Control and Monitoring System Optimalization of Combustion in Furnace Boiler Prototype at Industrial Steam Power Plant with Comparison of Neural Network (NN) and Extreme Learning Machine (ELM) Method

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Abstract— this paper is presenting a design and research studies in industrial steam power plant system called "control and monitoring system to optimize the combustion process in the furnace boiler prototype with comparison of neural network and extreme learning machine". Comparison between Neural Network and ELM (Extreme Learning Machine) methods will be used to this combustion control system and will be implemented in a prototype with microcontroller. This prototype is using the value of temperature sensor and value of smoke sensor in the furnace as parameter of heat to control the flow of air and fuel oil. The temperature sensor in this research is type K Thermocouple. The smoke sensor is MQ sensor. This prototype also used fan and pump oil as an actuator. Fans are used to supply the oxygen and pump is used to supply the fuel oil. From the experimental result, this prototype shows the optimization of combustion system using ELM (Extreme Learning Machine) method can work well compared with NN (Neural Network) method. ELM Control System has a very good response and it can work well (RMSE = 6,32456E-05). So, if the system is applied in the industrial steam power plant, it can improve the performance of combustion control systems and able to save the fuel.

Keywords—furnace boiler, neural network, extreme learning machine, type k thermocouple, mq7, microcontroller.

I. INTRODUCTION

In the industry of Electric Steam Power Plant, the boiler is one of the most important parts of the production process to provide heat by heating water into steam. To produce a steam, it required fuel combustion processes in the furnace. Furnace is a important component in the boiler that serves as the combustion chamber of the fuel. System optimization of the combustion process is very important in keeping the work efficiency of the whole system to minimize the losses that may occur as a result of incomplete combustion. In the industry of Electric Steam Power Plant, a system to control the fuel combustion process is using flow ratio control. In this system, an oxygen analyzer and temperature sensor were existed, both of them are used as a reference in determining the quality of the combustion process. However, the analysis results of the oxygen analyzer and temperature sensor are not used as a feedback control. Thus, there is a loss caused by incomplete combustion that occurs frequently.

To maximize the boiler performance, the furnace combustion process must be accurately regulated to produce a perfect combustion to minimize the losses from incomplete combustion processes. The ratio between air and fuel has an important role in combustion quality. If the amount of air is too small, will cause oxygen in the burning process is less. Thus, hydrocarbon fuels can not be converted into carbon dioxide and water. This causes waste on fuel, because not all the fuel can burn effectively and become an energy. In addition, too much air will also cause incomplete combustion.

To develop the system, in this research has made a system control and monitoring of fuel combustion process in the boiler furnace prototype by using an arduino microcontroller with comparison of Neural Network (NN) and Extreme Learning Machine (ELM) method based on numerical analysis [1-3] and artificial intelligence [4-15]. This prototype is using the fan and nozzle oil pump as actuators and using the type K thermocouple sensor and MQ7 to read the temperature and smoke in the combustion chamber (furnace) as a parameter for optimization of combustion.

By using two data processing methods, we will find the most optimal and effective method in order to get maximum performance result. Generally, both methods are included in the neural network algorithm class. They have an equal structure layers of neurons, such as input layer, hidden layer, and output layer[16]. The other similarities are in terms of determined the number of neurons in hidden layer, both ELM and NN are using random method.

ELM is a new variant of Neural Network [17]. It has good training time performance, extreme speed in learning speed, and has a better accuracy. This performance makes many researcher are interested to implement ELM in their experiment. It can address all issue about the length of time training on neural network for several decades.

The discussion on this paper is as follows ; In Section II, Explains the method of research and data processing. In Part III, data analysis and discussion of implemented NN and ELM method in hardware. And in part 4 is the conclusion.

II. METHODOLOGY

The purpose of this research is to compare the Neural Network method with Extreme Learning Machine (ELM) method in optimizing the temperature in furnace boiler using Thermocouple sensor.

A. Design System

This section describes the system design for this research. The things described are software design, hardware design and software & hardware integration in the prototype.

❖ Part 1

In part 1 is contained how to test the sensor and actuator calibration using Arduino IDE, the NN or ELM training and testing validation method by using Matlab, and monitoring process using Visual Studio 2013.

❖ Part 2

In part 2 contain how to make and designing the hardware. Hardware design of this research can be seen in figure 2.
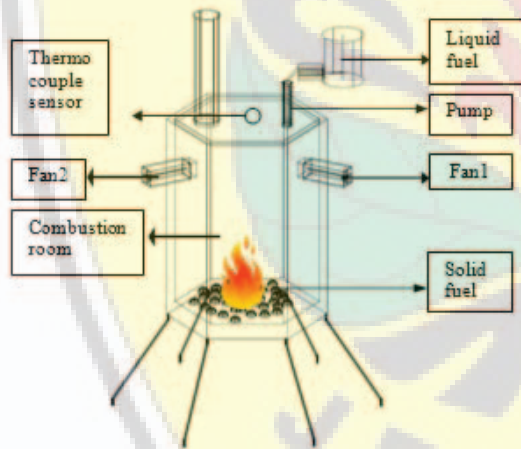

Fig 2. Design of Furnace Boiler

Figure 2 is the design of furnace boiler prototype. Combustion room is made from steel tank; it has the ability to be resist against heat. There are two sensors and two actuators in this system, the temperature value obtained from Type K Thermocouple and MQ7. The actuators are fans and nozzle oil pump. It will explain in Figure 3.
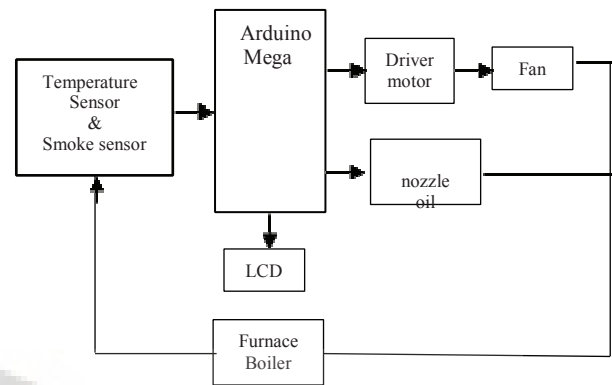

Fig 3. Hardware System

❖ Part 3

In stage 3 is containing the integration of software and hardware. The working principles on this research are:

1) In the initial condition, the driver motor on the fan is set off and the nozzle oil pump is not active.
2) Filling the solid fuel (charcoal) into the furnace.
3) Once the furnace is filled with solid fuel, then turn on the lighter manually, this process is called as a start-up process of the combustion system.
4) After start up process is finished, then set the start button on.
5) When the start button is active, the connection of serial communication has been succeeded and the nozzle oil pump and fan turns on
6) Then, the thermocouple sensor will read the temperature data and smoke sensor will read the carbon data.
7) The filling process is done until the temperature and carbon content of furnace boiler are specified.
8) When the temperature and carbon content is still not more appropriate than 49, there are some conditions that should be controlled.
9) The condition is controlled by using ELM or NN method; both of them are used to set the speed of fan and duration of nozzle oil pump to activate.
10) If the system has not been completed, the system will still running until the temperature and carbon content is specified.

11) If the system has been completed then the stop button is active, the nozzle oil pump and fan are off.

B. *The Application of Neural Network Method on The Plant*

❖ **Neural Network Design**

This research is using 2 input variable from type-k thermocouple sensor and mq-7 gas sensor and 2 outputs from speed of fan and duration of nozzle oil pump. The NN structure is using 2 hidden layers, 8-6 neurons, 3 biases and 3 "Logsig" functions.
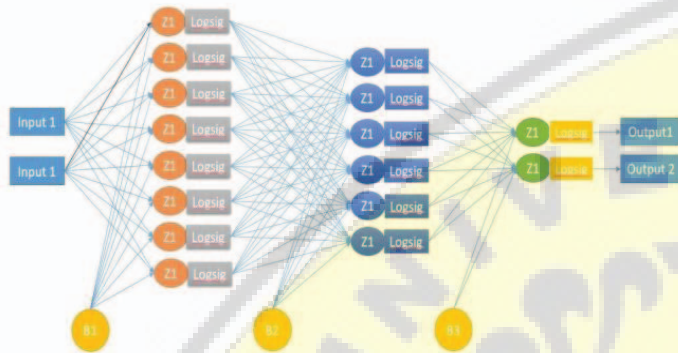

Fig. 4 Neural Network Design

❖ **Input and Output Data**

Total of primary data which is used to the training section are 67 data, Table 2 is the input and output data for the training process in Neural Network.

Table 2. NN Training Data

Num	Temperature (°C)	Smoke (bit)	DC fan (V)	Pump (sec)
1.	25	200	2.5	0.525
2.	25	250	3.33	0.5
3.	25	300	4	0.525
4.	25	350	5	0.45
5.	25	400	6	0.385
6.	25	450	6	0.38
7.	25	500	6	0.375
8.	30	250	3.5	0.45
9.	30	350	5	0.375
10.	30	450	6	0.365
11.	30	500	6.2	0.36
12.	35	200	3.5	0.375
13.	35	300	4	0.375
14.	35	400	6	0.36
15.	35	500	6.2	0.355
16.	40	200	4.1	0.36
17.	40	300	4.2	0.355
18.	40	400	6	0.35
19.	40	500	6.1	0.345
20.	45	200	4.5	0.35
21.	45	300	4.5	0.35
22.	45	400	6.5	0.345
23.	45	500	6.5	0.34
24.	50	200	5	0.346
25.	50	300	5.2	0.345
26.	50	400	7	0.35
27.	50	500	7.2	0.35
28.	55	200	5.5	0.35
29.	55	300	5.5	0.35
30.	55	400	7.5	0.33
31.	55	500	7.5	0.32
32.	60	200	6	0.32
33.	60	300	6	0.32
34.	60	400	8	0.315
35.	60	500	8	0.3
36.	65	200	6.5	0.28
37.	65	300	6.5	0.27
38.	65	400	8.5	0.26
39.	65	500	8.5	0.25
40.	70	200	7	0.24
41.	70	300	7	0.23
42.	70	400	9	0.22
43.	70	500	9	0.2
44.	75	200	7.5	0.18
45.	75	300	7.5	0.17
46.	75	400	9.5	0.16
47.	75	500	9.5	0.15
48.	80	200	8	0.14
49.	80	300	8	0.13
50.	80	400	10	0.12
51.	80	500	10	0.15
52.	85	200	8	0.145
53.	85	300	8	0.14
54.	85	400	10	0.135
55.	85	500	10	0.13
56.	90	200	8	0.125
57.	90	300	8	0.12
58.	90	400	10	0.15
59.	90	500	10	0.1
60.	95	200	8	0.1
61.	95	300	8	0.1
62.	95	400	10	0.1

63.	95	500	10	0.1
64.	100	200	8	0.1
65.	100	300	8	0.1
66.	100	400	10	0.1
67.	100	500	10	0.1

❖ **Neural Network Training Process**

The training process is started by using matlab software to get the best model based on the training data. Figure 5. shows the MSE result is stopped at 21th iteration. It means that the best training performance is reached at 9, 7098.10^{-9} and the training time is 0.99984 seconds.
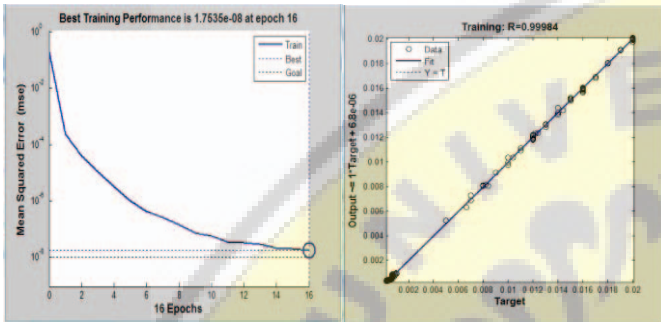

Fig. 4. Best Training Performance and Regression

The next process can be done by taking each weight in each layer to implement the calculation of NN on microcontroller.

❖ **Neural Network Training Result**

The obtained results from the training process are the weight of IW, LW and bias. Where the number of IW 2x8, the number of LW1 6x2, the number of LW2 8x6, the number of B1 1x68, B2 1x6 and B3 1x2. The weights were transferred to arduino IDE for processing.

Table 2. 1st layer Weight

IW1	IW2	B1
-29.7685	25.0571	-5.9771
-44.5820	23.8636	-6.4320
81.3361	-14.0661	2.0558
90.4031	12.5664	21.5912
-94.8604	10.4888	2.2644
-3.6680	-25.5886	16.8036
-15.0397	-26.8431	13.0871

105.6807	1.4910	-3.0401
2.3863	1.1611	2.9882
-2.5208	2.0531	0.8410
-0.7674	1.9066	2.0031
-1.9148	0.3453	0.4054
2.1413	1.6644	5.9389
-2.1618	-6.1014	-3.0087

Table 3. 2nd layer weight

LW4	LW5	LW6	LW7	LW8	B2
2.1614	-1.028	2.1379	0.3352	-4.7718	-5.2855
-1.790	1.6255	3.4147	2.2069	-1.6187	-0.3446
-2.601	-0.170	-1.448	3.5453	-4.0419	-4.7787
-1.755	2.2539	3.8194	-3.944	3.7006	1.9265
1.5690	4.5155	-4.818	0.5831	-0.9929	0.5239

❖ **Neural Network Weight Implementation**

After IW, LW and bias are obtained from the NN process, the next step is to implement the data into the arduino and monitor the output value in Visual studio. The equations for mathematic process are:

$$z1 = logsig ((a1 * IW11) + (b1 * IW21) + (1*B1)$$
$$||$$
$$z67 = logsig ((a67 * IW167) + (b67 * IW267) + (1*B167)$$
(1)

$$oz1 = (z1 * LW11) + \dots + (Z67 * LW167) + (1 * B21))$$
(2)

$$oz2 = (z1 * LW21) + \dots + (Z67 * LW267) + (1 * B22))$$
(3)

$$y1 = logsig (oz1)$$
(4)

$$y2 = logsig (oz2)$$
(5)

C. *The Application of Extreme Learning Machine (ELM) on the plant*

❖ **Extreme Learning Machine Design**

In this research, the number of ELM input consist of 67 neurons and two output neurons as shown in Fig. 5. The two input neurons contain the information about the data of thermocouple sensor and the data of smoke sensor. Output neurons will give information about speed of fan and duration of nozzle oil pump.
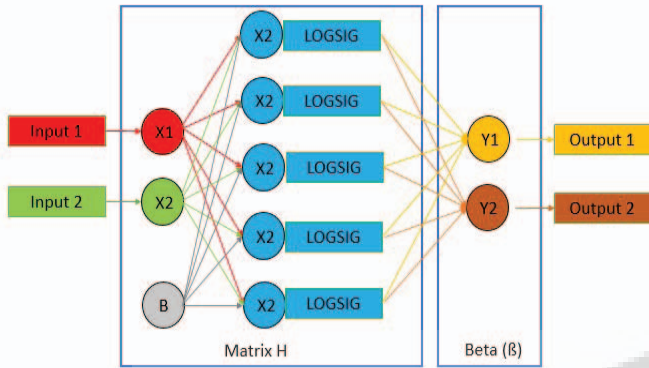
Fig. 9 Extreme Learning Machine Structure

From Figure 5 it can be explained that in Extreme Learning Machine method for this prototype is using 2 inputs and 2 outputs, matrix H with maximum dimension of 5x5 and minimum 2x2 and matrix Beta (β). The used activation function is the "LOGSIG" activation function.

❖ **Input and Output Data**

For input and output the training data process of ELM method is similar to table 2 above.

❖ **Extreme Learning Machine Training Process**

The weights (w, v, b) of the ELM training process are randomly assigned and calculated in the H matrix. In the training process the 14 parts weight training are the same with the word data entry practice so the H matrix becomes singular. Then the H matrix is used to determine Beta "β".

❖ **Extreme Learning Machine Training Result**

The result of training is matrix beta (β) with 5x2. Where:

$$Beta (ß) = H^T T \qquad (6)$$

Where the hidden layer output is noted as H, β is the output weight matrix and T is the value of training data output.

❖ **Beta (β) Implementation**

Here is the first row of the H matrix equation:

$$H = [logsig(w_{11}x_{11} + v_1x_{21} + b_1)... logsig(w_sx_{11} + v_sx_{21} + b_t] \qquad (7)$$

To determine the output value use the equation 8 :

$$y = H * ß \qquad (8)$$

III. DATA ANALYSIS AND DISCUSSION

A. Test Scenario or Procedure

This section will explain how the system testing process and compares the 4 actual training data based on NN and ELM training data results. Then a comparison is performed between the validation data with the actual data of NN and ELM.

B. Comparison of Neural Network Performance and Extreme Learning Machine

This section will compare the performance of Neural Network and Extreme Learning Machine to prove the best method. The result is shown in table 3.

Table 3. NN VS ELM Test Result Comparison

Test Data NN							
Input				**Output**		**Error²**	
Temp (°C)	**Smoke**	**Fan (V)**	**Pump (s)**	**0**		**NN**	
				Fan (V)	**Pump (s)**		
25	200	2,5	0,525	2,4198	0,5750	0,0064	0,002
30	250	3,5	0,45	3,6754	0,5096	0,0308	0,004
35	300	4	0,375	3,8993	0,3870	0,0101	0,000
40	300	4,2	0,355	4,4446	0,3569	0,0598	0,000
50	400	7	0,35	7,0985	0,3498	0,0097	0,000
55	400	7,5	0,33	7,5994	0,3501	0,0099	0,000
70	500	7	0,24	7,3001	0,2495	0,0901	0,000
75	500	9,5	0,15	9,7002	0,1505	0,0401	0,000
90	400	10	0,15	11,0051	0,1519	1,0102	0,000
95	500	10	0,1	9,8799	0,126	0,0144	0,001
Total Error						**1,2815**	**0,007**
Root Mean Squared Error						**0,22641**	**0,0171562**
Test Data ELM							
Input				**Output**		**Error²**	
Temp (°C)	**Smoke**	**Fan (V)**	**Pump (s)**	**ELM**		**ELM**	
				Fan (V)	**Pump (s)**		
25	200	2,5	0,525	2,5	0,525	0,000	0,000
30	250	3,5	0,45	3,5	0,45	0,000	0,000
35	300	4	0,375	4	0,375	0,000	0,000
40	300	4,2	0,355	4,2	0,355	0,000	0,000
50	400	7	0,35	7	0,35	0,000	0,000
Input				**Output**		**Error²**	
Temp	**Smoke**	**ELM**	**Pump**	**ELM**		**ELM**	

(°C)			(s)	Fan (V)	Pump (s)		
55	400	7,5	0,33	7,5	0,33	0,000	0,000
70	500	7	0,24	6,9998	0,2389	0,00000004	0,00000121
75	500	9,5	0,15	9,5	0,15	0,000	0,000
90	400	10	0,15	10	0,15	0,000	0,000
95	500	10	0,1	10	0,1	0,000	0,000
Total Error						0,00000004000	0,00000121000
Root Mean Squared Error						6,32456E-05	0,000347851

From table 3 above, it can be explained that Root Mean Squared Error (RMSE) value of the ELM method is smaller than the NN method. Training time for the NN method is longer than the average training time of 14 parts of the ELM training method. For more details, the performance comparisons of NN and ELM are shown in table 4 below.

Table 4. NN VS ELM Performance Comparison Result

No.	Description	NN		ELM	
		Output1	Output2	Output1	Output2
1.	Training RMSE	0.22641	0.01715	6.32E-05	0.000347
2.	Training Time	0.99984		0.014779	

IV. CONCLUSION

From the experimental results in this research can be concluded:

1. The Value of Extreme Learning Machine from matlab needs additional software because the typical of the data from inverse matrix have more than 12 digits so the arduino cannot process the data accurately.
2. Training time of ELM is faster than training time of NN.
3. Accuracy in ELM training results has an average error which is smaller than NN.
4. ELM method can be used as a primary choice rather than the NN to optimize the combustion system in furnace boiler.

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