Neural Network Modeling and Identification of Naturally Ventilated Tropical Greenhouse Climates

ROBIAH AHMAD[1], MD.NORAZLAN MD.LAZIN[2], SAIFUL FARHAN MOHD SAMSURI[3]
[1]UTM RAZAK School of Engineering and Advanced Technology,
UTM International Campus, 54100 Jalan Semarak, Kuala Lumpur,
MALAYSIA
[2,3]Department of Applied Mechanics, Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia, 81310 Skudai, Johor,
MALAYSIA
robiah@ic.utm.my, md.norazlan@gmail.com, saifulfarhan@gmail.com

Abstract: - Naturally ventilated tropical greenhouse is classified as a complex system because it involves with nonlinear process and multivariable system. The purpose of this study is to determine the mathematical model of NVTG climates to in order to describe and predict the dynamic behavior of temperature and humidity inside NVTG for development of its control system. The modeling of the system is divided into two parts namely parametric and nonparametric modeling. The auto regressive with exogenous input, ARX and nonlinear auto regressive with exogenous input, NARX model were used for the parametric models while neural network auto regressive with exogenous input, NNARX model was used for the nonparametric model. The recursive least square estimation, RLSE, was used for the parameter estimation of the parametric model while the artificial neural network, ANN used the Levenberg-Marquardt method for predicting the performance parameter of NVTG system for the nonparametric model. All the models established were validated using statistical validation method such as mean square error (MSE), root mean square error (RMSE), error index (EI) and for the nonparametric model it added with the correlation coefficient, (R). From the result, the best model for parametric model is identified with the error index of 0.0573 for temperature and 0.0362 for humidity. The best non-parametric model gives error indexes of 0.0025 for temperature and 0.0024 for humidity.

Key-Words: - Parametric, Non-parametric, Identification, Neural Network, Naturally Ventilated Tropical Greenhouse.

1 Introduction

Naturally Ventilated Tropical Greenhouse (NVTG) which also known as the tropical greenhouse in the South East Asia, is the new technology for the farmer in Malaysia. It is widely used lowland plantation for temperate crop which is quite similar to the greenhouse used in the highland for medium tempered crops such as vegetables, flowers and fruits [1]. The climate parameters such heat, vapors and humidity that vary inside of the greenhouse effect the plant growth. The outside climate of tropical greenhouses is mostly hot and humid, which is a major challenge to obtain the optimum climate through and energy balances.

The study on greenhouse started few years back to determine optimum climates that suitable for the plant growth, to protect the plant from the disease and insect, and also to lower the production cost. Besides, open farming exposed the plants to problems like higher possibility to disease attack and insect, over expose to the solar radiation and also bad weather like the heavy rain [2]. Due to the complexity of the phenomena involved inside NGVT during the plant growth process and the two important variables for photomorphogenesis of the plant which are temperature and hygrometry, are very sensitive to the outside weather, therefore it is imperative to have the mathematical model that best described the behavior of those parameters. Bennis et al. proposed performing regulation for the greenhouse internal state based on H2 robust control design [3], which that evaluated from control performance through a benchmark physical model derived from energy balance for the temperature and water mass balance for the hygrometry.

Besides, multi layers model of the greenhouse has considered to consider the complexity of the system and the phenomena involves to the system. Modeling of climate variables for each layer allows setting up the control dynamics in order to maintain an internal uniform distribution of the climates variables [4]. Artificial intelligence technique was used in the modeling and controls some climate variables that involve in the greenhouse system. Their objective is to demonstrate the validity of the use of AI techniques in the field of the greenhouse climate control. Due to the physical dynamics involved within a greenhouse, this paper obtained that fuzzy logic controller (FLC) gives the best performance in term of energy, precision and robustness [5]. An Elman neural network has been used to emulate the direct dynamics of the greenhouse. A multilayer feed-forward neural network has been trained to learn the inverse dynamics of the process to be controlled. The inverse neural network has been placed in cascade with the neural model in order to drive the system outputs to desired values [6]. Modeling and identification of nonlinear system is interest because it unnecessarily prior knowledge about the structure of the dynamical system. NN have a strong ability to perform nonlinear information processing. The adequacy of radial basis function neural networks to model the inside air temperature of a greenhouse as a function of the outside air temperature and inside relative humidity [7].

The objective of this study is to predict the performance of Naturally ventilated tropical greenhouse (NVTG) system using artificial neural network (ANN) by varying several parameters namely Humidity outside, Temperature outside, Irradiance, and wind speed. The ANN model based on the backpropagation algorithm has been developed to predict various output parameters of NVTG system. Data was acquired from the prototype scale of NVTG. The data was divided into training and testing sets to develop ANN model. Based on the six input parameters, the trained ANN model was used for predicting the performances of the NVTG system that is the humidity inside and temperature inside the NVTG system.

2 Data Acquisition for Modeling NVTG System

This subsection describes the experimental set-up for acquiring environmental climate of NVTG. The NVTG is located at the back of automation and control lab, Universiti Teknologi Malaysia in Skudai, Johor Bahru [8]. The prototype of NVTG is shown in Fig.1 with a floor area of 14.86 m2. In order to collect data for the simulation purpose, several sensors were installed and connected to a personal computer based control system. All the required data were collected and analyzed using software MATLAB R2007b.

Fig. 1 NVTG prototype with Chili plants

The flow to get collect and save the data start from the sensor placed on the suitable position inside and outside the NVTG prototype. After the sensor read the input, the data is transferred to the National Instrument wireless data acquisition (WIFI DAQ) system and the signal evaluates in the LABVIEW software in the PC-based system that use as the main storage for the data collection. The simulation studies for the inputs and outputs measurement are based on the one day data acquisition. The raw data was sampled with 30 second sampling time to be used in the simulation. The NVTG climate wireless monitoring system has various inputs parameters. This section explains the related parameters that have influence to the growth of chilies plantation inside NVTG. These parameters are wind speed, irradiance, inside and outside temperature, inside and outside humidity.

Based on Fig.2, the set of data shows the variation of speed of the wind within 24 hours. Wind blow more blustery around hour 8 to 10 cause by the raining and wind speed decrease till hours 16. Excessive wind speed can cause high transpiration

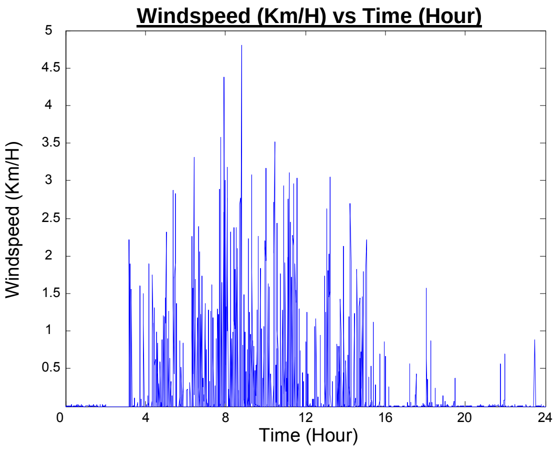

Fig. 2 Windspeed input data set in 24 hours

that creates water stress in plants. Water stress, which is also caused by insufficient soil moisture, is among the major causes of poor growth plants. It also makes plants more disposed to disease and less tolerant of destroyed by insect and pest.

Fig.3 shows that the variation of irradiance within 24 hours duration. From the graph, the value of irradiance increase from the sunrise around hour 1 until noon around hours 6 and decrease till hours 14. The irradiance goes to maximum above 10000 Lux at the afternoon around the hours 6 to 8. The irradiance is important for the photosynthesis process and it can give major effect for chilies growth inside the NVTG.

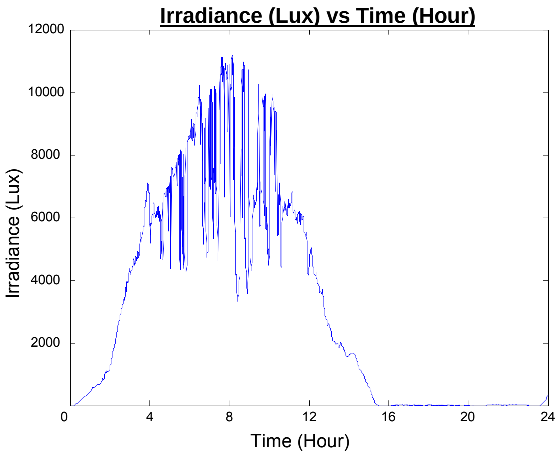

Fig. 3 Irradiance input data set in 24 hours

Fig.4 shows the variations of temperatures inside and outside NVTG. From the graph, during early morning starting from 12 am (hours 18) to 6 am (hours 24), the temperature was low and it started to rise up consequently as the sun raised. The maximum temperature obtained (34oc) on the 12 pm (hours 6) to 1 pm (hours 7). The effect of rain and the wind blowing possibly lower the inside temperature from 12 pm (hours 6) to 2 pm (hours 8). From the graph, the temperatures inside NVTG always higher than the temperature outside till the rain. Start from raining, the temperature decrease and the temperature inside lower than temperature outside. This situation occurs because the NVTG can absorb the heat and can maintain the temperature. After raining, around 3 pm (hours 9) to 4 pm (hours 10), the NVTG still maintain it temperature and the outside temperature start to increase and this yield the situation where the outside temperature is more hot that inside NVTG. The advantages of NVTG to hold the heat make it suitable for the chili cause higher the environment temperature the hotter the chili will be in flavor.

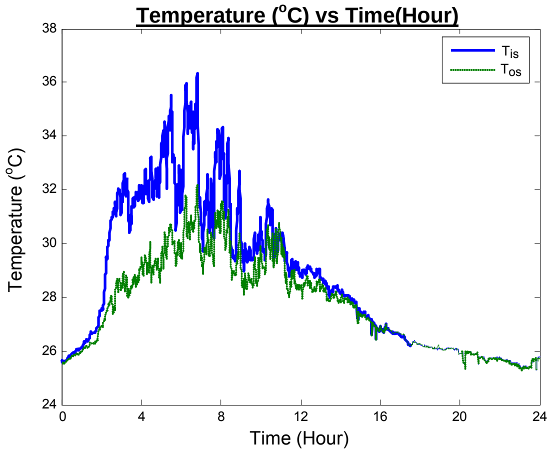

Fig. 4 Temperature input data set in 24 hours

Fig.5 shows the variation of humidity inside and outside NVTG. From the graph, the percentage of humidity outside NVTG is slightly higher than the percentage of humidity inside NVTG. The higher percentage of humidity show more comfortable the environment for the plants. Humidity is important to the plants because it partly controls the moisture loss from the plants. When the difference in humidity is large, the loss of moisture from the plant is rapid and severe. The pattern of the inside and outside humidity is almost same and so close to each other, this is not good cause the sensors shows that they cannot to take the good data. From the temperature data gets, it should have bit different pattern from the hours 2 up to the hours 12 on that days caused by the raining.

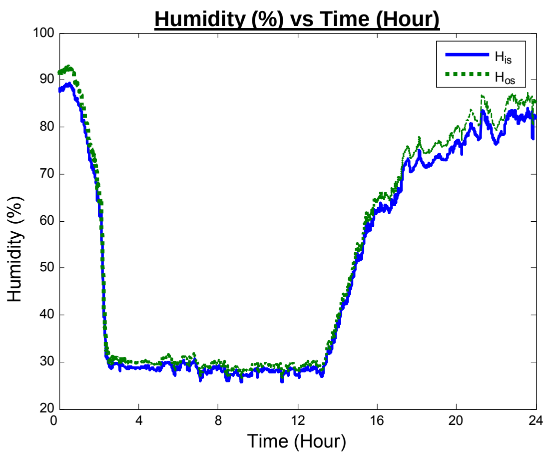

Fig. 5 Humidity input data set in 24 hours

3 Modeling and Simulation of NVTG

The simulation analyses are based on system identification and the mathematical model established using the parametric and non-parametric model. In this study, System Identification (SI) technique is used and this study differs on the model selection and the parameters estimation to analyze the NVTG model. In applying SI technique, several steps must be followed [9] which are data acquisition, determination of model structure, parameter estimation and finally model validation. The purpose of determining the mathematical model of NVTG climates is to describe the dynamic behavior of temperature and humidity inside NVTG. From the literature review, there are a lot of variables that might affect the variation or behavior of temperature and humidity inside the NVTG. However, for simplicity not all the parameters are taken into consideration. In this study only the parameters that possibly bring the major effect to the NVTG system are chosen. The data for simulation of the NVTG climates are from real experimental data. The data is obtained periodically through experiment and was taken continuously under 24 hours duration from this study on the chili inside the NVTG, the main parameters affected chili growth is temperature, humidity, wind speed and irradiance.

The first step in SI is data acquisition and the second step that is to obtain the model structure that represents NVTG. For this research, the ARX and NARX models structure are used for parametric model and NNARX model was used for the non-parametric model. Thirdly, parameter estimation of the model structure is identified by using RLSE for the model that establishes using the parametric model while the training using Levenberg-Marquardt method for MLP network that is done for non-parametric model. Finally, the last step involved is model validation. The procedure involved in model validation is OSA and the identified mathematical model will also go under several performance measures such as SSE, MSE, RMSE and EI. For the non-parametric model Post Training Analysis was used to validate the model. The best model was chosen based on their accuracy.

4 Parametric Modeling and Simulation of NVTG

The results of the predicted Temperature and Humidity inside the NVTG as well as the validation of the model established along with the residual graphs are presented and discussed.

Selection of model structure is important in order to describe the NVTG system to understand more about the behavior of the system. This model structure represent relates the past input and the output data to model the correct data. The outputs for representing the dynamic behavior of the measured inside temperature, T_{is} and measured inside humidity, H_{is} using polynomial equations are presented. The model is linear-in-parameter model. Model structure selections have to be view in terms of parametric and non-parametric model.

In this section, NVTG climatic parameters are initially modeled using ARX model structure representation. Studies are conducted by varying the ARX model structure parameters namely input lag, n_u and output lag, n_y. Then it followed by modeling using NARX model structure representation. Studies are also conducted by varying the NARX model structure parameters namely input lag, n_u and output lag, n_y.

The inside temperature, T_{is} and inside humidity, H_{is} were analyzed with varying the input lag, n_u and output lag, n_y values. There are four models that refer to combination of input lag, n_u and output lag, n_y. First model is the combination of input lag, n_u equal to 1 and output lag, n_y equal to 1. Second models are combinations of input lag, n_u equal to 1 and output lag, n_y equal to 2. Third models are combinations of input lag, n_u equal to 2 and output lag, n_y equal to 1. Forth models are combinations of input lag, n_u equal to 2 and output lag, n_y equal to 2. The graphs for the measured inside humidity, H_{is} and inside temperature, T_{is} are related to each other. Reading for inside humidity, H_{is} was recorded high when inside temperature, T_{is} is low. The comparisons between the actual and predicted outputs were also shown on the graphs. The data for both actual and predicted outputs give satisfactory results. The graphs also show that the predicted output fits to almost perfectly with the actual outputs. The results indicate that the difference or the errors between actual and predicted data are very small.

The parameters used for ARX model are input lag, n_u, output lag, n_y and nonlinearity, n_l for the ARX model is equal to 1 with the variation of the lag, n_u, output lag, n_y values. Hence the equations for ARX model are shown below:

$$H_{is}(t)=\begin{pmatrix} a_1H_{is}(t-1)+\ldots+a_2H_{is}(t-n_y)+a_3T_{is}(t-1)+\ldots \\ +a_4T_{is}(t-n_y)+a_5U_{ws}(t)+\ldots+a_6U_{ws}(t-n_u) \\ +a_7R_{ad}(t)+\ldots+a_8R_{ad}(t-n_u)+a_9H_{os}(t)+\ldots \\ +a_{10}H_{os}(t-n_u)+a_{11}T_{os}(t)+\ldots+a_{12}T_{os}(t-n_u) \end{pmatrix} \tag{1}$$

$$T_{is}(t)=\begin{pmatrix} a_1T_{is}(t-1)+\ldots+a_2T_{is}(t-n_y)+a_3H_{is}(t-1)+\ldots \\ +a_4H_{is}(t-n_y)+a_5U_{ws}(t)+\ldots+a_6U_{ws}(t-n_u) \\ +a_7R_{ad}(t)+\ldots+a_8R_{ad}(t-n_u)+a_9T_{os}(t)+\ldots \\ +a_{10}T_{os}(t-n_u)+a_{11}H_{os}(t)+\ldots+a_{12}H_{os}(t-n_u) \end{pmatrix} \tag{2}$$

The parameters used for NARX model are input lag, n_u, output lag, n_y and nonlinearity, n_l = 2. Hence the equations for NARX model are shown below:

$$H_{is}(t)=f^2\begin{pmatrix}H_{is}(t-1),..,H_{is}(t-n_y),T_{is}(t-1),..,T_{is}(t-n_y),\\ U_{ws}(t),..,U_{ws}(t-n_u),R_{ad}(t),..,R_{ad}(t-n_u),\\ H_{os}(t),..,H_{os}(t-n_u),T_{os}(t),..,T_{os}(t-n_u)\end{pmatrix} \quad (3)$$

$$T_{is}(t)=f^2\begin{pmatrix}T_{is}(t-1),...,T_{is}(t-n_y),H_{is}(t-1),...,H_{is}(t-n_y),\\ U_{ws}(t),...,U_{ws}(t-n_u),R_{ad}(t),...,R_{ad}(t-n_u),\\ T_{os}(t),...,T_{os}(t-n_u),H_{os}(t),...,H_{os}(t-n_u)\end{pmatrix} \quad (4)$$

From Table 1, the optimal and the best model is model 3 with output lag n_y, equal to two and the input lag n_u, of the regression is equal to one. Model validation for the identified linear model structure using ARX model is presented using simulation. The values of EI and RMSE for model 3 are 0.0572 and 0.0327 respectively while for the measured inside humidity, the error measurement of EI and RMSE are 0.0342 and 0.0259 respectively. The errors between the actual and predicted data are relatively small which indicate that the mathematical models for the system are acceptable. Nonlinear model structure using NARX model is presented. Simulation of NVTG with nonlinearity, n_l is 2. The best model is model 3 with values of EI and RMSE are 0.0362 and 0.0274 respectively while for the predicted inside temperature, T_{is} are 0.0573 and 0.0328 respectively. The errors between the actual and predicted data are relatively small which indicate that the mathematical models for the system are acceptable.

The graphs of the predicted data and the actual data are plotted and shown below. From Fig. 6 for ARX and Fig.7 for NARX, the graphs for predicted outputs-T_{is} H_{is} are indicated by green color and very close to the actual outputs indicated with blue color. These show that all the models are good in performances. From the graph, residual is high from hours 2 to hours 16 but it still under the 0.1 percent. It shows that all the models established were good enough for the NVTG system. The high residual is around hours 2 to hours 16 due to the added wind speed and irradiance values. The wind started to blow and gave a wind speed value starting from hours 3 to hour 16 and give effect to the prediction value of inside temperature.

Besides that, the irradiance sensor started giving values from hours 2 till hours 16. The residual graph shows that the residual is high when all of the inputs give their values in the prediction of the inside temperature. The humidity residual value is so small for almost all the time and shows that it almost perfect. These all could be caused by the data captured by the humidity sensor. For the models 1 to 4, the residual patterns are almost same and the different between them are the values of residual that up to the three decimal places.

Table 1. The predicted outputs i.e. Humidity inside, H_{is} and Temperature inside, T_{is} for ARX and NARX models.

Model			SSE	MSE	RMSE	eiRLSE
ARX	1	H	3.1291	0.0011	0.033	0.0577
		T	1.9326	6.71E-04	0.0259	0.0342
	2	H	4.937	0.0017	0.0414	0.0546
		T	6.1414	0.0021	0.0462	0.0808
	3	H	1.9368	6.73E-04	0.0259	0.0342
		T	3.0787	0.0011	0.0327	0.0572
	4	H	4.9372	0.0017	0.0414	0.0546
		T	6.0635	0.0021	0.0459	0.0803
NARX	1	H	2.1722	7.54E-04	0.0275	0.0362
		T	3.1731	1.10E-03	0.0332	0.0581
	2	H	5.2123	0.0018	0.0425	0.0561
		T	6.3204	0.0022	0.0468	0.0819
	3	H	2.1665	7.52E-04	0.0274	0.0362
		T	3.0897	0.0011	0.0328	0.0573
	4	H	5.2048	0.0018	0.0425	0.0561
		T	6.2198	0.0022	0.0465	0.0813

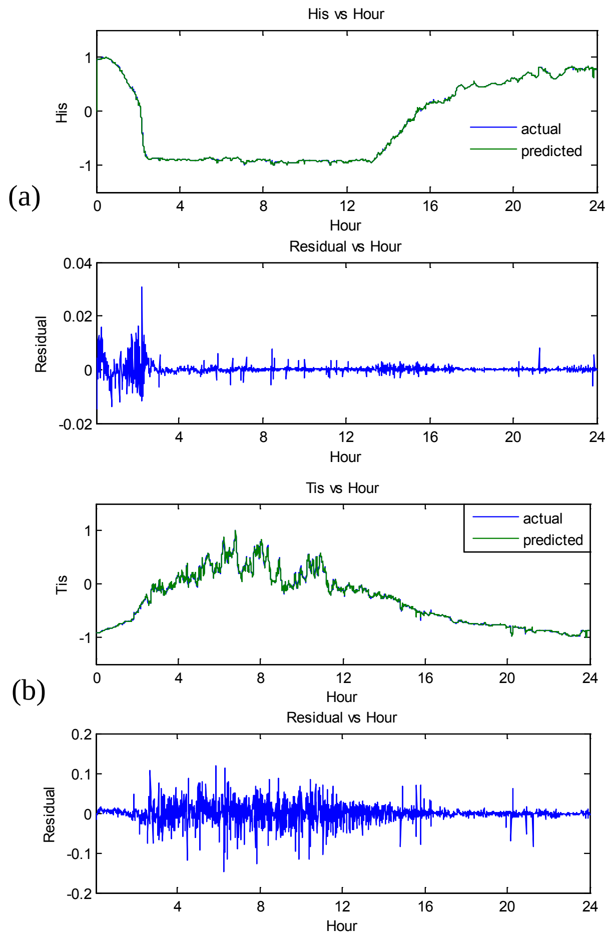

Fig. 6 The predicted and actual outputs (Humidity inside, H_{is} and Temperature inside, T_{is}) and residual for the model 3 of ARX

From the residual of both outputs shows that all models established are lower than 0.1 percent and it good enough for the modeled system. The NARX model is suitable for the NVTG system because it consider more parameters in the model establish and the performance is still good enough. The parameter estimation of the NVTG system used RLSE method and the parameter for the best model.

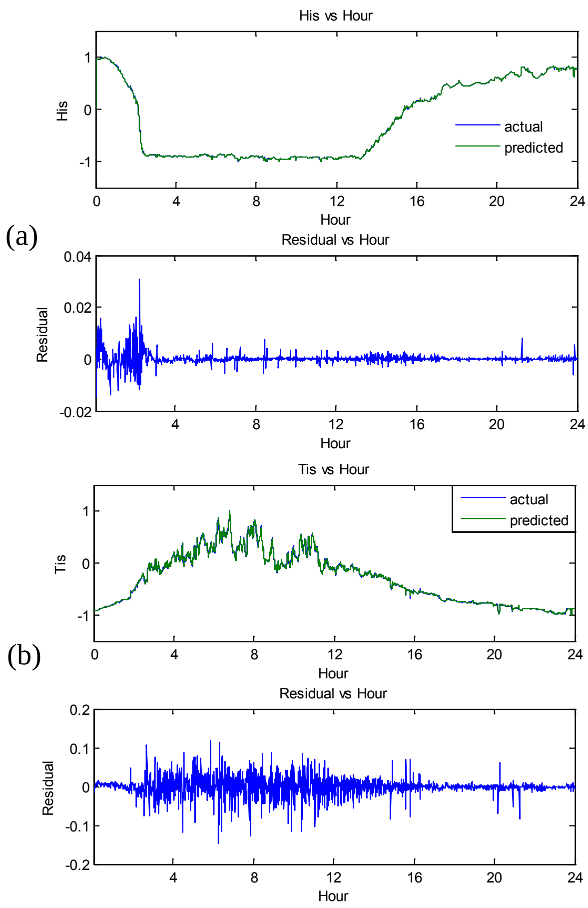

Fig. 7 The predicted and actual outputs (Humidity inside, H_{is} and Temperature inside, T_{is}) residual for the model 3 of NARX

5 Non-parametric Modeling and Simulation of NVTG

The simulation result for the NVTG climates using non-parametric model is presented in this section. For the modeling of NVTG system, normalized data was used and the architecture for the networks only used a single hidden layer. The output layer have two nodes that is inside temperature, T_{is} and inside humidity, H_{is}. The changed makes on the nodes that apply on the hidden layer used and the result on that were discussed on the next subsection. The architecture of the NVTG system used multilayer perceptron. The activation function used for hidden layer is the sigmoid. For backpropagation, it requires a continuous activation function. Sigmoid function used because this function is smooth and continuous. Effects of using difference number of neurons in the hidden layer on the NN model were discussed with varying the nod numbers in the same 2 hidden layers. Five separated model were analyzed, first model, N1 is the combination of 2 hidden layers and one nod, then second models were used 2 nod in the hidden layer until the last fifth model used 5 nod in the hidden layer. Table 2 shows the performances of the multilayer network for every model. The values of the root mean square error (RMSE), sum square error (SSE) and the error index (EI) for every model evaluated also in the table. The best network is for model N3 with root mean square (RMSE) of 0.18168, sum square error (SSE) of 0.00992, and error index (EI) was 0.0024 for inside humidity. For the inside temperature, root mean square (RMSE) of 0.14162, sum square error (SSE) of 0.00586, and error index (EI) was 0.00248 that is having the lowest values of the error.

The Multilayer Perceptron (MLP) is known for its ability to model simple as well as very complex functional relationship [10]. For this project, the multilayer feedforward networks are used. This network was trained using the backpropagation algorithm to obtain the weight in the network. Fig. 8 shows the architecture of the ANN model used for NVTG system with six inputs and two outputs.

Table 2. Performance of the MLP each five structures.

Model	**RMSE**		**SSE**		**EI**	
	His	*Tis*	*His*	*Tis*	*His*	*Tis*
N1	9.6153	14.116	26.608	57.350	0.1268	0.2468
N2	0.2276	0.1220	0.0150	0.0046	0.0030	0.0021
N3	0.1817	0.1416	0.0099	0.0059	0.0024	0.0025
N4	0.3822	0.2392	0.0508	0.0238	0.0050	0.0042
N5	0.3195	0.2552	0.0457	0.0329	0.0042	0.0044

Architecture of the ANN model used for NVTG system is six inputs and two outputs. The performance of a trained network can be measured to some extent by the errors on the training, validation and test sets, but it is often useful to investigate the network response in more detail. One option is to perform a regression analysis between the network response and the corresponding targets. Three variables are involved for this analysis *m*, *b*, and *r*. Variables m for the slope and *b* for the intercept of the best linear regression relating targets to network output. For a perfect fit where the

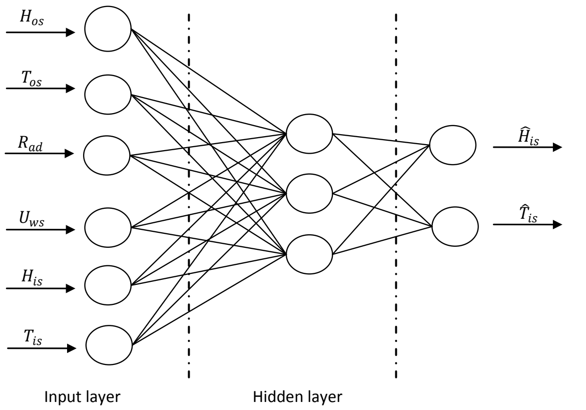

Fig. 8 The architecture of ANN model for NVTG system.

predicted output is exactly equals to the target, the slope would be 1 and the b-intercept is 0. The third variable that is *r* refers to coloration coefficient between the outputs and the targets. It measures how well the variation in the output is explained by the targets. It is perfect if the value *r* is equal to 1 [11].

In the simulation, the numbers of nodes used in the hidden layer were varied and the numbers of layers used are two layers with the normalized data were used. The result for the best model is model N3. This architecture consists of the network with 2 layers and for the 3 hidden layers, it has 1 node that related to the input layer and the output layer.

From Fig.9, the predicted outputs namely inside temperature, T_{is} and the inside humidity, H_{is} were plotted with the actual data It shows clearly that the predicted output in agreement with the actual output. It is difficult to distinguish the actual line on the figure. The residual of plots for both outputs in Fig. 10 are small with the values average under 0.01. This shows that the model is good enough for describing system behavior.

Fig. 11 and 12 illustrate the graphical outputs provided by prostreg routine in MATLAB. The network outputs are plotted versus the targets as open blue circles. The best linear fit is indicated by a dashed blue line and the perfect fit output equal to targets is indicated by the solid red line. The correlation coefficient is 0.99996 for both humidity inside and temperature inside that really close to 1, these shows that the outputs are well modeled.

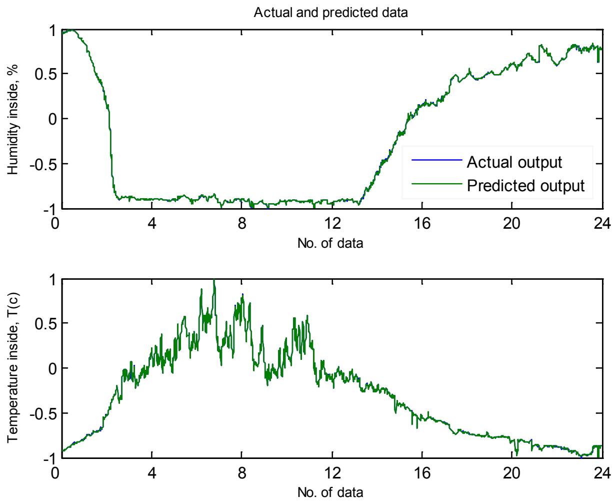

Fig. 9 The actual and predicted outputs for temperature and humidity for model N3.

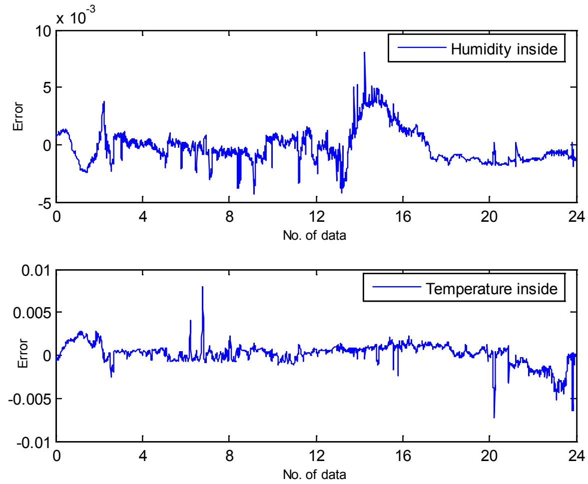

Fig. 10 Residuals of the predicted output with actual output for model N3

In this network that using the 3 hidden layer neurons, the fit is good and difficult to distinguish. The neural network prediction for predicted inside temperature, T_{is} yield a root mean square error (RMSE) of 0.12 % and error index was 0.21 %. For the inside humidity, H_{is} yield a root mean square error (RMSE) of 0.15 % and error index was 0.2 %. The results show that the network gives an accurate predicted network outputs, where the best linear fit equation for each figure is refers to A = mt + b, m for the slope and b for the intercept of the y-axis.

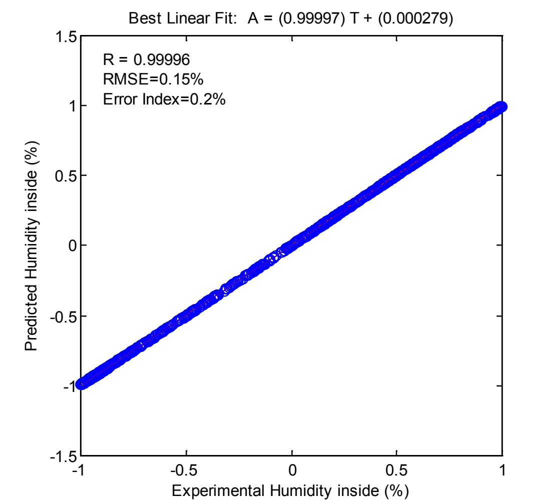

Fig. 11 The NN predictions for inside humidity vs. the actual inside humidity for model N3

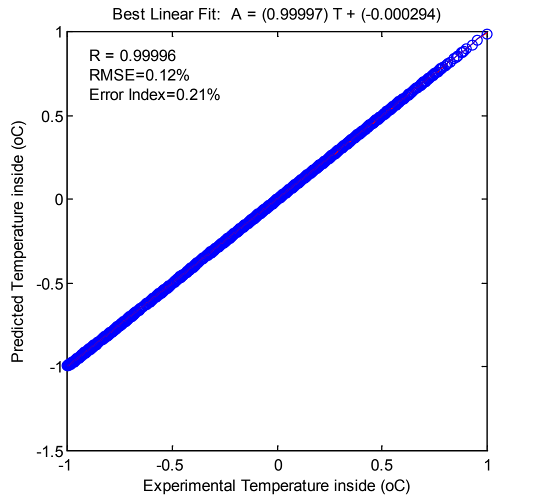

Fig. 12 The NN predictions for inside temperature vs. the actual inside temperature for model N3

As a result from the study, the result shows that the suitable ANN model for the simulation is by using all six variables inputs and three nodes in a hidden layer. The performance of the ANN predictions was measured using the mean square error, root mean square error, error index and correlation coefficient. The ANN model for the NVTG system shows a good performance with the RMSE between 0.135-0.207 percent for humidity inside and 0.121-0.166 percent for temperature inside. Besides that, the error indexes are between 0.18-0.32 percent for H_{is} and 0.21-0.29 percent for T_{is}. Moreover, the correlation coefficient that is the relationship between predicted outputs with the experimental values gives results close to one within range 0.99995 to 0.99997. Based on the performances of ANN modeling, the model built using the ANN can be used for the optimal model.

After analyzing several NN parameters, the properties of the suitable NN model for NVTG system is shown in the Table 3.

Table 3. The properties of the suitable NN model for NVTG system

Structure	**Feedforwarad neural network**
Algorithm	Backpropagation
Type of training	Levenberg-Marquardt
Learning rate	0.5
Number of epoch	1000
Transfer function	Tangent sigmoid and linear
Data type	Normalized data
Network structure	Three nodes in a hidden layer

6 Conclusion

Naturally ventilated tropical greenhouse is considered as a complex system since it involves with multivariable inputs and outputs (MIMO) system. NVTG system is a system that represents time varying behaviors and generally depends on meteorological conditions. The main objective of the study is to model and simulate NVTG climatic system using the parametric and non-parametric model. From the result, the best model for parametric model is model 3 of NARX model with the error index 0.0573 for temperature and 0.0362 for humidity. For the non-parametric, the best model is model N3 of NNARX model. The error indexes for model N3 are 0.0025 for temperature and 0.0024 for humidity. So the best model is the NNARX model by using the artificial neural network. The developed mathematical model can help control designer in developing the control system for NVTG system

References:

[1] R. Kamaruddin, *Naturally Ventilated Tropical Green House for temperate crop production.* Malaysian Agricultural research and Development Institute, (MARDI). Teknologi Pertanian. Agromedia Article. ISSN:1511-094X. 22, 2007, pp. 44-45.

[2] M. Mancuso and F. Bustafa, A wireless sensors network for monitoring environmental variables in a Tomato Greenhouse, *IEEE International Conference on Factory Communication Systems*, 2006, pp. 107-110.

[3] N. Bennis, J. Duplaix, G. Enea, M. Haloua, H. Youhal, Grenhouse climate modeling and

robust control, *Computer and Electrical*, Vol. 61, 2008, pp. 96-107.

[4] R. Caponetto, L. Fortuna, G. Nunnari, L. Occhipinti, M. G. Xibilia, , Soft Computing for Greenhouse Climate Control, *IEEE transactions on fuzzy system*, Vol. 8, No. 6, 2000, pp. 753-760.

[5] P. Javadikia, A.Tabatabaeefar, M. Omid, R. Alimardani, M. Fathi, Evaluation of Intelligent Greenhouse Climate Control System, Based Fuzzy Logic in Relation to Conventional Systems, *International Conference on Artificial Intelligence and Computational Intelligence AICI'09*, Vol. 4, 2009, pp. 146-150.

[6] Fourati, F. and Chtouru, M., "A greenhouse control with feedforward and recurrent neural networks", *Simulation Modeling Practice and Theory*, Vol. 15, 2007, pp. 1016-1028.

[7] Ferreira, P. M., Faria, E.A., Ruano, A. E., "Neural network models in greenhouse air temperature prediction", *Neurocomputing*, Vol. 43, 2002, pp.51-75.

[8] Md. N. Md. Lazin, *Natural ventilated Tropical Greenhouse (NVTG) modeling and simulation*, Universiti Teknologi Malaysia, (2010).

[9] L. Ljung, *System Identification-theory for user*, New Jersey: PTR Prentice-Hall, 1987.

[10] M. Noergaard, O. Ravn, N. K. Poulsen, L. K. Hansen, *Neural networks for modeling and control of dynamic systems*. London, Springer, Verlag., 2000.

[11] H.Demuth, and M. Beale, *Neural network toolbox user guide*, UK, The math works, Inc., 2000.