

# Optimization and Prediction of Motorcycle Injection System Performance with Feed-Forward Back-Propagation Method Artificial Neural Network (ANN)

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## Article history

Received: 18-04-2015

Revised: 11-05-2015

Accepted: 08-02-2016

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**Abstract:** This research studied the use of Artificial Neural Network (ANN) using feed-forward back-propagation model to optimize and predict the performance of a motorcycle fuel injection systems of gasoline. The parameters such as speed, throttle position, ignition timing and injection timing is used as the input parameters. While the parameters of fuel consumption and engine torque is used as the output layer. Lavenberg-Marquardt model type with train function tanh sigmoid and 25 neurons number is used to generate the target value and the desired output. Variation of ignition timing as optimization variable in a wide range of speed and throttle position is used in experimental tests. ANN is used to investigate the prediction of performance motorcycle engines and compared with the test results. Results showed that the operation of ANN in predicting engine performance is very good. From the test results obtained a smooth contour MAP compared to the initial state. The prediction result and performance test show a good correlation in small error value of training and test that is regression with range 0.98-0.99, mean relative error with range 0.1315-0.4281% and the root mean square error with range 0.2422-0.9754%. This study shows that the feed-forward back propagation on ANN model can be used to predict accurately the performance of a motorcycle engine injection system.

**Keywords:** Artificial Neural Networks, Back Propagation, Ignition Timing, Optimization

## Introduction

The development of automotive technology at the present is very rapidly marked by using injection system (FI). Nowadays motorcycle on the market almost entirely using injection system (FI). The use of old motorcycles and other external factors caused a decline in the performance of the vehicle. It encourages researchers to be able to optimize the engine conditions with various method. Like the conventional method. This method will certainly take a long time and a lot of cost. So we need a right simple method to overcome the problems in conducting research.

Artificial Neural Network (ANN) is a numeric method whose that concept mimics the existing neural network system in the human body, which is built nodes are interconnected to one another. According to Yusaf *et al.* (2010) ANN is widely used to predict the performance and exhaust emissions of a diesel engine

and gasoline both similar results were reported recently (Phacbhai *et al.*, 2014). The ANN principle is similar to the black box model that provides information system based on the fixed or not fixed input parameters with the train data previously (Golcu *et al.*, 2005). In some cases the use of conventional ANN in determining the torque and Fuel Consumption (FC) more on large capacity machines with variations in type of fuel used. Cay (2013) reported that ANN can investigate Fuel Consumption (FC) on a gasoline engine 4 stroke 4-cylinder with data from the training result and test proposed by ANN. Train model used in the process of observation using a feed-forward back propagation model. Feed-forward back-propagation is a train neural network system that can calculate the error rate of its output, so that the neural network which used to have the smallest errors (Jha, 2014). By using feed-forward back propagation model, the training result and test can show

a good correlation. ANN also can investigate characteristics of Internal Combustion Engine (ICE) dual-fuel with different fuel mixtures (Jahirul *et al.*, 2009). The use of several models of feed forward back propagation selected to predict the performance of this engine. Feed-forward back propagation generally use the model function of Levenberg-Marquardt (LM). In the observation process, models function of LM gives excellent results for predicting engine performance.

To obtain maximum results in predicting the data there are several ways and the way that often done is divide the data which will be in train and will be tested. The possibility that not all the experimental data will be in train. Togun and Baysec (2010) research the use of Artificial Neural Network (ANN) models to predict torque and Brake Specific Fuel Consumption (BSFC) at a gasoline-fueled engine. ANN model is proposed based on that experimental results. Experimental studies completed to obtain data which will be in train and will be in test. Jahirul *et al.* (2013) has shown that from 81 data consists of 63 train data and 18 test data in ANN process. The division multiple train and test data very helpful if there are much of result data so that the experiment will be faster.

Some ANN *variables* such as the number of neurons is also one of the factors of accuracy predictions. Jahirul *et al.* (2009) using ANN to predict the engine performance parameters. The use of Feed-forward back propagation model with Levenberg-Marquardt (LM) function model investigated in several variations of hidden neurons. Based on the nonlinear regression value and difference in outcome prediction error of each neuron is very small. The error value in the range of 0.0012-0.0099 and nonlinear regression in range 0.9904-0.9912. By making some variation of neurons with different of not significant error value will be wasting time and memory for calculation.

According to Oguz *et al.* (2010) that by using of numerical analysis or Artificial Neural Network (ANN) to predict the performance of the machine that can be advantageous in terms of time and cost. So that not necessary to repeated testing or guessing own performance that will eventually be re-examined. Because ANN has been very accurate predictions statistically.

In this study, we will investigate the ability of artificial neural network using ANN feed-forward back propagation model with Levenberg-Marquardt function 25 number of neurons model to optimize and predict the performance of a motorcycle fuel injection systems of gasoline on a variety of engine rotation (speed) and opening valve (throttle position). In this case the engine performance parameters as output parameters is fuel consumption and engine torque. The results show that there is a good correlation between the results of experiments with ANN prediction.

## Experimental Setup

A motorcycle injection system (FI) of gasoline fuel used in this work. This injection system engine with a displacement volume 110 cm<sup>3</sup> and a compression ratio of 14.7: 1 is used as the standart operating state. The power of this engine is 6.27 kW at speed 8000 rpm, while maximum torque is 8.68 Nm at speed 6500 rpm which will be operated at range of speed 1500-9250 rpm. Table 1 Summary of motorcycle specifications injection system (FI) that will be tested. The standart data is based on state running on the dynamometer which is connected to the scanner to read the ignition timing and data acquisition to measure the engine's torque. Operating the engine at range of speed 1500-9250 rpm with engine output concentrations is torque of the engine, Fuel Consumption (FC).

Performance test conducted by the materials. Such as dynamometer EECL-01 as the track of motorcycle injection system. Keihin ECU type with a serial number KZL-C31 is used on this motorcycle to control the parameters of the machine during operation. To know the value of parameters like ignition timing and injection timing required additional tools namely HiDS Scanner to read these parameters. HiDS scanner connected to the motorcycle injection when operating at range of speed 1500-9250 rpm. The condition of the machine is on 29°C so that no environmental factors that affect the performance of the engine. In the motorcycle injection paired a tool namely acquisition data which connected to the signal control tool that reads the signal than the sensors of motorcycle. The incoming signal will be changed by the conditioner signal to the digital system process by DAQ hardware in the form of torque at various speeds. Experimental procedures in detail can be seen in Fig. 1.

Techniques of Artificial Neural Network (ANN) is used to optimize and predict the parameter value of testing machine data. From 640 data sets selected 170 data to train and test. Initial experimental data obtained by conventional measurement without involving ANN. As in Table 2 that is the initial data measurement injection system of motorcycle engine (FI). This 170 data sets is processed and analyzed by the ANN feed-forward back propagation model with Levenberg-Marquardt function train model. Neuron number 25 single layer applied to obtain the accurate data.

By entering the input *variables*, namely speeds, throttle position, ignition timing and injection timing obtained from the readings on the scanner HiDS. While to the output *variables* selected Fuel Consumption (FC) and engine torque. The training process is not carried out as a whole but by dividing 170 previous data into 10 terms. This is done to minimize the error in predicting the result of the model ANN.

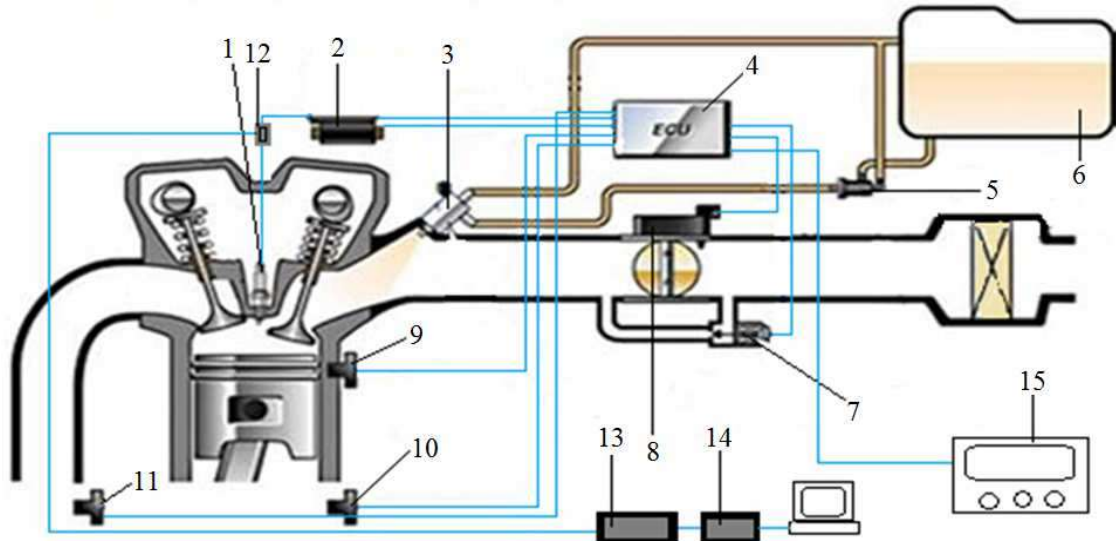


Fig. 1. Schematics of the experimental system. 1. Ignition; 2. Ignition coil; 3. Injector; 4. Electronic Control Unit (ECU); 5. Fuel filter; 6. Fuel tank; 7. Bypass valve; 8. Intake air pressure sensor, Intake air temperature sensor and Throttle position sensor; 9. Engine temperature system; 10. Crankshaft position sensor; 11. Oxygen sensor; 12. Inductive pick up; 13. Signal conditioner; 14. DAQ hardware; 15. Scanner HiDS

Table 1. Specifications engine of the motorcycle fuel injection system

Characteristics of the engine	Specifications
Stroke Diameter	50.0×55.0 mm
Stroke Volume	108.0 cm <sup>3</sup>
Compression Ratio	14.7: 1
Displacement	110 cm <sup>3</sup>
Motorcycle	Automatic Fuel Injection
Maximum Power	6.27 kW (8.52 psi)/8000 rpm
Maximum Torque	8.68 Nm (0.89 kgf.m)/6500 rpm
Engine Speed	1500-9250 rpm
Ignition Timing	11-55°C A (Bell, 1981)

Table 2. Ignition timing map of motorcycle fuel injection system

Speed (rpm)	Throttle position (%)									
	10	20	30	40	50	60	70	80	90	100
1750	15.0	15.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2000	17.0	16.5	16.5	16.5	16.5	16.5	16.0	16.0	15.5	15.5
2500	21.0	18.0	18.0	17.5	19.0	17.5	17.0	17.0	17.0	17.0
3000	25.0	20.5	21.0	19.0	21.5	19.5	19.0	18.5	18.0	18.0
3500	31.5	26.5	25.0	21.0	24.0	21.0	21.0	20.0	19.5	19.5
4000	35.0	29.5	26.0	22.0	24.0	23.0	22.0	22.0	21.0	21.0
4500	39.0	32.5	28.5	24.0	25.5	24.5	24.0	23.0	22.0	22.0
5000	43.5	36.0	30.5	27.0	26.5	26.0	25.0	25.0	22.0	22.0
5500	47.0	39.0	32.0	29.0	27.5	26.5	25.5	25.0	23.5	22.0
6000	49.0	42.0	34.0	31.5	29.5	28.5	26.5	25.5	24.0	22.0
6500	50.0	44.0	35.5	32.0	30.0	29.5	27.5	26.0	24.0	22.5
7000	50.0	46.5	36.0	32.5	31.0	30.0	27.5	26.5	24.5	23.0
7500	50.0	48.5	36.5	33.0	31.5	31.0	28.0	26.5	25.0	23.0
8000	50.0	49.0	37.0	34.0	33.5	32.0	28.5	26.5	26.0	24.5
8500	50.0	49.0	40.0	37.0	35.5	33.5	29.5	28.5	27.5	26.5
9000	50.0	49.0	40.0	37.0	37.0	36.0	33.5	32.0	31.0	29.0
9250	50.0	49.0	40.0	38.0	37.0	36.0	34.0	32.0	31.0	31.0

Optimization is done by advancing the ignition timing starts from +2 to +5°CA then do the training back to obtain the next predict results. Testing was conducted to obtain the accuracy prediction of ANN.

## Theory and Methods

### *Injection System (FI)*

The injection system is a system that supplies fuel to use injector on orders of Electrical Control Unit (ECU). Electronic Control Unit (ECU) is an intelligent electronic device that capable of processing multiple input data from the sensors to provide the appropriate output to improve the quality of combustion. Volume and time of spraying fuel (gasoline) injected directly into the combustion chamber electronically (Heywood, 1988). Injection system (FI) with the fuel injection process occurs at the end of the intake manifold before entering the inlet valve when the inlet valve is open. Ideally, the system (FI) should be able to supply the amount fuel varies, so that changes in the operating conditions of the engine work can be achieved with optimum engine work (Bell, 1981). Optimal conditions of a machine can be seen from the performance value of the machine itself.

Engine performance is the ability of the machine to do the rounds to generate energy and power. To determine the level of engine performance in apply the ANN model selected based on parameters that take affect such as: Fuel consumption, torque and power. One of injection system vehicle performance is determined by the length of the ignition timing and injection timing (Kullolli *et al.*, 2014).

### *Effect of Ignition Timing to Engine Performance*

Li *et al.* (2010) has shown that ignition timing greatly affects the performance of a machine. To get the maximum power of the engine, the air-fuel mixture compressed should give the maximum pressure at the beginning of the expansion step, so that the combustion must be started before the piston reaches Top Death Center (TDC). To achieve maximum power can only be achieved if the ratio of air and fuel right and also with the right time too. Modify the ignition timing by advancing the ignition timing to obtain a more optimal performance (Zareei and Kakaee, 2013). This is done because there is a time lag between the arcing sparks with the onset of combustion of fuel and also depends on the nature of combustion properties of each fuel has a specific time to end the combustion process. The ignition timing control that regulates the working process of motorcycle engine.

Ignition timing and injection timing plays an important role in performance, fuel consumption and pollution formation. Injection timing affects the

ignition delay due to temperature and pressure changes significantly close to the Top Dead Point (TDC). By advancing injection timing, the initial air temperature and lower pressure so that the ignition delay will be increase temporarily slowed closer with TDC when the air temperature and pressure were slightly higher, resulting in shorter ignition delay (Mohan *et al.*, 2013). However, slowing down or advancing injection timing beyond certain limits which varies of the machine can cause of a poor combustion. Rahman *et al.* (2014) has shown that injection timing also has a strong effect on the performance of the engine, especially on fuel consumption and engine torque. While the length (duration) injection will varies depending on the engine working conditions. When injection takes a long time of duration, then the amount of fuel will be more and more.

### *Artificial Neural Network Modeling*

ANN typically consists of input layer, hidden layer and output layers. The information contained in the input layer is mapped to the output layer through the hidden layer (Ilankumaran *et al.*, 2015). Each node on each layer has an error rate, which will be used for the training process. Neural network with layers has a concept of work as follows: Specific output of neurons is a function of the input weight function, neurons reflection and activation function. Figure 2 shows the basic artificial neurons of the hidden layer. In a simple form, each single neuron is connected to other neurons from the previous neuron continuously adapted to it's synaptic weight:

$$S_i = n = \sum_{j=1}^n x_j w_{ij} + b_j \quad (1)$$

Which is:

$$y_j = f(n) = f\left(\sum_{j=1}^n x_j w_{ij} + b_j\right) \quad (2)$$

In Equation 1 and 2 are the general equations that underlie ANN model process with  $S_i$  is activation function used.  $X_i$  is input variables selected in the model.  $W_{ij}$  is the amount of weight that selected by random and  $b_j$  is the refractive adaption of each weight.

ANN modeling in predicting an engine case is based on relationships corresponding function in order to obtain the best correlation. The selection of neuron number is not take effect if the parameters of input and output as in Fig. 3 shows an illustrative example of a network topology with 4 input variables, 25 neurons and 2 output are interconnected to configure a specific network. ANN as mediator determines target

of in out and output correlation results from the calculation of training function namely feed-forward back propagation. Feed-forward back-propagation is one of computing program for the application of a neural network that is widely used to solve non-linear problem and network multiplayer by generalize the Widrow-Hoff equation (Principe *et al.*, 1999). Neural network must be train again and again with the corresponding input pattern, so that the neural network can recognize that patterns and gained weight and also refraction of each layer with the smallest error because the weakness of feed-forward back-propagation which is:

- Feed-forward back-propagation can recognize the input pattern that has been taught but cannot recognize the new input pattern
- In recognizing the new input pattern, the pattern must be train so that the old pattern will be forgotten
- Initiation of weight is entering the weights and refraction values for each layer with random numbers

Feed-forward back-propagation generally uses binary sigmoid function and bipolar sigmoid function. Usually the basic shapes used in back-propagation models are feed-forward and Levenberg-Marquart (LM) with training function tanh sigmoid that is (Jha, 2004; Sayin *et al.*, 2007):

$$\sigma(t) = \tanh(t) = \frac{e^t - e^{-t}}{e^t + e^{-t}} \quad (3)$$

The derivatives is:

$$\frac{d\sigma(t)}{dt} = 1 - \tanh^2(t) = \text{sech}^2(t) = 1 - \frac{(e^t - e^{-t})^2}{(e^t + e^{-t})^2} \quad (4)$$

In Equation 3 and 4 shows  $\sigma(t)$  as a target to be achieved. The target is based on a training function that reached from the initial weight that was given by input.

While  $t$  is the neuron's target to calculated as the weight initialization of weight output.

That accuracy targets reached are visible on the error value during iteration. The value of the correlation error prediction is determined by the results of error value on ANN model to obtain the optimal and the best result. There are 3 criteria R, RMSE and MRE chosen to evaluate the network to find the optimal solution as follows:

$$R^2 = 1 - \frac{\sum_j (t_j - o_j)^2}{\sum_j (o_j)^2} \quad (5)$$

$$RMSE = \left( \frac{\sum_j^n (t_j - o_j)}{n} \right) \quad (6)$$

$$MRE = \frac{1}{n} \sum_1^n \left| 100 * \frac{(t_j - o_j)}{t_j} \right| \quad (7)$$

Which are  $t_j$  is amount the targets,  $o_j$  is number of output and  $n$  is the number of neurons. Three 3 standard criteria of R, RMSE and MRE selected to evaluate various network (R is an error, RMSE is root mean square error and MRE is mean relative of error. A numerical analysis of the network response and the corresponding target to study more precisely the response network (Shojaefard *et al.*, 2012). The best prediction results have been selected from the smallest error with the regression close to 1. It means that the value among achieved target against output showed good accuracy.

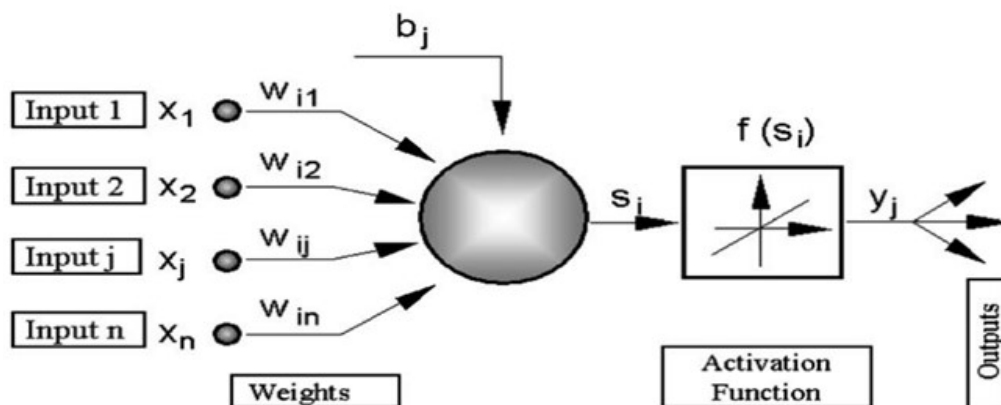


Fig. 2. A Basic artificial neuron

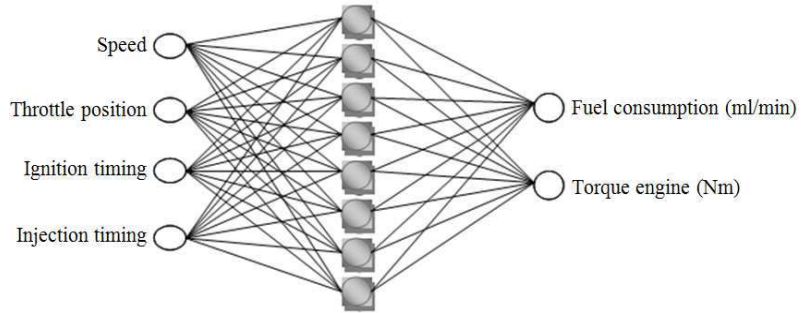


Fig. 3. ANN with network topology

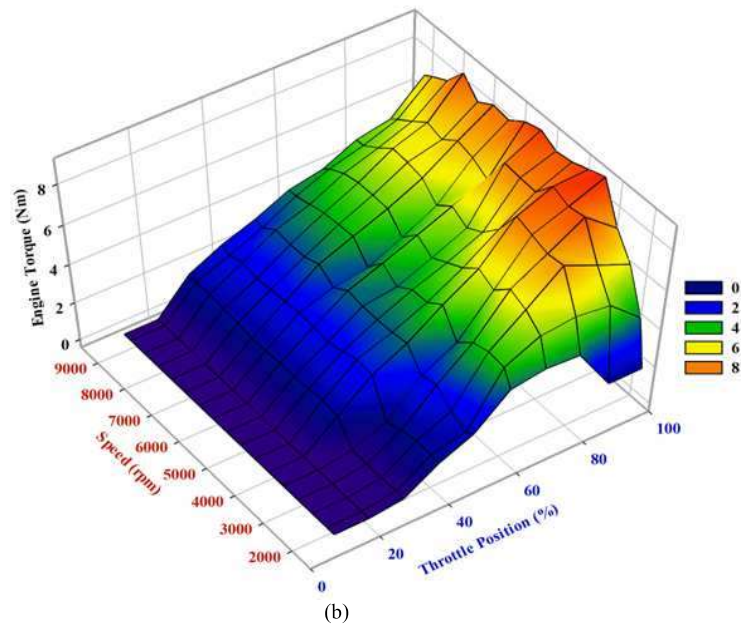
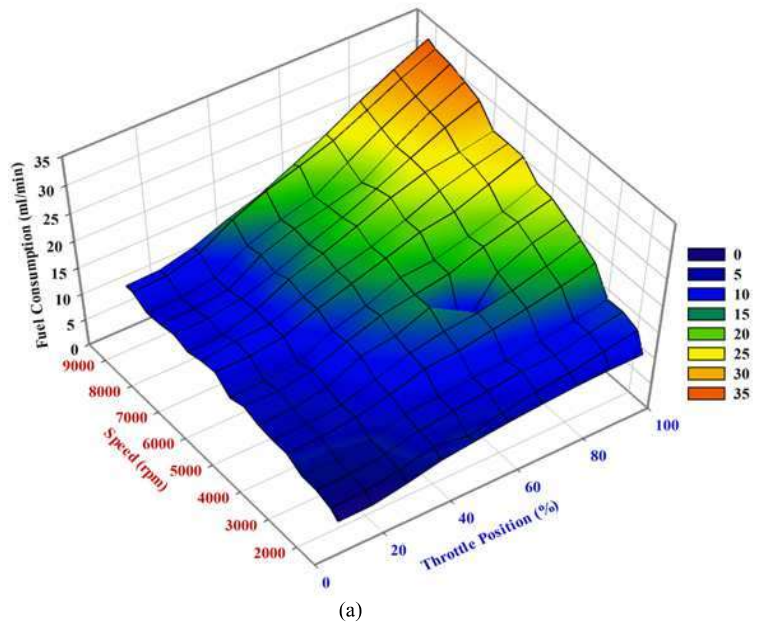


Fig. 4. (a) Fuel Consumption (FC) Map of motorcycle injection system; (b) Engine torque map of motorcycle injection system

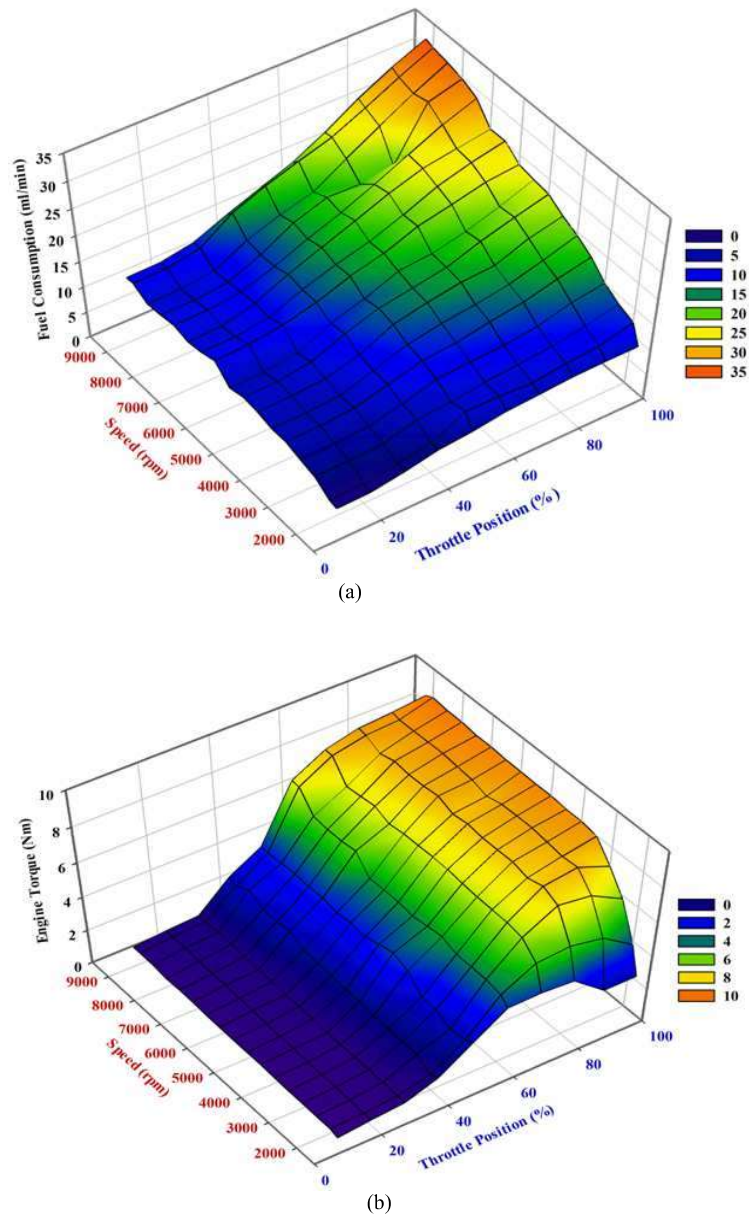


Fig. 5. (a) Fuel Consumption (FC) Map test results ANN ignition +2°C; (b) engine torque map test results ANN ignition +2°C

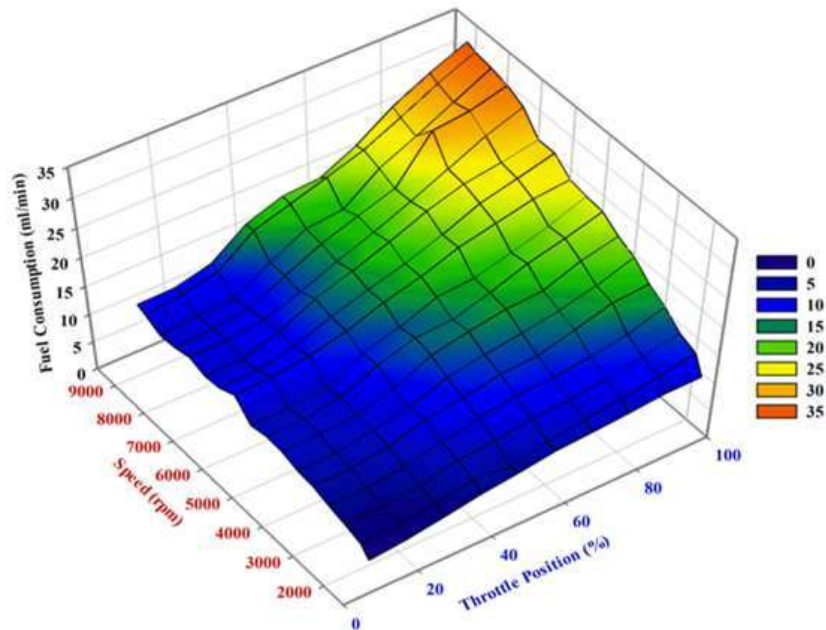
Contour MAP engine torque against speed and throttle looks rough. So, we need optimization using ANN method. Imperfect combustion as the impact of control ignition timing and injection timing is not appropriate.

Figure 5b shows the contour MAP engine torque on the speed variation and throttle position where the engine ignition timing is advanced 2°C. The result is a significant increase in torque occurs at speeds and forming a smooth contour. Fuel consumption is also changing as a result of an increase in torque. On Fig. 5a shows a fairly smooth contour MAP compared to the initial state in which Fig. 4a Fuel consumption decline

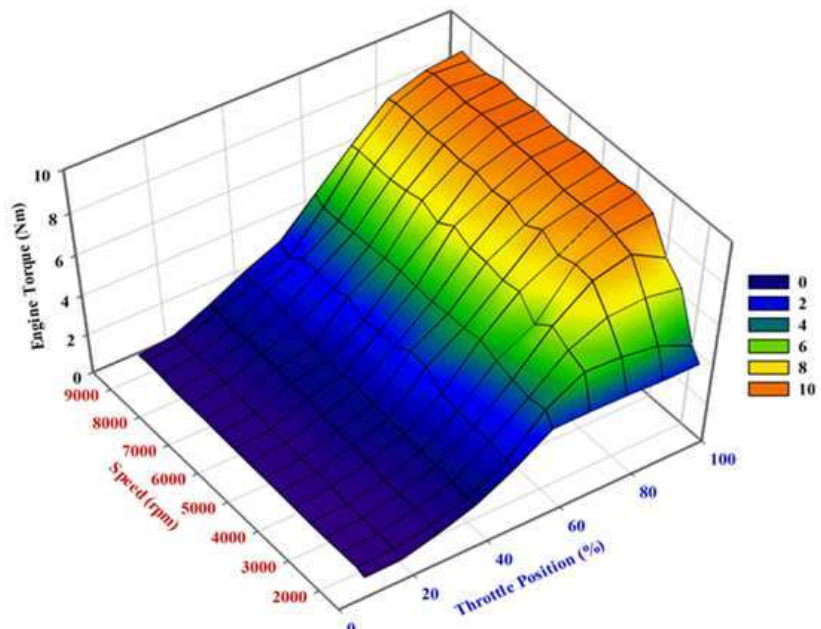
on speed of 4500 rpm at throttle position 70%. Correlation of predictions result and experimental for engine torque and fuel consumption in Fig. 8a and 10a show good results for the ignition timing is advanced 2°C. Test points are formed as a result of this relationship approach the ANN linear line with error value of the training output  $R^2$ , MRE and RMSE are 0.99, 0.3487 and 0.0372% respectively for the fuel consumption. While the error value of the test output are 0.99, 0.2832 and 0.2860% respectively to the value of  $R^2$ , MRE and RMSE. For more details about fuel consumption error value of training and test results overall can be seen in Table 3.

Table 3. Error value of Fuel Consumption (FC) using training and test ANN

Train function	Ignition Timing	Training output layer			Test output layer		
		R <sup>2</sup>	MRE	RMSE	R <sup>2</sup>	MRE	RMSE
Lavenberg Marquardt Feed	+2	0.99	0.3487	0.0372	0.99	0.2832	0.2860
Forward Back Propagation	+3	0.98	0.2411	0.0273	0.99	0.2487	0.3209
	+4	0.99	0.2872	0.0257	0.99	0.2673	0.2422
	+5	0.99	0.3565	0.0355	0.98	0.2975	0.2640



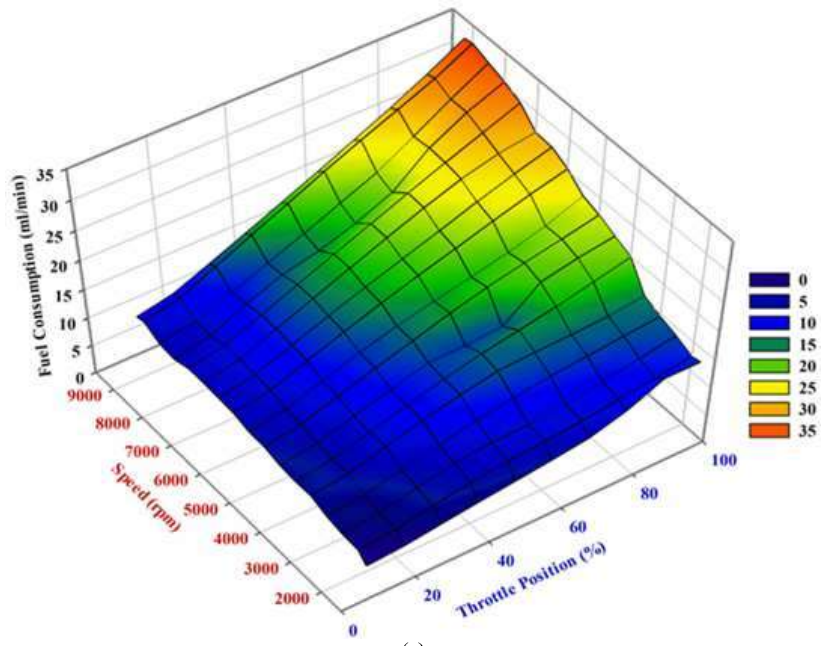
(a)



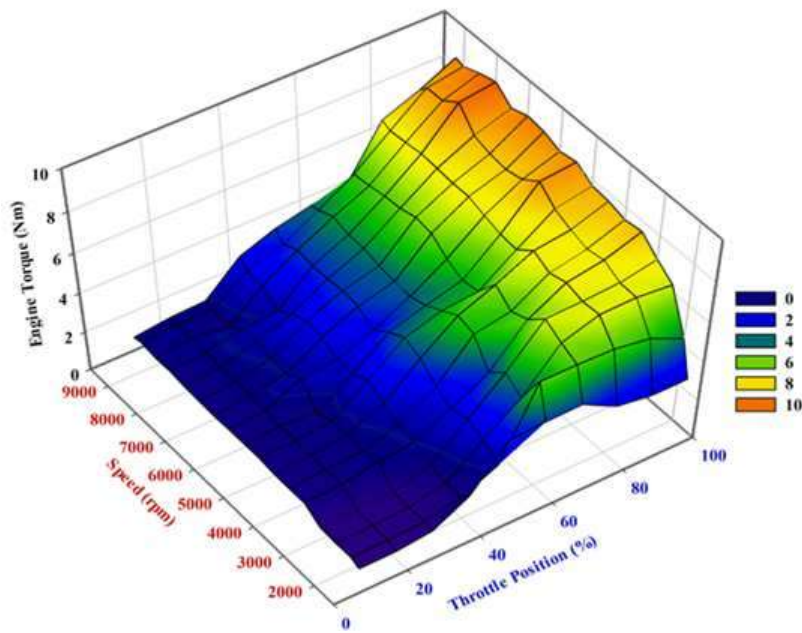
(b)

Fig. 6. (a) Fuel Consumption (FC) map test results ann ignition +3°C; (b) Engine torque map test results ANN ignition +3°C





(a)



(b)

Fig. 7. (a) Fuel Consumption (FC) map test results ANN ignition +4°C; (b) torque engine map test results ANN ignition +4°C

Table 4. Error value of engine torque using training and test ANN

Train function	Ignition Timing	Training output layer			Test output layer		
		R <sup>2</sup>	MRE	RMSE	R <sup>2</sup>	MRE	RMSE
Lavenberg Marquardt Feed	+2	0.98	0.1315	0.8368	0.99	0.2244	0.8531
Forward Back Propagation	+3	0.99	0.1933	0.5643	0.98	0.2395	0.5788
	+4	0.99	0.3455	0.8743	0.99	0.3328	0.9754
	+5	0.99	0.4281	0.9753	0.99	0.3577	0.8864

Figure 6a and b show that the contour MAP fuel consumption and engine torque with the ignition timing is advanced 3°C. The experimental results for the engine torque shows a smooth contour with an increase in torque as a result of the advancement of ignition timing as in Fig. 8b This increase triggers a fuel consumption in Fig. 6a where the contour begins smooth. ANN prediction based on input and output with advancing the ignition timing to obtain satisfactory results. Experimental as validation of the use of the ANN model as shown in Fig. 8b and 10b that the ANN predictions and experimental results for the torque and fuel consumption are good. It is visible from a small error values for the engine torque at the training outputs 0.99, 0.1933 and 0.5643% for each error value  $R^2$ , MRE and RMSE. While it test output results are in small error value too, namely 0.98, 0.2395 and 0.5754% on each of  $R^2$ , MRE and RMSE. Good prediction results not only in advanced ignition timing 2 and 3°C but for the ignition

timing is advanced 4 and 5°C also showed a good correlation between experimental and predicted of ANN results. But in Fig. 7a and b contour MAP fuel consumption and engine torque is not smooth. By advancing 4°C can increase high torque, it resulting instability of fuel combustion. The best predictions views by the smallest of error value. Linear regression is to know the relationship between a variable with another variable. On Fig. 9a and 11a for the ignition timing +4°C with correlated relationship where the test point between the prediction results and actually as well as Fig. 9b and 11b for ignition +5°C with satisfactory results. Error value of each ignition timing also small for training and test output. In more details about the calculation of the error value overall can be seen in Table 3 and 4. The results of these predictions can be received with a small percentage of error value and certainly proves that the use of ANN in optimizing and predict the engine performance is very appropriately.

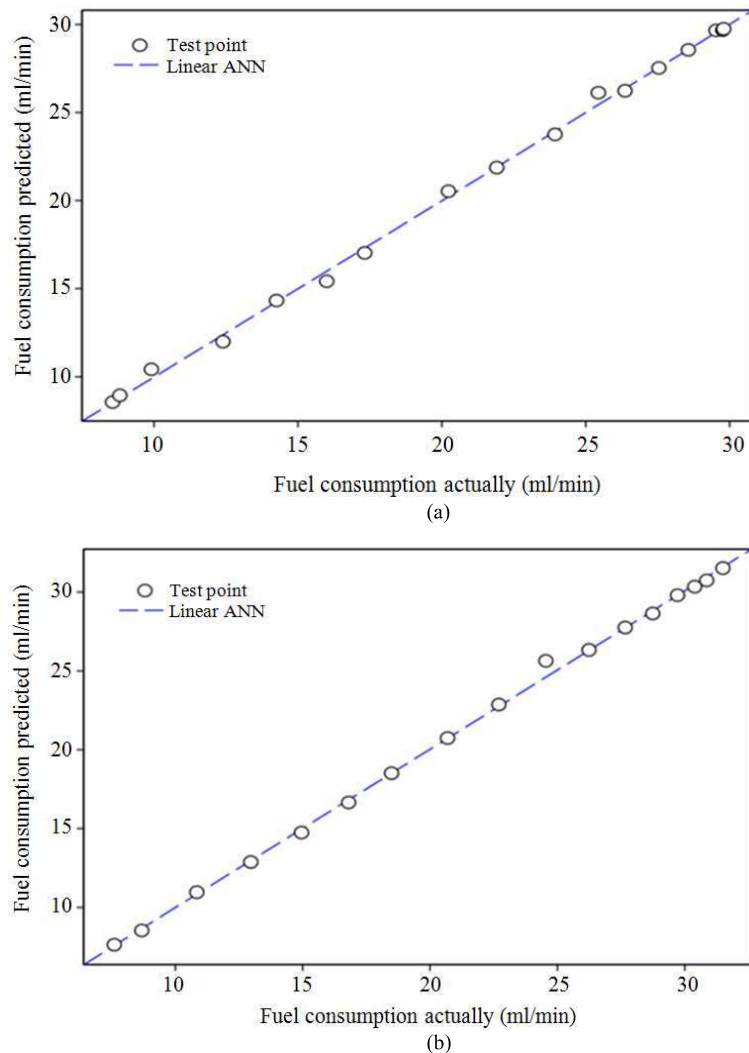
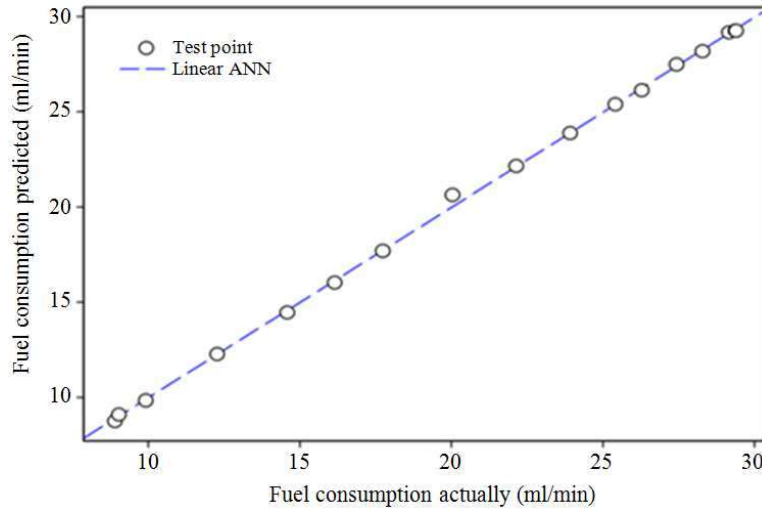
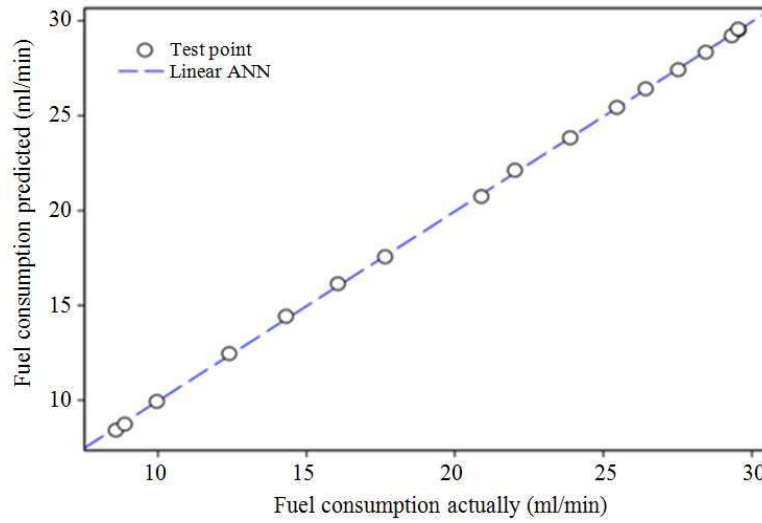


Fig. 8. (a) FC predicted Vs FC actually for ignition +2°C; (b) FC predicted Vs FC actually for ignition +3°C

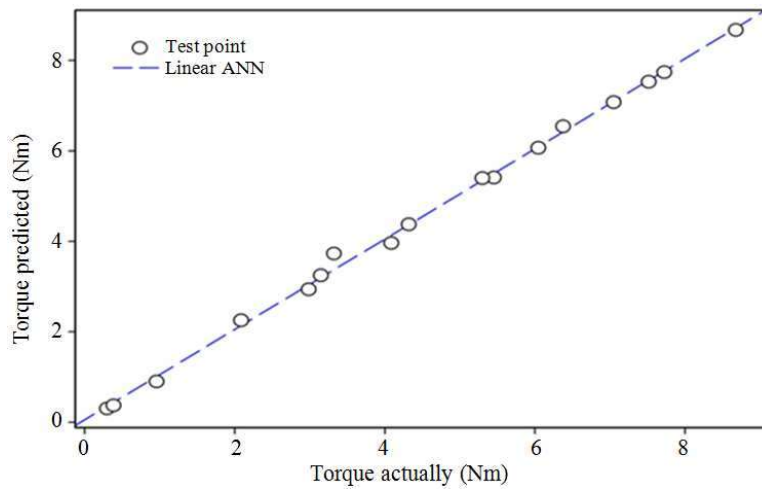


(a)



(b)

Fig. 9. (a) FC predicted Vs FC actually for ignition +4°C A; (b) FC predicted Vs FC actually for ignition +5°C A



(a)

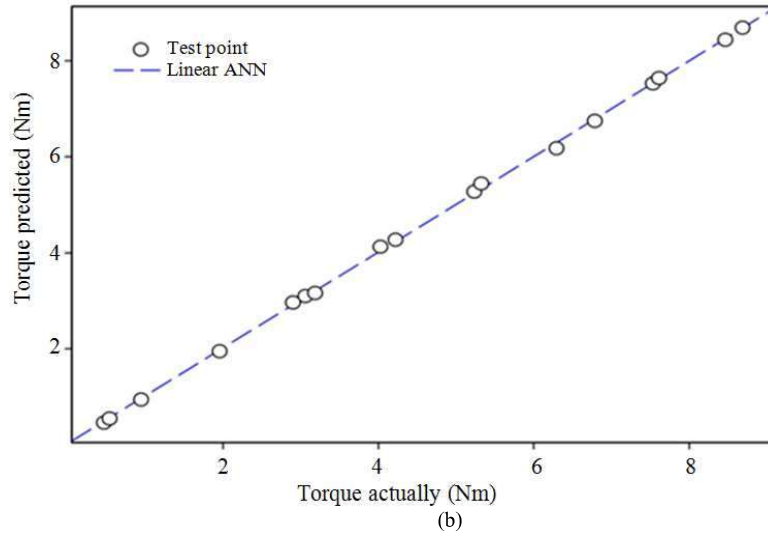


Fig. 10. (a) Torque predicted Vs torque actually for ignition +2°C; (b) torque predicted Vs torque actually for ignition +3°C

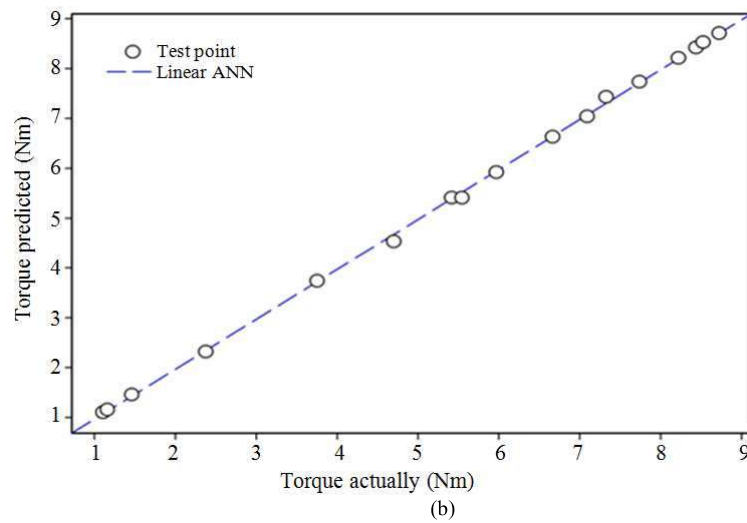
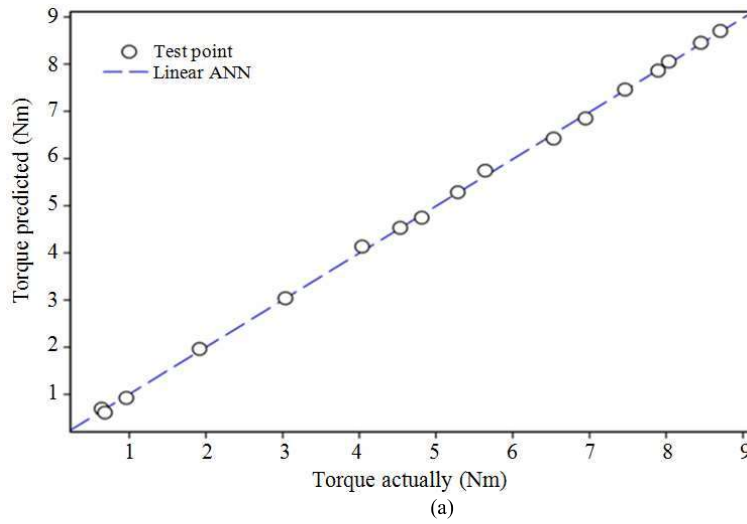


Fig. 11. (a) Torque predicted Vs torque actually for ignition +4°C; (b) torque predicted Vs torque actually for ignition +5°C

## Conclusion

The intent of this paper is the use of Artificial Neural Network (ANN) to estimate the performance of a motorcycle with the injection system using the initial ignition timing differences. To train the network speed, throttle position, ignition timing and injection timing are used as an input and the output are Fuel Consumption (FC) and engine torque. These studies consistently use gasoline to predict fuel consumption and engine torque on the engine. Ignition timing is advanced 2°-5°CA and tested to be developed. Then ANN predicting the performance of engine that has been measured compared with test results and obtained the smooth contour MAP on ignition timing +2 and +3°CA for test results engine torque and Fuel Consumption (FC). The relationship between the prediction and actually using ANN linear regression with the best accuracy. ANN model prediction accuracy of the data obtained the best error value namely regression between range 0.98-0.99, mean square error between range 0.1315-0.4281% and the root mean square error between 0.0257-0.9753% for training data, while for test data obtained the error value namely regression between range 0.98-0.99, mean square error between range 0.2244-0.3577% and root mean square error between range 0.2422-0.9754%.

Overall results indicated that the ANN can be used as an alternative way to optimize and predict the performance of a motorcycle engine. So ANN with feed-forward back propagation model can be the best solution to predict accurately the performance of a motorcycle engine fuel injection system of gasoline consistently.

## Acknowledgment

We would like to thanks and awards firstly for Energy Efficiency and conservation laboratories, Department of engineering, University of Diponegoro (UNDIP), which is supporting this research financially and secondly for Puji Ahmad Karyadi, ST who helped in retrieval of data.

## Author's Contributions

**La Ode Ichlas Syahrullah:** Designed the experimental method, analysis of data, revise the results of a review paper, writing and completing of the paper.

**Nazaruddin Sinaga:** Designed the experimental method, analysis of data, revise the results of a review paper.

## Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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