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FUZZY TAKAGI SUGENO KANG FOR PREDICTION WITH QUADRATIC NONLINEAR REGRESSION

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Abstract

Fuzzy logic is a logic that has the value of fuzziness between true or false. One of the fuzzy method that become popular recently is Fuzzy Takagi Sugeno Kang (TSK). TSK method is a fuzzy method that is mostly applied for solving the forecasting or classification problem. The output acquired from this method is a constant or a polynomial. In this research, the output of each rule is approximated by applying the nonlinear quadratic regression method. The data used in this research is the data of the river water quality in Yogyakarta. The variable used in this method is BOD (Biochemical Oxygen Demand), DO (Dissolved Oxygen), and TSS (Total Suspended Solid). The forecasting result will be evaluated with the application of Mean Absolute Percentage Error (MAPE). The error results in this research measure the accuracy from a certain problem by calculating the absolute error in each period and divide its value with the observation value in each period. The MAPE value acquired from this research is 14.98%. Based on this MAPE value, it can be concluded that the model used in this research is included in a good category.

Keywords: fuzzy, takagi sugeno kang, nonlinear regression,forecasting

INTRODUCTION

Fuzzy logic was introduced by Prof. Lotfi A. Zadeh in 1965. The fundamental of the fuzzy logic is a theory of fuzzy set. The value of the membership degree or the membership function becomes the main characteristic of the fuzzy logic analysis. Fuzzy logic is applied as a method to map a problem from input to achieve the expected output. The membership function can be defined as a certain curve that illustrates the mapping process of the input data coordinates into theirs membership value that ranged from intervals of 0 to 1. The membership value acquired from the operation result of two sets is known as a predicate. There are three basic operators that invented by Zadeh, there are operator AND, operator OR, and operator NOT [1].

One of the most widely used fuzzy methods is fuzzy Takagi Sugeno Kang (TSK). Fuzzy TKS is a fuzzy method introduced by Takagi-Sugeno Kang in 1985. In general, fuzzy TSK has an output in the form of constant or polynomial [2].

There are few studies about fuzzy TSK that have already been studied. One of them is conducted by [3].They combined fuzzy TSK with Fisher-Yates Algorithm to create an educational game. Fuzzy TSK in their research is applied to do a scoring with time, value, and the number of stars as input variables. The research resulted in a conclusion that the acquired accuracy level is higher. Another research conducted by [4] and [5] applied TSK for decreasing the noise on the data. This research concluded that the noise immunity created from the TSK system leads to better classification performance.

Fuzzy TSK is also often applied in the medical sector. [6] applied TSK to determine the accurate diagnosis solution from the uncertainty problem of the Hepatomegali disease initial diagnosis. In addition to that, [7] also applied TSK for diagnosing a mental health problem. The designed system was able to provide an optimum diagnose result corresponds with the result acquired from the expert. The web-based disease diagnosis also applied TSK to perform the measurement of the disease severity level by using triangle and trapezoid membership functions. The application system that is applied can be used to diagnose an illness that contains many form of diseases, symptoms, basic rules, and the diagnosis of certain disease based on the historic illness [8].

Another research conducted by [9] applied a system that was able to identify meat quality with an experiment using the HSV method on the color of the meat. This research applies the fuzzy Sugeno method to do the pattern identification and decision-making on the freshness of the analyzed meat. There are three stated conditions for the meat freshness level, there are very good, good, and not good. The research resulted in a 60% of success level and 40 % of error level from 20 experiments.

The rules determination for approximation of the fuzzy adaptive granular TSK, which is applied in the fine-tuning process, covers the universal approximation properties and facilitates the application of many optimization and adaptive methods. Bermani et al [10] proposed a hybrid learning to provide a possibility to apply both of the advantages of Mamdani and TSK in a unique learning strategy, resulting in a simple basic extraction rule but accurate.

A research studied by Muizatul et al [11] applied the fuzzy Sugeno method for determining the optimum route distance from the google maps data. This fuzzy logic application could solve the problem of determining the optimum route by comparing 3 routes in each of the starting and ending points with few condition factors, distance, time, and road density.

Fuzzy rules are very important in the fuzzy TSK system because these rules do not only accommodate the mapping mechanism of the input pattern but also make the fuzzy system representable. One of the things that can be done to limit or strengthen the fuzzy rules is by applying the weight rules. The weight rules application will enhance the ability of the fuzzy rules to solve a problem with many possibilities. However, most of the weight rules that are applied on the fuzzy rules are constant. This means that the weight rules won't be altered after the learning algorithm is determined. For practical application, each of the fuzzy rules need to conclude a different degree of belief linear with the different input pattern.

In the research conducted by [12], new fuzzy TSK system was proposed, where each of the fuzzy rules was customized by the dynamic individual weight rule (DRW). DRW is a non-linear function from the input pattern that represents the fuzzy rules degree of belief (acceptability) that works on the input pattern. Furthermore, as for the input pattern, its isolation can be measured with the aggregate of the DRW value from the fuzzy rules in the proposed fuzzy system. As for the improvement for this research, we will try to develop the fuzzy TSK system that can provide a mechanism for measuring the fuzzy rules acceptability that works on each of the individual features involved in the input pattern.

Based on the few statements above, the output of the fuzzy TSK can be in the form of constant or polynomial. Therefore, this research will discuss how to acquire a polynomial as the output of the fuzzy TSK.

MATERIAL AND METHOD

Fuzzy Set

Definition 1. Suppose X stated the universe set, $\boldsymbol{x}$ X is the member of universal set, X and A stated the fuzzy set, then, the fuzzy set with the membership function $\mu_A(x)$ is [13]

$$\boldsymbol{\mu_A(x): X \rightarrow [0, 1]}$$

Fuzzy set A, in the universe of X can be defined as the set of pair order that described as follows [14]:

$$A = \{(x, \mu_A(x) | x \in X)\}$$

with $\mu_A(x)$ is the membership function of x the fuzzy set of A that located in the intervals $[0, 1]$.

Fuzzy set is a classification process based on the linguistic variable, which is defined as the membership function [13]. Fuzzy set has two attributes, such as:

a. Linguistic, which defined as the naming of a certain group that represents a certain situation or condition using natural language, such as Young, Middle-aged, Old.
b. Numeric, which defined as a certain number value that represents the size of certain variable, such as 40, 25, 35.

Takagi Sugeno Kang

a. Fuzzification

Fuzzification process is a transformation process that alter the value of the crisp set into the linguistic variable with the application of fuzzy membership function.

Linear-increasing membership function [15]:

$$\mu(x; a, b) = \begin{cases} 0 & x \leq a \\ \dfrac{(x-a)}{(b-a)} & a \leq x \leq b \\ 1 & x \geq b \end{cases} \quad (1)$$

Linear-decreasing membership function [15]:

$$\mu(x; a, b) = \begin{cases} 1 & x \leq a \\ \dfrac{(b-x)}{(b-a)} & a \leq x \leq b \\ 0 & x \geq b \end{cases} \quad (2)$$

b. Rule Establishment

Rule establishment is a method of rule arranging in the form of a fuzzy implication that stated the relationship of input variable and output variable with "If-Then" form of rule.

The form of fuzzy zero-order can be described as follows [16]

$$If\ (x_1\ is\ Q_1) . (x_2\ is\ Q_2). \dots . \ (x_i\ is\ Q_i)$$
$$Then\ z = k$$

As for the Fuzzy one-order, the description is (Wiktorowicz & Krzeszowski, 2020)

$$If\ (x_1\ is\ Q_1) . (x_2\ is\ Q_2). \dots . \ (x_i\ is\ Q_i)\ Then$$
$$z = p_1 * x_1 + \dots + p_i * x_i + k$$

With:

Q_i = Fuzzy set of-i for antecedent or cause
x_i = Fuzzy set of-i for variable
i = $1, 2, 3, \dots, n$
k = Crisp constant for consequence
p_i = Constant of-i.
. = Operators (or and and)

c. Inference Fuzzy

Inference fuzzy can be defined as the conclusion from the set of fuzzy rules [11].

$$\alpha_{predicate} = min(\mu_{sf}[x_i], \mu_{kf}[x_i]) \quad (3)$$

With:

i = $1,2,3, \dots, N$.
$\mu_{sf}[x_i]$= Fuzzy membership value rules of -i.
$\mu_{kf}[x_i]$= Fuzzy membership consequence rules of-i.

d. Defuzzification

Defuzzification process is the process of transforming the output value of the inference fuzzy into the crisp value *(crisp)* [18].

$$z^* = \frac{\sum_i^N y_i z_i}{\sum_i^N y_i z_i}; i = 1,2,3, \dots, N \quad (4)$$

With:

y_i = Output values of the rules of -i

z_i = Membership degree output values of rules of -i

Non-linear Quadratic Regression

Non-linear quadratic regression method is one of the two-order polynomial regression method. Generally, the equation of the non-linear quadratic regression is [19]:

$$\hat{Y} = \beta_0 + \beta_1 X_i + \beta_2 X_i^2 + \varepsilon_i \quad (5)$$

with:

$\hat{Y}$ = Estimator value for variables

$\beta_0, \beta_1, \ldots, \beta_n$ is a constant parameter.

X_i = Free variable on the observation of -i.

***Mean Absolute Percentage Error* (MAPE)**

MAPE is one of the methods that is applied to measure the accuracy of certain forecasting processes by calculating the absolute error on each of the periods and divide it with the observation value on that period. MAPE can be measured by the equation as follows [20], [21]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - y'_i)}{n}} \quad (6)$$

With:

y_i = Actual data of -i.

y'_i = Forecasting data of -i.

n = Number of data.

The value prediction criteria for MAPE based on the research by [20] is:

Tabel 1. MAPE Prediction Criteria

MAPE	Prediction Criteria
<10%	Very good
10%−20%	Good
20%−50%	Adequate
>50%	Bad

RESULT AND DISCUSSION

The method applied in this research is fuzzy TSK with non-linear quadratic regression. The data used in this research is the data of river water in Yogyakarta. The river water quality is affected by many variables of pollution [22]. The river water data of Yogyakarta in 2020 is illustrated as follows:

Tabel 2. River water data

No	BOD (*Biochemical Oxygen Demand)*	DO *(Dissolved Oxygen)*	TSS (*Total Suspended Solid)*
1	2.84	8.67	10.8
2	2.98	8.77	9.20
3	3.19	9.37	9.35
⋮	⋮	⋮	⋮
24	2.13	9.20	8.6
25	4.63	7.47	9.8
26	3.62	8.38	8.71

Based on the data in table 2, the fuzzification process can be applied through equation (1) and (2). The fuzzification result for each variable is described as follows:

Variable x_1 (BOD)

$$\mu_{low}(x_1) = \begin{cases} 1 & , x_1 \leq 2.07 \\ \frac{(6.69 - x_1)}{(6.69 - 2.07)} & , 2.07 \leq x_1 \leq 6.69 \\ 0 & , x_1 \geq 6.69 \end{cases}$$

$$\mu_{high}(x_1) = \begin{cases} 0 & , x_1 \leq 2.07 \\ \frac{(x_1 - 2.07)}{(6.69 - 2.07)} & , 2.07 \leq x_1 \leq 6.69 \\ 1 & , x_1 \geq 6.69 \end{cases}$$

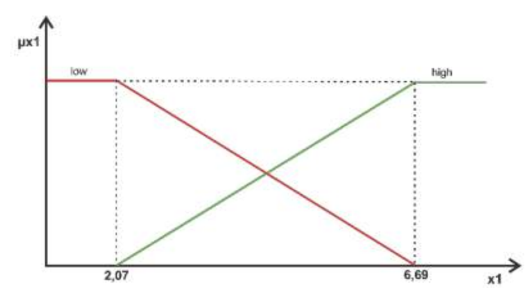

Figure 1. BOD membership value

Variable x_2 (DO)

$$\mu_{down}(x_2) = \begin{cases} 1 & , x_2 \leq 7.08 \\ \frac{(10.42 - x_2)}{(10.42 - 7.08)} & , 7.08 \leq x_2 \leq 10.4 \\ 0 & , x_2 \geq 10.42 \end{cases}$$

$$\mu_{up}(x_2) = \begin{cases} 0 & , x_2 \leq 7.08 \\ \frac{(x_2 - 7.08)}{(10.42 - 7.08)} & , 7.08 \leq x_2 \leq 10.42 \\ 1 & , x_2 \geq 10.42 \end{cases}$$

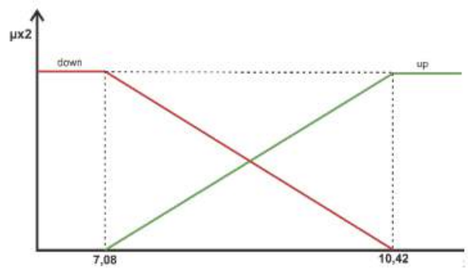

Figure 2. DO membership value

Variable y (TSS)

$$\mu_{clear}(y) = \begin{cases} 1 & , y \leq 3.55 \\ \frac{(11.65 - y)}{(11.65 - 3.55)} & , 3.55 \leq y \leq 11.65 \\ 0 & , y \geq 11.65 \end{cases}$$

$$\mu_{notclear}(y) = \begin{cases} 0 & , y \leq 3.55 \\ \frac{(y - 3.55)}{(11.65 - 3.55)} & , 3.55 \leq y \leq 11. \\ 1 & , y \geq 11.65 \end{cases}$$

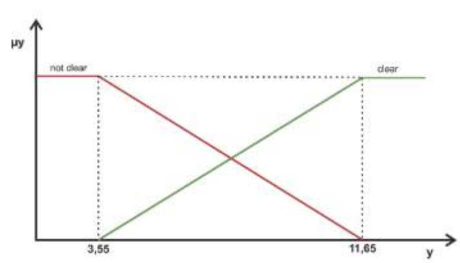

Figure 3. TSS membership value

The measurement of the membership degree from the membership function variable then applied and resulting in:

$x_1 = 2.84$

$$\mu x_1 \text{low } [2.84] = \frac{6.69 - 2.84}{6.69 - 2.07} = 0.84$$

$$\mu x_1 \text{high } [2.84] = \frac{2.84 - 2.07}{6.69 - 2.07} = 0{,}17$$

$x_2 = 8.67$

$$\mu x_2 \text{down } [8.67] = \frac{10.42 - 8.67}{10.42 - 7.08} = 0{,}52$$

$$\mu x_2 \text{up } [8.67] = \frac{8.67 - 7.08}{10.42 - 7.08} = 0{,}48$$

After the membership function has been calculated, the next step is to establish the rules.

Tabel 3. Established Rules

Rule	x_1	x_2	y
R_1	High	Increase	Muddy
R_2	High	Increase	Clear
R_3	High	Decrease	Muddy
R_4	High	Decrease	Clear
R_5	Low	Increase	Muddy
R_6	Low	Increase	Clear
R_7	Low	Decrease	Muddy
R_8	Low	Decrease	Clear

Based on the rules that acquired in table 4, it can be concluded that there are 4 rules that will be applied in TSK, such as:

[R1] If x_1 is high and x_2 is increase, then y is muddy.

[R2] If x_1 is high and x_2 is decrease, then y is clear.

[R3] If x_1 is low and x_2 is increase, then y is clear.

[R4] If x_1 is low and x_2 is decrease then y is muddy.

Furthermore, the measurement of the alpha predicate is initiated by using equation (3). This calculation of alpha predicate for each rule is resulted in:

[R1] If x_1 is high and x_2 is increase, then y is muddy.
$\alpha_{predicate} = \mu x_1 \text{high} \cap \mu x_2 \text{ increase} = 0.28$
[R2] If x_1 is high and x_2 is decrease, then y is clear.
$\alpha_{predicate} = \mu x_1 \text{high} \cap \mu x_2 \text{ decrease} = 0$
[R3] If x_1 is low and x_2 is increase, then y is clear.
$\alpha_{predicate} = \mu x_1 \text{low} \cap \mu x_2 \text{ increase} = 0.01$
[R4] If x_1 is low and x_2 is decrease, then y is muddy.
$\alpha_{predicate} = \mu x_1 \text{low} \cap \mu x_2 \text{ decrease} = 0$

Next, the output for each rule is measured by applying non-linear quadratic regression. This calculation resulted in:
[R1] If x_1 is high and x_2 is increase, then y is muddy.
$y = 18.884 - 0{,}659x_1 - 0.108x_2^2$
[R2] If x_1 is high and x_2 is decrease, then y is clear.
$y = -3.442 + 02.585x_1 + 0.062x_2^2$
[R3] If x_1 is low and x_2 is increase, then y is clear.
$y = 27.3 - 7.009x_1 + 0.084x_2^2$
[R4] If x_1 is low and x_2 is decrease, then y is muddy.
$y = 2.539 - 1.036x_1 + 0.104x_2^2$

After the output for each rule already acquired, then, the measurement of y value for each data will be measured:

Tabel 4. Regression value for each data

y_1	y_2	y_3	y_4
8.894	8.560	13.709	7.414
8.614	9.030	12.874	7.451
7.300	10.248	12.316	8.365
⋮	⋮	⋮	⋮
8.339	7.312	19.481	9.135
9.806	11.986	-0.464	3.546
8.914	10.270	7.826	6.092

The defuzzification value then will be measured by applying equation (4).

$$z^* = \frac{(0.28 \times 8.894) + (0 \times 8.560) + (0.01 \times 13.709) + (0 \times 7.414)}{0.28 + 0 + 0.01 + 0}$$

$$= 8.945$$

The defuzzification result above is applied only for the first data. The result for the second data and so on can be observed from this following table.

Tabel 5. Actual data and Forecasting result

Actual data	Forecasting
10.8	9.11
9.20	8.80
9.35	7.52
⋮	⋮
8.60	8.83
9.80	9.36
8.71	8.87

Table 5 illustrates the actual data and forecasting results. The first data acquire the forecasting result of 9,11; the second data acquire the forecasting result of 8,80 and so on.

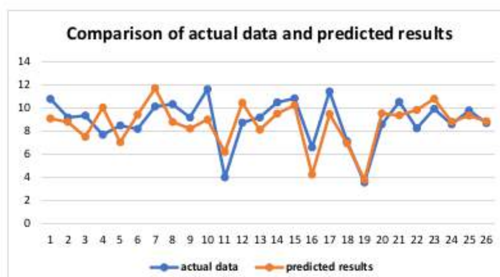

Figure 3. Comparison of actual data and predicted results

From figure 5 above, the value of Mean Absolute Percentage Error (MAPE) is obtained, valued at 14,93%. Based on [20] the table 1, it can be concluded that the model analyzed in this research can be included in the category of good.

CONCLUSION

This research uses fuzzy Takagi Sugeno Kang (TSK) that is applied on the climate data. The output of fuzzy TSK is a polynomial that is approximated by the non-linear quadratic regression method, which is acquired from each rule. The acquired forecasting result produce the Mean Absolute Percentage Error (MAPE) value of 14,93%. Based on the MAPE result, the model analyzed in this research can be considered as good. For the improvement, the other different data and polynomial approximation method needs to be analyzed further.

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