measurable financial advantages, because expensive and time-consuming investigations are reduced to the indispensable minimum. Necessaries to execute are only to the investigations made for verification of computed results.

The prediction of steels mechanical parameters after normalisation process is not an easy process at all. The determination of the chemical composition influence is particularly difficult, especially in the case of rolled sheet metal plates [8]. Because of the fact that there is no physical models allowing to connect the influence of the chemical compositions and the parameters of the mechanical and heat treatment on properties of manufactured steels, existing models are mainly based on the statistical analysis and have limited range of use. They are the most often prepared to describe one single steel species manufactured in equal conditions.

Application of artificial neural networks is considerably simplifies the modelling methodology. There is no need to posses the function of input and output parameters in evident form.

Diesel engine performance and exhaust emission analysis using Waste Cooking Biodiesel fuel with an Artificial Neural Network

This study deals with artificial neural network (ANN) modeling a diesel engine using waste cooking biodiesel fuel to predict the brake power, torque, specific fuel consumption and exhaust emissions of engine. To acquire data for training and testing the proposed ANN, two cylinders, four-stroke diesel engine was fuelled with waste vegetable cooking biodiesel and diesel fuel blends and operated at different engine speeds. The properties of biodiesel produced from waste vegetable oil was measured based on ASTM standards. The experimental results reveal that blends of waste vegetable oil methyl ester with diesel fuel provide better engine performance and improved emission characteristics. Using some of the experimental data for training, an ANN model based on standard Back-Propagation algorithm for the engine was developed. Multi layer perception network (MLP) was used for nonlinear mapping between the input and the output parameters.

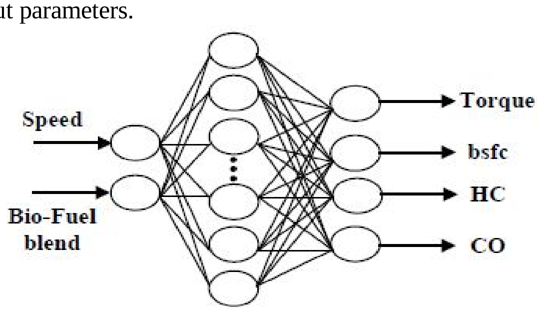


Figure 6.Configuration of Multilayer Neural Network for predicting engine parameters

Different activation functions and several rules were used to assess the percentage error between the desired and the predicted values. It was observed that the ANN model can predict the engine performance and exhaust emissions quite well with correlation coefficient (R) were 0.9487, 0.999, 0.929 and 0.999 for the engine torque, SFC, CO and HC emissions, respectively. The prediction MSE (Mean Square Error) error was between the desired outputs as measured values and the simulated values by the model were obtained as 0.0004.

Properties of Diesel & Biodiesel Fuels				
Property	**Method**	**Units**	**Diesel**	**Biodiesel**
Flash point, closed cup	D 93	°C	64	182
Pour point	D 97	°C	0	-3
Kinematic viscosity, 40 ° C	D 445	mm^2/s	4.03	4.15
Sulfated ash	D 874	wt. %	-	0
Total Sulfur	D 5453	wt. %	0.05	0.0018
Copper strip corrosion	D 130	-	1a	1a
Cloud point	D 2500	°C	2	0

Modeling with the ANN

An ANN model for the diesel engine with diesel and biodiesel blended fuels was developed using the 10 data gathered in test runs. In the model, 80% of the data set was randomly assigned as the training set, while the remaining 20% of data are put aside for prediction and validation. A network with one hidden layer and 25 neurons proved to be an optimum ANN.

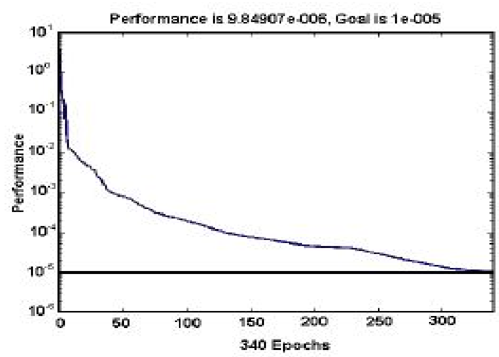
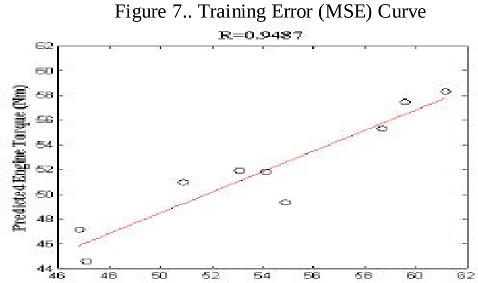


Figure 7.. Training Error (MSE) Curve



(a)

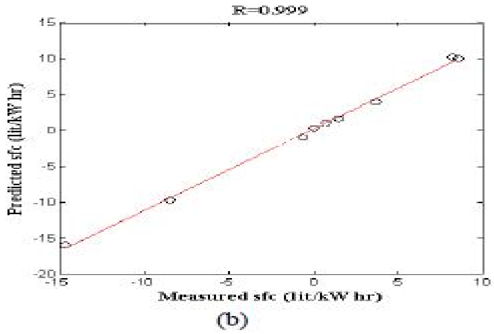
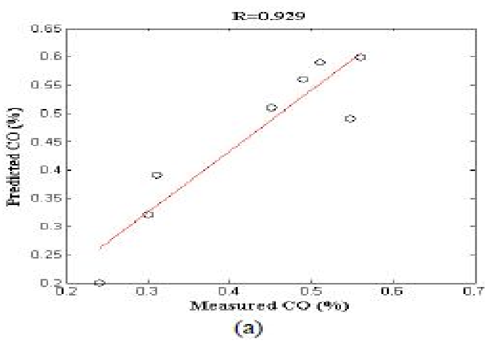


Figure 8.The predicted output vs. the measured values, (a) engine torque (b) SFC



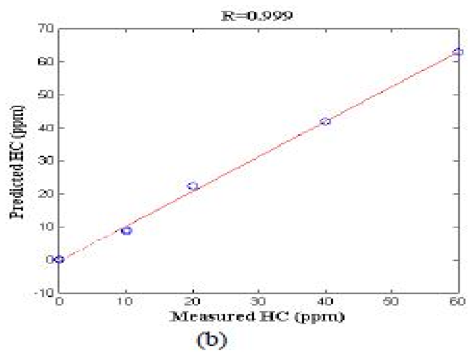
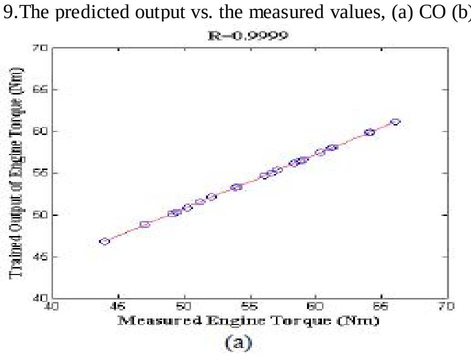


Figure 9.The predicted output vs. the measured values, (a) CO (b) HC



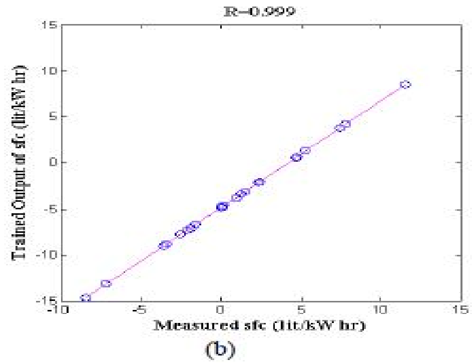
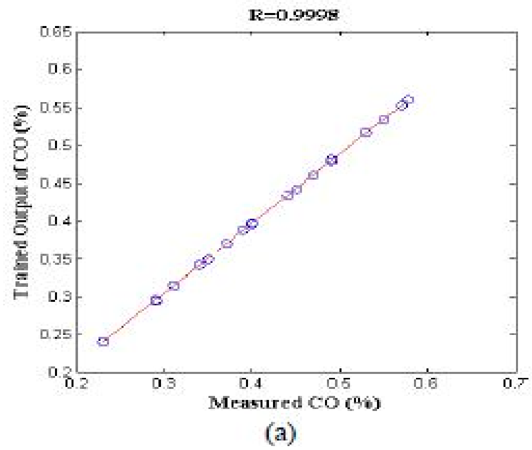


Figure 10.The trained outputs vs. measured values, (a) engine torque (b) SFC



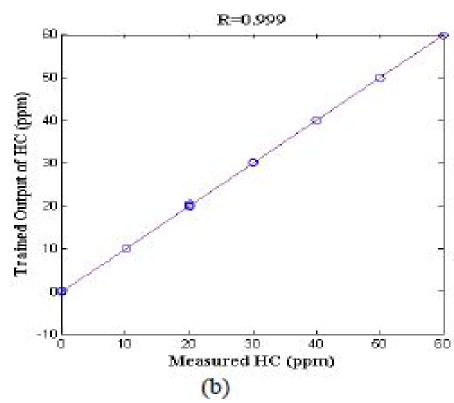


Figure 11.The trained outputs vs. measured values, (a) CO (b) HC

8 CONCLUSIONS

An Artificial Neural Network (ANN) was developed and it was trained with the collected data of performance testing on engines, included in this work. Finally, the results indicated that the training of ANN using Back Propagation Algorithm was sufficient enough to predict the performance parameters of engine such as engine torque, sfc, and exhaust gas components. These parameters were tested for different values of engine speeds and different ratios fuel blends. In the end it was observed that R values were very close to one for torque, SFC, CO and HC, while the MSE error was 0.0004. After the analysis of the experimental data carried out by using ANN revealed that there is a good correlation between the predicted data resulted from the ANN and measured data obtained from manual performance testing. Therefore, ANN proves itself as a desirable method for prediction for the evaluation of engine parameters. Also, ANN can be used on a priority basis, since other mathematical and numerical algorithms might fail as the nature of the problem involved is very much complex and multivariate. In a generalised way of speaking, ANN provides accuracy combined with simplicity in the analysis of performance indicating parameters of IC Engine.

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