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Estimation of Hourly Solar Radiation on Horizontal Surface Using GAMF (Genetic Algorithm Modified Fuzzy) (Case Study in Surabaya)

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Abstract. The biggest renewable energy sources in Indonesia is solar energy. The installed capacity of Solar Power System in 2017 is still very far from the target. Solar radiation is very infulental on the photovoltaic performance in generating energy. The need for solar radiation estimation has become important in the design of photovoltaic system. Previous research has been done using Extreme Learning Machine (ELM) and Adaptive Neuro Fuzzy (ANFIS) methods. In this research, Genetic Algorithm Modified Fuzzy (GAMF) method used to estimate the solar radiation. Meteorogical dates used in this research are temperature, humidity, wind velocity and wind direction. There are 2 types of datas that are BMKG data and measurement data. Three experimental variations of input variation were performed for each data. For BMKG data the best estimation result is obtained when using humidity, temperature and wind velocity as variation inputs with RMSE and MAE of 145.19 and 72. While for the best result estimation result data obtained when applying humidity, temperature, wind speed and wind direction as variation inputs with values of RMSE and MAE were 1.44 and 0.65.

1. Introduction

The position of Indonesia is located in the equator, making Indonesia as a country with abundant solar energy resources, where the average solar radiation intensity is around 4.8 kWh / m^2 per day in all parts of Indonesia [1]. The data released by the EMR Ministry states that the installed capacity of the 2017 Solar Power System (PLTS) is 80 MW of the government target of 5,000 MW in 2019 and 6,400 MW in 2025 [2] Based on the data above installed capicity at this time still very far from the target of 2019 and 2025, whereas the potential for the development of PLTS in Indonesia itself is very large.

Low amount of energy generated by a PLTS can be caused by various factors. One of them is the Photovoltaic placement used for energy conversion. To obtain optimum output, Photovoltaic needs to be placed in such a way as to obtain maximum solar radiation. Photovoltaic is generally placed in a permanent position without change, so it will get maximum solar radiation only when the sun is perpendicular to the field. As the sun and Photovoltaic fields form an angle θ, there is a decrease in solar radiation. To know the amount of solar radiation received by Photovoltaic required a measuring instrument of solar radiation or the commonly used is phyranometer. This study is expected to produce solar radiation estimators at a cost that is more efficient than the previous tool. Modeling of solar radiation received at the surface of the earth, especially in the Surabaya area, further research is needed

to obtain an estimator according to the conditions in Surabaya.

Previous researchs have been conducted on estimating solar radiation with various methods in [3] [4] [5]. In the research [3] modeling for hourly solar radiation using artificial neural network feedforward backpropagation. This research reach accuracy of 93.09% in estimating solar radiation per hour. It shows better accuracy than using mathematical modeling. While in research [4] esplained estimation of solar radiation per hour with method of ELM (Extreme Learning Machine), both method that used for feedforward backpropagation method have value of MSE (Mean Square Error) equal to 0,3378 and method ELM obtained MSE of 5.88E-14. In addition, for the learning speed in the testing process for feedforward backpropagation method has a duration of learning speed of 0.2171 seconds and for the ELM method has a duration of learning speed of 0.0156 seconds from the estimated solar radiation. It shows that ELM method is better in terms of accuracy and learning speed compared with feedforward backpropagation method. Antother study [5], estimating solar radiation using ANFIS (adaptive Neuro Fuzzy) method. In this research we got comparison between estimation using ELM and ANFIS method, ANFIS has better RMSE and MAE compared to ELM. The smallest RMSE value is 0.87 and the smallest MAE is 0.22. This shows that in this case ANFIS method has better estimation ability than using ELM.

In the next research will be developed a new method in determining the estimated solar radiation per hour on horizontal surface (case study in Surabaya) using method of GAMF (Genetic Algorithm Modified Fuzzy).

2. Methodology

Estimation to hourly solar radiation on horizontal suface using GAMF method in Surabaya developed due to research method shown in figure below:
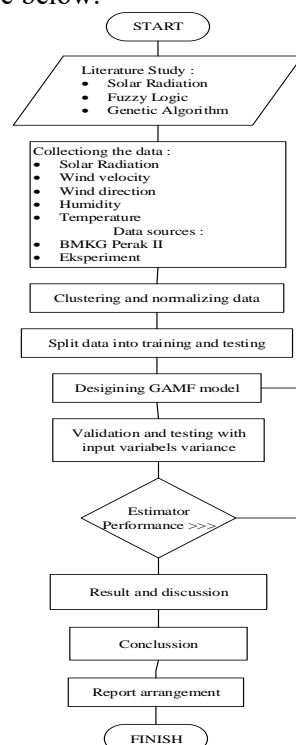

Figure 1. Methological Flowchart

2.1 Collectiong the Data

The research using two kind of data from The Meteorology, Climatology, and Geophysics Body (BMKG) Perak II Surabaya and experiment. The research uses hourly data. These are solar radiation on a horizontal surface (W/m^2), air temperature (^{o} C), relative humidity (%), wind speed (m/s) and directions. That data were taken during January 2015 until December 2017 for BMKG data and February 2018 until April 2018 for experiment data.

Training and testing data classification

Both of data divided into two two parts they are training and testing with ratio 80 :20. The training and testing process will be divided into 3 experiments with variation of input variables. The input variables used are: humidity, temperature, wind speed and wind direction. While the output variables are solar radiation. This is done to find the input variation that produces the best estimation output. The input variations scheme are explain in figure below.
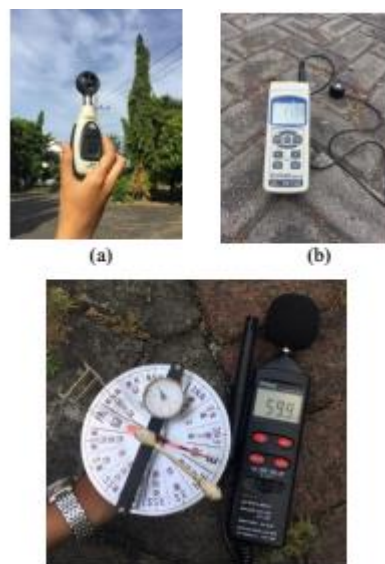

Figure 2. Collecting the data (a) Wind velocity (b) Solar radiation (c) Wind direction, Humidity and Temperature

Table 1 : The input variations scheme

Experiment	Input variations
P1	Temperature, Humidity
P2	Temperature, Humidity, Wind velocity
P3	Temperature, Humidity, Wind velocity, Wind direction

Determining number and type of membership function

To get a good estimation result required the right type of membership function. In this research used membership type function gauss with membership membership function 3. Membership function used is gauss type because it is considered the most optimal compared to other membership function types that is trim, trap and gbell. The membership function obtained from the training results for the four input variables used are as follows:
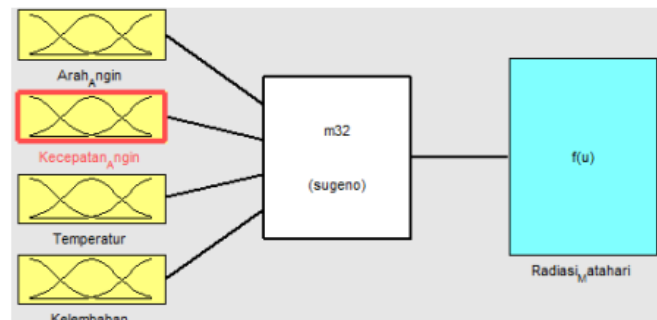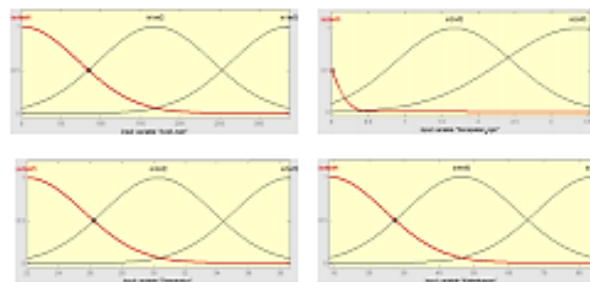
Figure 3. Membership Functions

Figure 4. Membership Function Curve

Number of membership functions used for this research are 3, from the training process generates a rule based for output and input pair with the number of rule based 9 for 2 variations of input variables, 27 for 3 input variations and 81 for 4 variations of input variables.

Analyze the Estimation Result

After getting the estimated output obtained from MATLab with the "evalfis" command then calculation done with Microsoft Excel to get the error value. The type of calculation performed are Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). The calculation formula for determining RMSE and MAE is as follows.

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{t=1}^{N}(y_t - t_\tau)^2} \tag{1}$$

$$\text{MAE} = \frac{1}{N} \sum_{t=1}^{N}|(y_t - t_\tau)| \tag{2}$$

GA Optimization

The estimation results obtained from the fuzzy method given as the initial population then optimized to obtain more optimum results with the genetic algorithm method. The optimization process is carried out for the three experiments of input variation. The objective function used in the optimization process using genetic algorithm is error. The magnitude of the error can be calculated from the difference in target solar radiation with the estimated solar radiation obtained from the fuzzy method.

3. Result and Discussion

3.1. BMKG Data Analysis

Data analysis has been done on secondary data obtained from BMKG Maritim Perak II Surabaya within 3 years period from January 2015 until December 2017. The data obtained consist of wind speed, wind

direction, temperature, humidity, and solar radiation with the amount of 10542 data pairs. The secondary data characteristics BMKG Maritime Perak II Surabaya is as follows:

Table 2. Characteristic of Data BMKG

	Temperature (°C)	Humidity (%)	Wind speed (m/s)	Wind direction (°)	Solar radation (W/m²)
Range	22,4-37,7	30,94-100	0-8,75	0-359	0-1207
Span	15,3	69,06	8,75	359	1207
Mean	28,94	76,33	1,87	157,3	400,96
Std. Dev	2,45	11,48	1,17	96,04	295,33
Max	37,7	100	8,75	359	1207
Min	22,4	30,94	0	0	0

There are two types of classification data, training data and data testing. Classification is done with the ratio of 80:20 so that obtained training data amounted to 8434 pairs of data and data testing amounted to 2108 pairs of data.

3.2. Experiment Data Analysis

The experiment data is obtained from measurement with measuring instrument. The amount of experiment data are 685 pairs of data and classified into data training and data testing with a ratio of 80:20. So that obtained training data amounted to 548 pairs of data and data testing amounted to 137 pairs of data. The characteristics of the measurement data are as follows.

Table 3. Characteristic of Experiment Data

	Temperature (°C)	Humidity (%)	Wind velocity (m/s)	Wind direction (°)	Solar radiation (W/m²)
Range	22,6-38,6	8,5-84,2	0-3,53	0-337,5	21,8-1073
Span	16	75,7	3,53	337,5	1051,2
Mean	30,62	35,35	0,79	127,77	534.15
Std. Dev	4,77	17,4	0,573	96,04	313,704
Max	38,6	84,2	0	359	1073
Min	22,6	8,5	0-3,53	0	21,8

3.3 Modeling Analysis (BMKG Data)

Based on the results of the computations performed using MATLab software using the Fuzzy-Sugeno method, the estimation stage is divided into 2, namely training and testing. Here is the result of training from simulation on experiment P1, P2, P3 with Fuzzy method and GAMF.
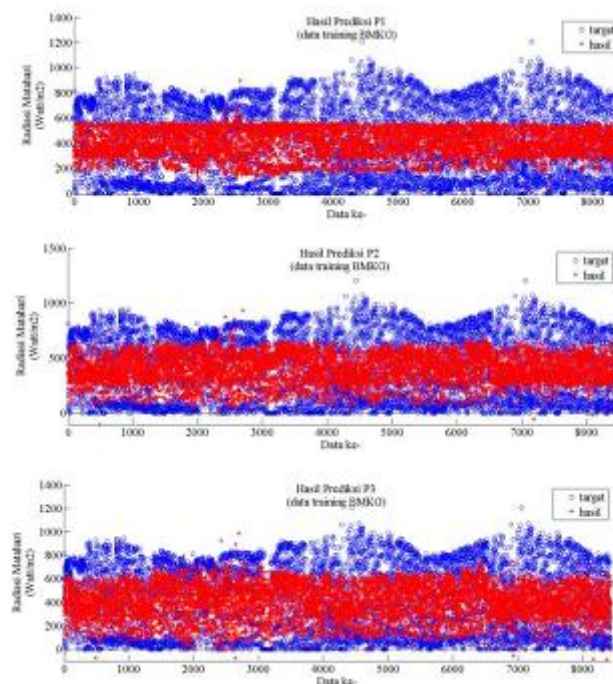
Figure 5. Estimation Result from Fuzzy Merhod
(BMKG training data) (a) P1 (b) P2 (c) P3

Figure 5 shows the distribution of target solar radiation and estimation results for each experiment using the Fuzzy method for BMKG training data. In Figure 5 (a) a maximum error of 2119435,15, a minimum error of 0.01, and a MAE of 232. In Figure 5 (b) a maximum error of 1879834,90, a minimum error of 0, and a MAE of 219. 5 (c) maximal error of 1493389,78, minimum error of 0.01, and MAE of 209. Thus, the best estimation results obtained when using variations of input variables as many as 4 pieces
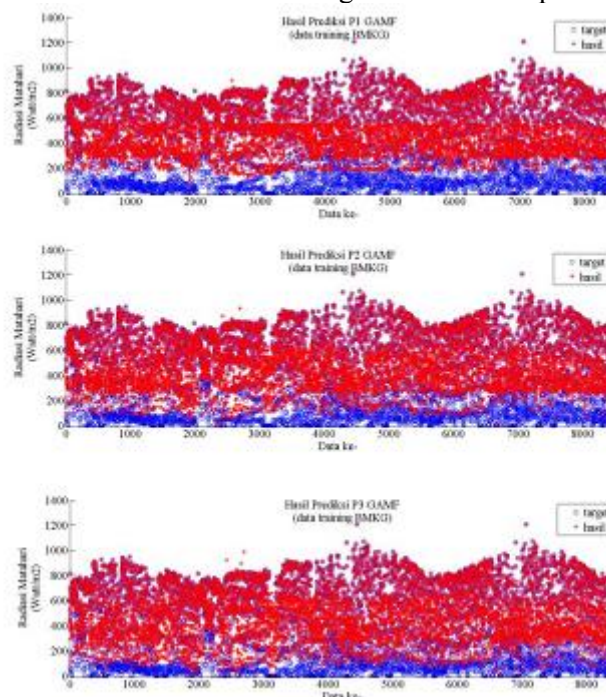

Figure 6. Estimation Result from GAMF method
(BMKG training data) (a) P1 (b) P2 (c) P3

In Figure 6 we can see the spread of target solar radiation and estimation results for each experiment using the GAMF method. In this Figure it can be seen that the spread of the estimation results is more evenly distributed than the previous figure, indicating that the estimation is close to the target. Based on data calculation performed, GAMF method has a smaller MAE value when compared to Fuzzy method that is 115; 109 and 104 for each input variation.

Based on the results of the training, we have obtained the comparison of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) results for the Fuzzy and GAMF methods as follows:

Table 4. RMSE and MAE Analysis from BMKG data training

P-	Structure	RMSE *(training)*		MAE *(training)*	
		Fuzzy	**GAMF**	**Fuzzy**	**GAMF**
P1	3, Gauss, 100	271,22	191,95	232	115
P2	3, Gauss, 100	262,15	186,35	219	109
P3	3, Gauss, 100	253,56	181,25	209	104

Based on Table 4 we can see significant decrease in RMSE and MAE in GAMF method when compared with Fuzzy method. The smallest RMSE and MAE, 181,25 and 104, were obtained when the input variation was 4, so the most optimum estimation result for BMKG data training was using P3 experiment with GAMF method.

As for testing phase BMKG data for experiments P1, P2 and P3 with Fuzzy and GAMF method can be seen in the picture below.
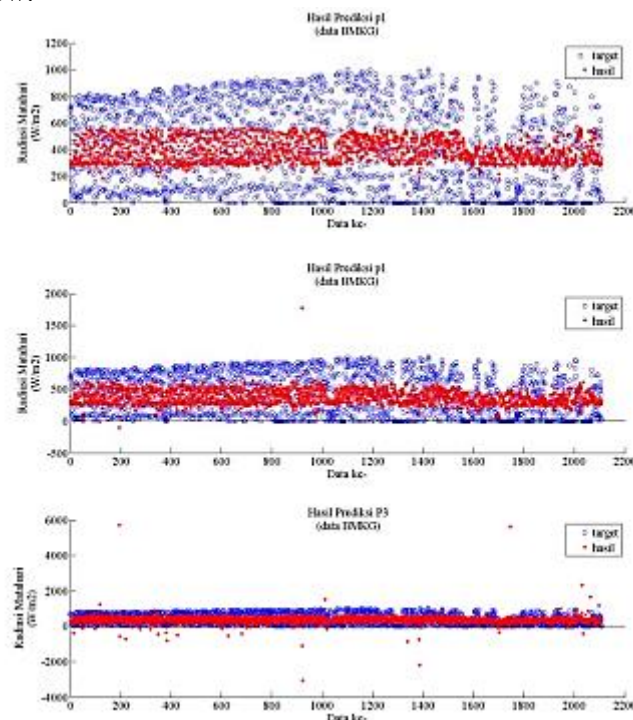

Figure 7. Estimation Result from Fuzzy method
(BMKG testing data) (a) P1 (b) P2 (c) P3

Figure 7 shows the distribution of target solar radiation and estimation results for each experiment using the Fuzzy method. The data used is BMKG training data. In Fig. 7 (a) the maximal error is 577830.89, the minimum error is 0.0044, and the MAE is 265. In Figure 7 (b) the maximal error is 1775652,14, the minimum error is 0.1542, and the MAE is 257. In fig. 7(c) maximum error of 5616792,55, minimum

error of 0.0630, and MAE of 289. Thus, for training data using BMKG data, the best estimation results obtained when using 3 variation of input variables.
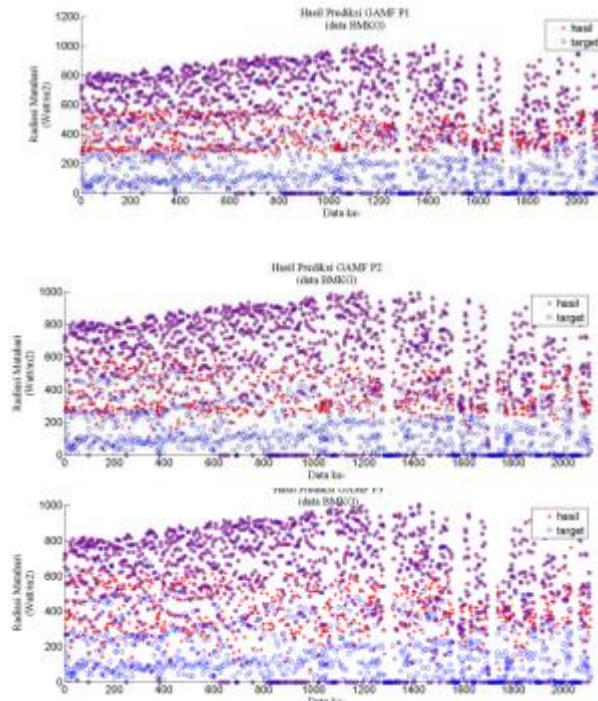

Figure 8. Estimation Result from GAMF method
(BMKG testing data) (a) P1 (b) P2 (c) P3

Figure 8 shows the distribution of target solar radiation and estimation results for each experiment using the GAMF method. In this Figure it can be seen that the spread of the estimation results is more evenly distributed than the previous figure, indicating that the estimation is close to the target. Based on data processing done, GAMF method has a smaller MAE value when compared to Fuzzy method that is equal to 74; 65 and 72 for each input variation.

The three experiments that have been done using BMKG data testing obtained comparison of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) for Fuzzy and GAMF method are as follows:

Table 5. RMSE and MAE Analysis from BMKG data testing

P-	Structure	RMSE (testing)		MAE (testing)	
		Fuzzy	**GAMF**	**Fuzzy**	**GAMF**
P1	3, Gauss, 100	301,19	138,67	265	74
P2	3, Gauss, 100	297,89	126,61	257	65
P3	3, Gauss, 100	388,46	145,19	289	72

Based on Table 5 we can see significant decrease in RMSE and MAE on GAMF method when compared with Fuzzy method. For BMKG data, the smallest RMSE and MAE values of 126.61 and 65 are obtained when the input variation is 3, so the most optimum estimation result for BMKG data training is using P2 experiment with GAMF method.

3.4.Modeling Analysis (Experiment Data)

Based on the results of the computations performed using MATLAB software using the Fuzzy-Sugeno method, the estimation stage is divided into 2, namely training and testing. The following is the result

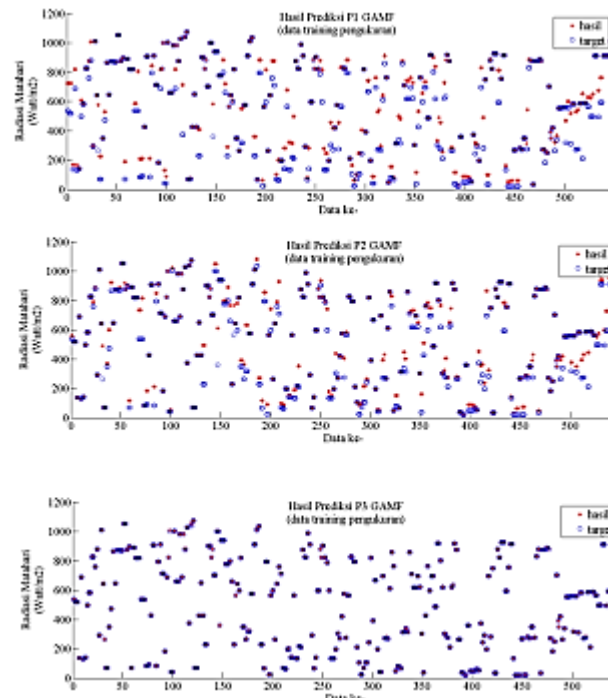of the training of measurement data from the simulation on experiment P1, P2, P3 with Fuzzy method and GAMF:

Figure 9. Estimation Result from Fuzzy method
(Experiment training data) (a) P1 (b) P2 (c) P3

Figure 9 shows the distribution of target solar radiation and estimation results for each experiment using the Fuzzy method. The data used is BMKG training data. In Figure 9 (a) a maximum error of 226.23, a minimum error of 0.3642, and a MAE of 140.24. In Figure 9 (b) the maximal error is 349.39, the error is at least 0.0213, and the MAE is 94.45. there is Figure 9 (c) maximal error of 10.62, minimum error of 0.0025, and MAE of 2.94. Thus, for training data using BMKG data, the best estimation results obtained when using 4 variations of input variables.

In Figure 10 we can see the distribution of target solar radiation and estimation results for each experiment using the GAMF method. In this Figure it can be seen that the spread of the estimation results is more evenly distributed than the previous figure, indicating that the estimation is close to the target. Based on data processing performed, GAMF method has a smaller MAE value than Fuzzy method that is equal to 56; 35 and 0 for each input variation.
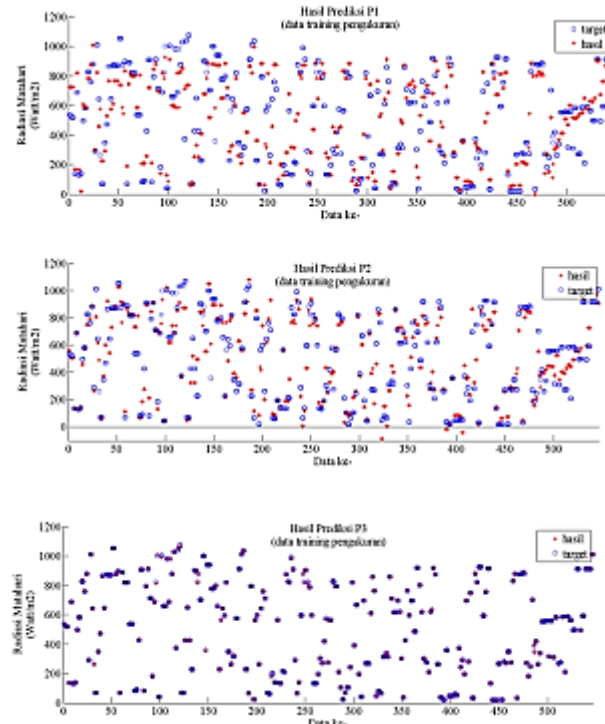
Figure 10. Estimation Result from GAMF method
(Experiment training data) (a) P1 (b) P2 (c) P3

Based on the results of the training, we have obtained the comparison of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) results for the Fuzzy and GAMF methods as follows:

Table 6. RMSE and MAE Analysis from experiment data training

P-	Structure	RMSE (training)		MAE (training)	
		Fuzzy	**GAMF**	**Fuzzy**	**GAMF**
P1	3, Gauss, 100	140,24	97,43	112	56
P2	3, Gauss, 100	94,45	69,34	70	35
P3	3, Gauss, 100	2,94	0,54	2	0

Table 6 shows a significant decrease in RMSE and MAE in the GAMF method when compared to the Fuzzy method. The smallest RMSE and MAE are 0,54 and 0, obtained when the input variation is 4, so the most optimum estimation result for the training of measurement data is using P3 experiment with GAMF method.

As for testing phase BMKG data for experiments P1, P2 and P3 with Fuzzy and GAMF method can be seen in the picture below:
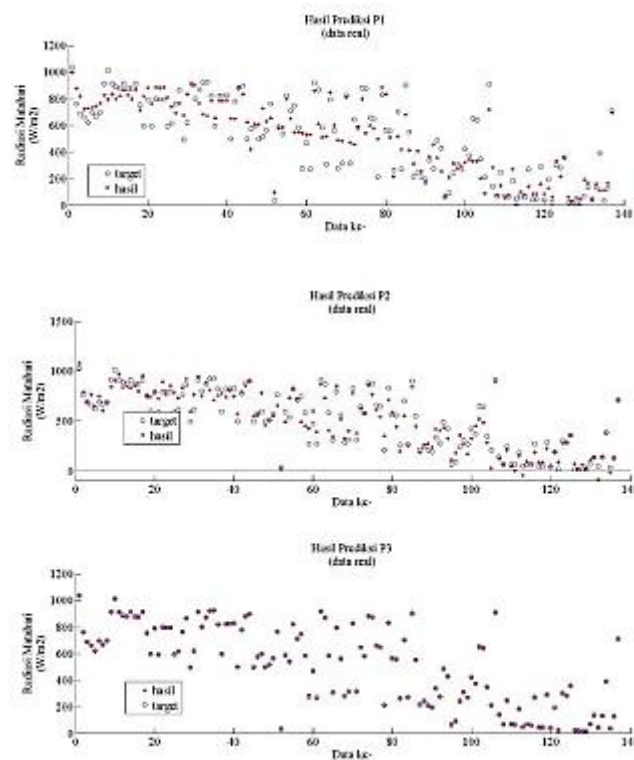
***Figure 11.** Estimation Result from Fuzzy method (Experiment testing
data) (a) P1 (b) P2 (c) P3*

Figure 11 shows the distribution of target solar radiation and estimation results for each experiment using the Fuzzy method. The data used is BMKG training data. In Figure 11 (a) a maximum error of 226.23, a minimum error of 0.36, and a MAE of 126.44. In Figure 11 (b) a maximum error of 303.0732, a minimum error of 0.0213, and a MAE of 8.68. There is Figure 11 (c) maximal error of 9.38, minimum error of 0.0035, and MAE of 2.1. Thus, for training data using BMKG data, the best estimation results obtained when using 4 variations of input variables.
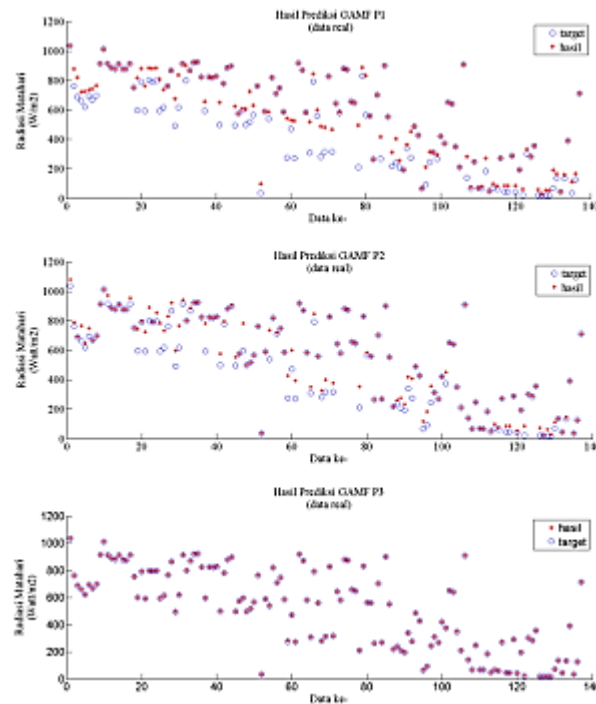
Figure 12. *Estimation Result from Fuzzy method (Experiment testing data)*
(a) P1 (b) P2 (c) P3

In Figure 12, we can see the spread of target solar radiation and estimation results for each experiment using the GAMF method. In this Figure it can be seen that the spread of the estimation results is more evenly distributed than the previous figure, indicating that the estimation is close to the target. Based on data processing done, GAMF method has a smaller MAE value than Fuzzy method is 49.85; 30.31 and 0.65 for each input variation.

Based on the result of radiation estimation by using MATLab software on data testing result of measurement then continued with data calculation using microsoft excel to get comparison of result of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) for Fuzzy and GAMF method as follows:

Table 7. RMSE and MAE Analysis from experiment data testing

P-	Struktur	RMSE (testing)		MAE (testing)	
		Fuzzy	**GAMF**	**Fuzzy**	**GAMF**
P1	3, Gauss, 100	126,44	87,21	99,31	49,85
P2	3, Gauss, 100	84,68	57,34	65,78	30,31
P3	3, Gauss, 100	2,10	1,44	1,26	0,65

Based on Table 7 we can see significant decrease in RMSE and MAE in GAMF method when compared with Fuzzy method for all varieties of input variables. In the table, the smallest RMSE and MAE values of 1.44 and 0.65 are obtained when the input variation is given 4 with the GAMF method, so the most optimum estimation result for the measurement data testing is using P3 experiment with the moisture input variable, temperature, wind speed and wind direction.

4. Conclusion

Based on data analysis and discussion about solar radiation estimation using GAMF method, it can be drawn the conclusion as follows:

- The best estimation parameter for BMKG data is using 3 variation of input variables they are humidity, temperature and wind speed. As for the data measurement results, using variations of 4 inputs they are humidity, temperature, wind speed and wind direction. It can be seen based on the smallest RMSE and MAE values.

- The design of the GAMF method for estimation of solar radiation using the Sugeno-type Fuzzy, and the estimates produced by Fuzzy are optimized using genetic algorithm methods. In Fuzzy model type of membership function used is Gaussian with number of membership function as much 3. On GA optimization objective function used is error, with amount of iteration counted 100.

- Accuracy of solar radiation estimation results by using GAMF method can be seen from result of RMSE and MAE produced. For data BMKG, RMSE and MAE most optimum that is equal to 126,61 and 65. As for experiment data are 1,44 and 0,65.

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