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Artificial Neural Network Based Model for Temperature Prediction of an Industrial Oven

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***Abstract**: Industrial ovens often consume a considerable amount of the electrical energy and have a significant effect on the quality of the product and the production cost. The cost of energy all over the world is increasing and the natural resources are depleted as more and more energy is being harnessed. Temperature and heat losses contribute significantly to this problem and needs to be controlled. This thesis presents a model for the prediction of temperature that is used to predict the temperature of an oven.*

In this research, a back propagation neural network model was developed. Experiments were conducted where the oven was heated up over a period of time and the temperature was recorded over this period of time. The obtained temperature values were trained, tested and validated on the MATLAB's Neural Network Toolbox. A comparison of the target data against the output data was done and it was found to be a good model for prediction since the value of statistical measure was 1 (R=1) for all the data values (Training, testing and validation data). The oven model used in this research had a problem of temperature control where temperature could shoot above or cool below the set temperature. This rendered the lab samples to extreme temperatures and losses of energy. This research contributes in a big way to the methods of temperature control in the industrial process heating processes and energy management and conservation processes.

***Keywords:** Back Propagation, industrial oven, feed forward neural network, Oven heating, temperature prediction*

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I. Introduction

An oven is a heated chamber that is applied in a number of industrial uses. Some of the applications include drying, baking of components, curing and so on. The performance of an oven when it is compared to various practices reduces with time as a result of various reasons. These aspects include; structural/mechanical degradation, changing process requirements and technological advancements. Ovens are used for both large-scale and small-scale applications. These ovens come in a variety of forms and with variety of physical sizes, ranges of temperature as well as configurations. The industrial types find their applications in various fields such as; manufacture of chemical, food processing, lab sample analysis, as well as in electronics where the electronic circuits passed over conveyor ovens to fix components. In the industrial sector, energy is used for wide range functions including process and assembly, steam and cogeneration, heating, lighting, process heating and cooling, and air conditioning for rooms and buildings [1].

A sizeable proportion of energy is often consumed by the ovens found in manufacturing industries. Considerable research has been going on to get the best methods for controlling process heating processes and thus reduces excessive energy consumption. Unfortunately, it has not yet been generalized the tool to reduce the energy consumption within the industrial oven. The environmental impact of the energy industry is diverse. Industrial energy consumption affects the environment in a number of ways. Millennium and millennium, human beings have harnessed energy from all dimensions of life. It all started by the invention of fire from lighting, heating, cooking as well as safety by the ancient man, millions of years ago. In modern years, the trend is moving towards the design of renewable sources of energy. However, there are heating practices that are adverse to the environment. Rapidly advancing technologies can achieve a transition of energy generation, water and waste management, and food production towards better environmental and energy usage practices using methods of systems ecology and industrial ecology. Fig. 1 shows á distribution of primary energy consumption by energy type all over the world from 1970 to 2010 [2].

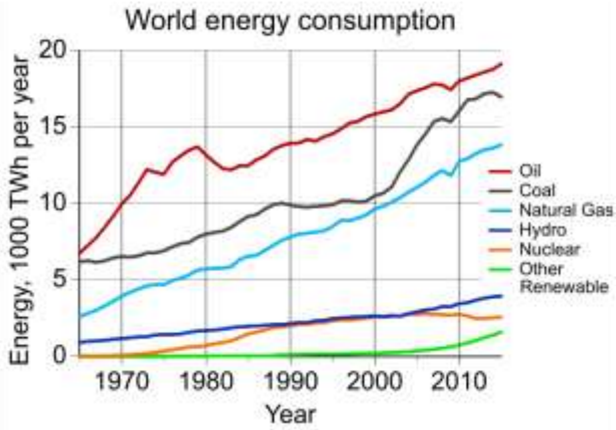

Figure 1: World consumption of primary energy by energy type [2]

Temperature prediction is a great concern in all sectors including the environment, industry and the broad agriculture sector. Artificial neural networks provides is a good tool of soft computing which is highly suitable for many situations including those where underlying processes exhibit chaotic features. The concept of using artificial neural networks originated from an attempt to use to design and implement a mathematical model that was able to recognize a complex pattern that are on the same line as a normal biological neuron work. It can be said to be an information processing paradigm which is inspired in a great way by the way the biological nervous, like the brain, process their information. The primary element of this paradigm is the structure of the information processing system. ANN is composed of a very large number of processing components which are highly interconnected in unison to solve a given specific problem. Generally, an artificial neural network is configured for a specific problem at hand. For example, pattern recognition, clustering and so on through a learning process. In normal biological systems, learning involves adjustment to the synaptic connections that normally exists between the biological neurons. ANN works through the same concept [3].

The applications of neural networks to control the industrial systems have increasingly become important in the industries today. The massive parallel processing, non-linear mapping, and the self-learning abilities of the neural networks are the main contributing factors for the design and the developments of the intelligent control systems. In the back propagation neural network based control, a generalized rule is used, then, a gradient decent search technique is used. The back propagation technique has its disadvantages among them including, lack of convergence, but it's a simple yet a very powerful mathematical algorithm that has made it the mainstay of the neuro-computing. Before any neural network is used to control any model, it must go through the dynamics of the model of the plant [4].

M. Shashi and Y. Radhika [5] used time series data of the maximum temperature at a particular location to predict the maximum temperature of the next day. The performance of their system was totally based on time duration of 2 to 10 days. To do this, the kernel's optimal values were used. This prediction technic was slower because the Support Vector Machine relied on its memory to store and processes the data. Smith et al [6] based their research in developing an ANN model which had reduced average prediction error. To achieve this, they increased the number of distinct observations that were used in training, adding more inputs terms that described the duration of prior temperature data that was included in each observation, and examining the number of hidden layer nodes used in the network. Models that were used to predict the temperature at hourly intervals were created from one hour to twelve hours going ahead. Each of their artificial neural network model, having a network architecture and a set of associated parameters was then evaluated by instantiating and training thirty networks and calculating the mean absolute error (MAE) of the resulting networks for some set of the input patterns.

Govind Kumar et al [7] discussed briefly on how various connectionist paradigms can be constructed by the use of different learning methods and investigate whether they can deliver the necessary performance. In return, it resulted to robust performance and it could reliably generate a forecast model of the stock market indices. Omaima N. A. Al-Allaf [8] eliminated the rather difficult task of manual selection of the non-face training datasets that is chosen to scan the whole space of non-face images. Typical heuristics like applying the fact that faces hardly overlap in case of images, improving the accuracy. The comparison with various other state-of-the-art face identification technologies were represented; indicating that the system had a comparable performance as detection and false-positive rates are concerned.

The Neural Networks package supports different types of training or learning algorithms. One such algorithm is Back Propagation Neural Network (BPN) technique. The main advantage of the BPN neural network method is that it can fairly approximate a large class of functions. This method is more efficient than numerical differentiation [9, 10].

In this paper, a neural network based approach has been proposed and developed to improve the accuracy and the prediction efficiency of an oven's temperature control system. This method does not require mathematical models that are complex and can predict the oven's heating based on the prior knowledge and learning. The proposed approach in this paper is able to be realized in the practical applications of oven heating systems, which solves many problems of energy losses, conservation and the reduction of pollution emissions.

II. Experimental Works

2.1 Temperature Data

Experiments were conducted on the oven and temperature recorded over a period of time. B & R automation studio data acquisition system (DAQ) was interfaced with the oven model as shown on Fig. 2.

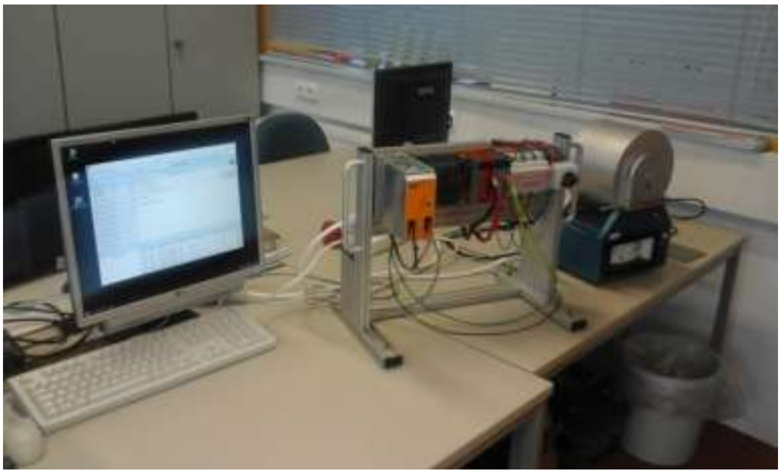

Figure 2: Data Acquisition system

A J-type thermocouple was used to measure the temperature as the oven heated gradually from the room temperature to a temperature of 500 degrees Celsius. The code developed was done in such a way that on the B & R kit, it was possible to record the temperature readings per second for over 3000 seconds. The program code was in such a way that it was possible to measure the temperature and save it with time on an excel file and transfer it automatically to a USB stick. The same procedure was repeated with a piece of metal inside the work-piece. The piece of metal was supposed to influence the behavior of heating of the oven. The data was collected the same way it was done using an empty oven. This data was saved on an excel work-sheet.

2.2 ANN learning and training

The best training procedure was found as to compile a wide range of data sets which exhibit all different characteristics of the problem being solved. Using poor data for training leads to an unreliable and unpredictable network. The number of hidden neurons chosen affects how well a network is able to separate data. When a large number of hidden neurons is used, it ensures that the network is able to correctly predict the data that has been used to train it. The only problem is that when a new data is introduced, the network's ability to generalize it is compromised. The initial chosen when training also matters. This is because the learning algorithm uses a steepest descent technique. This technique rolls straight downhill in the weight space until it reaches the first valley. The learning rate chose also influences the final outcome of the model. This is because it controls the size of the step that is normally taken in a multi-dimensional weight space when each weight is successfully modified. Too large learning rate results to local minimum being overstepped constantly resulting to formation of oscillations and also low convergence of the lower mean state error.
Tansig and the *pureln* transfer functions were selected as the transfer function for the input and output layers respectively. This research used *trainlm* as the training function. The temperature data was collected in intervals of one second. 70% of the data was used as the training set of data while 15% was used as the testing data set. The remaining 15% of the data was used validation data set. This data was divided randomly to achieve these portions. The model is as shown on Fig. 3.

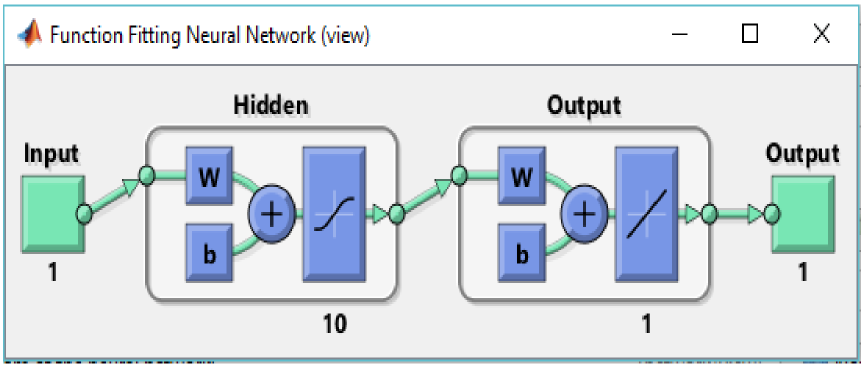

Figure 3: A neural network fitting structure model

III. Results And Discussion

Fig.4 shows a histogram obtained from the MATLAB's neural network tool box comparing the training, testing and the validation data. The error histogram is used in comparing the errors occurring during training, validation and testing of the trained data.

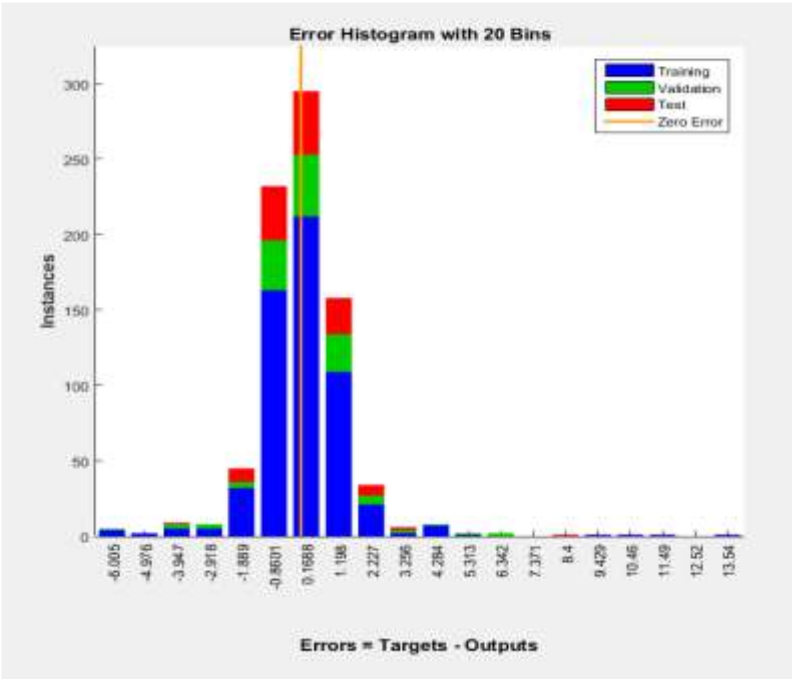

Figure. 4: Error histogram

From the error histogram shown on Fig. 4, all the blue bars represents the training data, the green bars represent the validation data and the red bars represent the testing data. Error histograms are used to indicate outliers, which are the data points where the fit is significantly worse than the majority of the data. In this problem, most of the errors fall in between -3 and 3, in-fact, there is a training point with an error of 13 and validation points with errors of 5 and 6.

Fig.5 shows the plots of the data vs. the original data in all the steps including training, testing and validation. It shows the relationship between the measured temperature data (target values) and the predicted temperature (output values) for training and validation steps respectively. The value R represents the statistical measure of how close the data are fitted to the regression line.

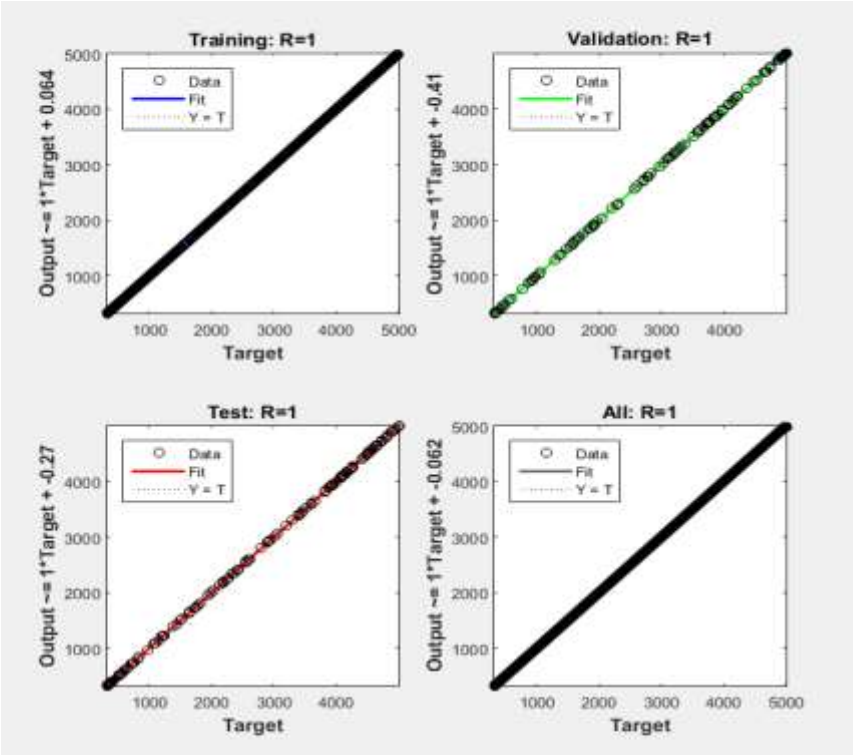

Figure 5: Original data vs the fitted data during training

Fig.5 displays the plots of the output networks with respect to the training, validation and the test sets of data. It is known for a fact that for a perfect fit, the data should always fall along the 45 degrees line where the outputs are to the targets. In this particular problem, the line fits pretty well for all the data sets with the R values for each set of 1. To obtain this value, the data was retrained for four times. During the retraining, the initial weights and biases were of the network kept changing therefore improving the network to the better. The continuous line indicates the original data while the dotted lines indicate the fitted data to the system. This tells that the given data is somewhat monotonically increasing with time, and therefore this model can be said to be a linear fit regression. The MSE is the same for both the neural network and the linear regression and therefore both models are well fitted. Fig.6 shows the training error for the first time as the system was being trained and the weights adjusted progressively.

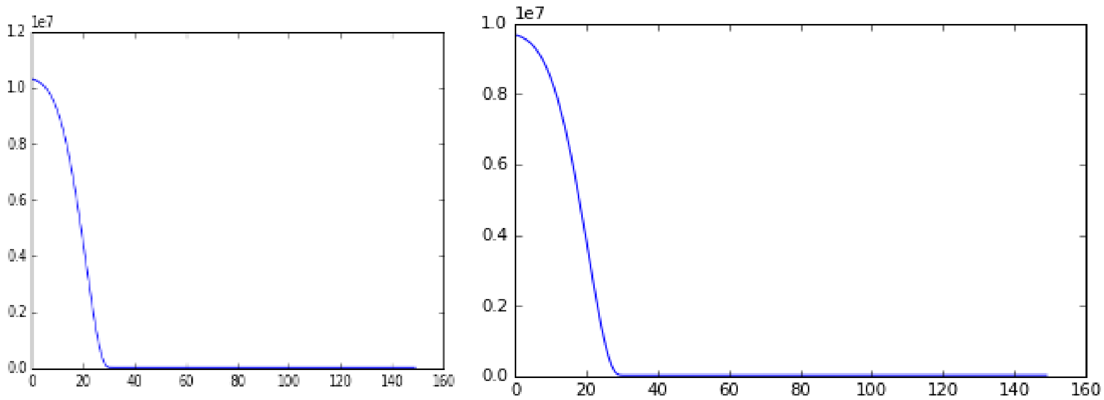

Figure 6: First training error loss and Training error loss on second weight adjustment

Plots appearing on Fig.7 shows the training error and validation error loss plots as the weight adjustment are done on the network. As seen from the graphs, the training error which was initial very high because initial weights are randomly assigned. So when these weights are multiplied by the output of the neurons the error increases in the forward propagation and final error calculated with the training out and this error is propagated backward i.e., backward propagation and the weights are arranged accordingly and this repeats until the error is saturated or confined in an interval, the number of epoch is also set to run to run the model.

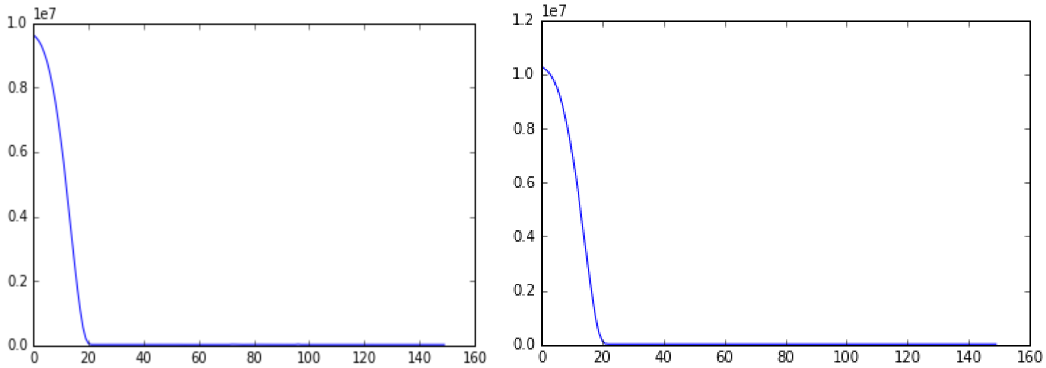

Fig. 8 Validation error loss on first training and Validation error loss on weight adjustment

Validation error which was very high in the beginning, as the weights are adjusted the error also decreased with the increase in iterations and got saturated after a while. Hence, the error changes shows that it is the global minimum position of the space. On varying the number of the hidden layers, the error plot remains the almost the same. The only thing that changes is the rate at which the steady state is reached i.e. it is faster as the hidden layers are increased than when they were few.

IV. Conclusion

This research covered temperature of an oven prediction model using the artificial neural networks. Back propagation model was used on training the set of data that was collected on a lab sample analysis oven. Through the implementation of this system, it can be concluded that the data obtained was almost linear and therefore training was easier. This fact eliminated the need to use much of genetic algorithm in the system to refine the accuracy of prediction. The convergence speed was good and no oscillations were experienced during the training of the network. When incorporated into the MATLAB's neural network tool, back propagation's performance was satisfactory as the number of errors were minimal. Back propagation neural network approach when used for temperature prediction can yield better results compared to the conventional methods of predicting the temperature. With this approach, it is possible to determine the non-linear relationship existing between the historical data saved over a period of time fed to the system on the training phase and make temperature prediction for the future.

It can also be concluded that there exists some external factors environmental factors included that hinder the achievement of the best prediction accuracy results. Sensor errors that occurred during the temperature measurement disturbed the system and decreased the accuracy significantly.

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