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The Forecasting Air Humidity Levels With Clustering and Hesitant Fuzzy Soft Set using 4-Factor Fuzzy Time Series

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Abstract m-Factor FTS (fuzzy time series) is a method for forecasting with more than one factor and the success of the prediction is determined by its accuracy. Hence, this study aims to determine the accuracy of 4-factor FTS to predict the daily average air temperature which is influenced by humidity, duration of solar radiation, and wind speed in Sleman Regency from April-August 2021. The partitioning of 4-factor FTS forecasting for the universe of discourse produces a uniform and non-uniform subintervals. Also, fuzzy clustering is applied in non-uniform partitioning, while hesitant fuzzy soft set is used to overcome the non-single degree of membership. Consequently, the forecasting error is calculated using the mean absolute percentage error (MAPE), which indicates an accuracy of 97.9%.

***Index Terms* -- Forecasting accuracy, m-factor fuzzy time series, fuzzy c-means, hesitant fuzzy soft set**

I. INTRODUCTION

Air temperature plays an important role in various fields of life, such as air transportation, agriculture, and health [1]. However, it fluctuates every time due to several factors, hence the prediction is urgently needed. In this study, m-factor fuzzy time series is used to predict air temperature by considering other factors.

M-factor fuzzy time series is the development of FTS introduced by Song and Chissom [2], [3]. In this method, there is only one main factor, while the others serve as support [4]. The success of forecasting is determined by its accuracy. Hence, the higher the value, the closer the actual situation.

Furthermore, the accuracy of m-factors FTS forecasting is influenced by the universe of discourse which is partitioned into 2 types of subintervals, namely uniform and non-uniform. These subintervals formed are used as a parameter of the membership function. The previous studies [5], [6], and [7] performed only one type of partitioning, using uniform interval, while [8], [9], [10], and [11] carried out non-uniform interval partitioning with different method such as clustering which is frequently used.

However, [12] and [13] provided a novelty to the previous studies by performing two partitioning at once, namely the non-uniform using a cumulative probability distribution approach, and the fuzzy c-means method with Euclidean distance. These two types of subintervals affect the fuzzification process, hence more than one degree of membership is obtained. Moreover, the hesitant fuzzy set (HFS) theory introduced by Torra and Narukawa [14] was applied to overcome this problem. Furthermore, in 2013, Babitha [15] combined HFS and soft set theory by Molodtsov [16] into a hesitant fuzzy soft set (HFSS) theory to solve the problem of a set of membership degrees.

This study aims to determine the forecasting accuracy of the average air temperature in Sleman Regency for April-August 2021, which is influenced by humidity, duration of solar radiation, and wind speed. Forecasting was carried out using a 4-factor FTS with the universe of discourse partitioned into two intervals. The combination of Minkowski Chebyshev distance and fuzzy c-means was used in non-uniform partitioning, while the membership degrees were avoided by applying the HFSS theory.

II. LITERATURE REVIEW

A. Fuzzy Time Series

Definition 1. [3] $Y(t)(t = \ldots, 0, 1, 2, \ldots)$ is defined as a subset of $\mathbb{R}$ which is the universe of discourse, and as a fuzzy set $f_i(t)(i = 1, 2, 3, \ldots)$ When $F(t)$ is a set with a member of $f_i(t)$, then $F(t)$ is called a fuzzy time series as defined in $Y(t)(t = \ldots, 0, 1, 2, \ldots)$.

Suppose that fuzzy time series $F(t)$ is influenced by time series $F(t)$ dipengaruhi oleh $(F_1(t-1), F_2(t-1), \ldots, F_m(t-1)), (F_1(t-2), F_2(t-2), \ldots, F_m(t-2)), \ldots, (F_1(t-n), F_2(t-n), \ldots, F_m(t-n))$, then the m-factor fuzzy logic relationship is defined in the n-th order with the equation $(F_1(t-n), F_2(t-n), \ldots, F_m(t-n)), \ldots, (F_1(t-2), F_2(t-2), \ldots, F_m(t-2)), (F_1(t-1), F_2(t-1), \ldots, F_m(t-1)) \to F(t)$. In this equation, $F_1(t)$ acts as the main factor, and $F_2(t), F_3(t), \ldots, F_m(t)$ as the supporting factors [17].

B. Fuzzy C-Means with Distance Combination by Minkowski Chebysev

Fuzzy C-Means (FCM) was launched by Jim Bezdek [18] with the basic concept of determining the center of the cluster thereby marking the average location of each cluster [19]. This centre is obtained through the following equation:

$$V_{kj} = \frac{\sum_{i=1}^{p}\left((\mu_{ik})^f \times X_{ij}\right)}{\sum_{i=1}^{p}(\mu_{ik})^f}$$

The initial value obtained is not accurate, therefore iterations are carried out to improve the cluster center and the degree of membership, hence the movement is directed to the right location. The iteration minimizes the objective function thereby showing the distance of the data point to the cluster center and the weighted degree of membership. Also, the similarity between two objects in the case of clustering is a measure of the distance. Basically, several distances are useful, but according to [20], optimal results was obtained by combining FCM with Minkowski Chebysev. The objective function for FCM combined with Minkowski Chebyshev distance is as follows:

$$\min P(U,V) = \sum_{i=1}^{p}\sum_{k=1}^{c}(\mu_{ik})^f \left(w_1 \sqrt[p]{\sum_{j=1}^{q}|x_{ij} - v_{kj}|^p} + w_2 \max_j |x_{ij} - v_{kj}| \right)$$

With limitations of $\sum_{k=1}^{c}\mu_{ik} = 1, 0 < \mu_{ik} < 1$.

The FCM iteration stops when meeting the condition $\left|P^{(t)}(U,V) - P^{(t-1)}(U,V)\right| < \varepsilon$, where ε is the smallest expected error in which the value has been determined at the beginning of the process.

C. Hesitant Fuzzy Soft Set

Definition 3. [16] Given a universe of discourse of U and parameter set of A. $P(U)$ is the power set of U. The pair (F, A) is soft set of U if and only if F is the mapping of A on $P(U)$.

Definition 4. [21] Given a universe of discourse U, hesitant fuzzy set on U is a mapping defined by a function of h_H as follow:

$$h_H : U \to [0,1]$$

Hesitant fuzzy set on U is represented as:

$$\widetilde{H}(U) = \{\langle u, h_H(u)\rangle | u \in U\}$$

$h_H(u)$ is the set of possible degrees of membership of the element $u \in U$ on the set $H, H \subset U$.

Definition 5. [15] Given a universe of discourse U, parameter set of A, and $\widetilde{H}(U)$ is the HFS on U. The pair $(\widetilde{F}, A)$ is called hesitant fuzzy soft set on U, if $\widetilde{F}(a) \in \widetilde{H}(U)$ for each $a \in A$.

Definition 6. [22] Given a collection of hesitant fuzzy set element $h_i, i = 1,2,\dots,n$, the aggregation operator of hesitant fuzzy soft weighted average (HFSWA) is defined as follows:

$$HFSWA(h_1, h_2, \dots, h_n)$$

$$= \cup_{\lambda_1 \in h_1, \lambda_2 \in h_2, \dots, \lambda_n \in h_n} \left\{ 1 - \prod_{i=1}^{n} (1 - \lambda_i)^{w_i} \right\} \quad (1)$$

Where w_i is the weight of each λ_i in which the value lies in the interval $[0,1]$ and $\sum_{i=1}^{n} w_i = 1$.

D. Mean Absolute Percentage Error (MAPE)

MAPE is used to calculate the accuracy of forecasting appropriately when the actual value is large but not useful when the value is zero [23].

$$MAPE = \frac{1}{n} \sum_{t=1}^{n} \frac{|Y_t - \hat{Y}_t|}{|Y_t|} \times 100\% \quad (2)$$

Y_t is the actual value at t-th time and $\hat{Y}_t$ is the value of forecasting results at t-th time.

According to [24], The use of MAPE for forecasting accuracy is divided into the following 4 criteria:

TABLE I
MAPE CRITERIA

MAPE Value	Description
<10%	Very Good
10%-20%	Good
20%-50%	Sufficient
>50%	Poor

III. Implementation of FCM and HFSS for 4-Factor FTS Forecasting

The steps in 4-factor FTS forecasting with the implementation of FCM and HFSS are:

1) Defining the universe of discourse as follows:

$$U_j = [a_j, b_j] = [X_{j,min} - \sigma_j, X_{j,max} + \sigma_j] \quad (3)$$

$X_{j,min}, X_{j,max}$ are the minimum and maximum value of the $j, (j = 1,2,3,4)$ -th factors and σ_j is the standard deviation of the j-th factors.

2) Partitioning the universe of discourse interval into 7 uniform and 7 non-uniform subintervals. Uniform partitioning is performed by determining the length of the subinterval using the following equation:

$$\ell_j = \frac{b_j - a_j}{r} \quad (4)$$

r is the total subintervals formed, $r = 7$.

While the combination of FCM with Minkowski Chebysev distance was used for non-uniform partitioning. Based on the optimal cluster center obtained from the last iteration, an interval is formed with the following equation:

$$B_{j1} = [a_j, m_1], B_{j2} = [m_1, m_2], \dots, B_{jr} = [m_{k-1}, b_j] \quad (5)$$

Where $m_1, m_2, \dots, m_{k-1}$ is the median of two consecutive cluster centers.

3) Performing fuzzification using the triangular membership function

$$\mu(x)=\begin{cases}0 & x\le a; x\ge c\\ \dfrac{x-a}{b-a} & a\le x\le b\\ \dfrac{b-x}{b-a} & b\le x\le c\end{cases} \quad (6)$$

4) Building HFSS and performing aggregation using the HFSWA operator in equation (1). The weights used for aggregation are as follows:

$$w_s=\frac{\ell_s}{\ell_s+\ell_{ts}};\ w_{ts}=\frac{\ell_{ts}}{\ell_s+\ell_{ts}} \quad (7)$$

5) Forming a fuzzy logic relationship (FLR) order 3.

6) Performing defuzzification using the following equation [25]:

Defuzzification for the main factor:

$$crisp(H_k)=\frac{\sum_{i=1}^{p} h_{i,k}\times Y_i}{\sum_{i=1}^{p} h_{i,k}} \quad (8)$$

Defuzzification for the supporting factor:

$$crisp(H_{jk})=\frac{\sum_{i=1}^{p} h_{i,jk}\times X_{i,j}}{\sum_{i=1}^{p} h_{i,jk}} \quad (9)$$

7) Calculating forecasting results with this equation [25]:

$$\hat{Y}_i=\frac{1}{m}\left(\sum_{j=1}^{m}\frac{\sum_{r=1}^{n}(X_{j,(i-r)})\times(Y_{i-r})}{\sum_{r=1}^{n}(X_{j,(i-r)})}\right) \quad (10)$$

Where, m is the total supporting factors, n is the orders that used, $X_{j,(i-r)}$ and Y_{i-r} is the crisp value of each corresponding linguistic value.

8) Calculating forecasting accuracy using MAPE in equation (2).

IV. Result and Discussion

In this study, the daily climate data in Sleman Regency for April-August 2021, obtained from the BMKG official website is used [26]. The data consists of 4 factors, namely the average temperature (Y) as the main factor, the average humidity (X_1), the length of solar radiation (X_2), and the average wind speed (X_3) as supporting factors. Each of these four factors is defined by the universe of discourse as follows:

U1=[23.030, 28.870], U2=[71.598, 96.402], U3=[-2.486, 13.086], U4=[-0.634, 2.634]

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The universe of discourse is partitioned into 7 uniform and 7 non-uniform subintervals, moreover, the numbers shows the linguistic values of each variable. After 66 iterations, the optimal cluster center obtained is used to construct non-uniform subintervals using equation (5). Hence, the subinterval of each variable formed is as follows:

TABLE II
SUBINTERVAL Y

Uniform Subinterval Y	Non-Uniform Subinterval Y
A1 = [23.030, 23.864]	B1 = [23.030, 26.303]
A2 = [23.864, 24.699]	B2 = [26.303, 26.348]
A3 = [24.699, 25.533]	B3 = [26.348, 26.351]
A4 = [25.533, 26.367]	B4 = [26.351, 26.365]
A5 = [26.367, 27.201]	B5 = [26.365, 26.382]
A6 = [27.201, 28.036]	B6 = [26.382, 26.416]
A7 = [28.036, 28.870]	B7 = [26.416, 28.870]

TABLE III
SUBINTERVAL X_1

Uniform Subinterval X_1	Non-Uniform Subinterval X_1
A11=[71.598, 75.141]	B11=[71.598, 81.878]
A12=[75.141, 78.684]	B12=[81.878, 82.854]
A13=[78.684, 82.227]	B13=[82.854, 83.129]
A14=[82.227, 85.770]	B14=[83.129, 83.341]
A15=[85.770,89.313]	B15=[83.341, 83.481]
A16=[89.313, 92.856]	B16=[83.481, 84.847]
A17=[92.856, 96.399]	B17=[84.847, 96.402]

TABLE IV
SUBINTERVAL X_2

Uniform Subinterval X_2	Non-Uniform Subinterval X_2
A21=[-2.486, -0.216]	B21=[-2.486, 5.735]
A22=[-0.216, 1.964]	B22=[5.735, 6.460]
A23=[1.964, 4.189]	B23=[6.460, 6.613]
A24=[4.189, 6.414]	B24=[6.613, 6.714]
A25=[6.414, 8.639]	B25=[6.714, 6.836]
A26=[8.639, 10.864]	B26=[6.836, 7.202]
A27=[10.864, 13.089]	B27=[7.202, 13.086]

TABLE V
SUBINTERVAL X_3

Uniform Subinterval X_3	Non-Uniform Subinterval X_3
A31=[-0.634, -0.167]	B31=[-0.634, 1.100]
A32=[-0.167, 0.300]	B32=[1.100, 1.104]
A33=[0.300, 0.767]	B33=[1.104, 1.106]
A34=[0.767, 1.234]	B34=[1.106, 1.109]
A35=[1.234, 1.701]	B35=[1.109, 1.110]
A36=[1.701, 2.168]	B36=[1.110, 1.119]
A37=[2.168, 2.635]	B37=[1.119, 2.634]

A_r and B_r are the linguistic values for the main factor, while A_{mr} and B_{mr} represents the values for the supporting factor, where m is the index of supporting factors and r shows the total linguistic values.

Each factor has two types of subintervals as parameters of the triangular membership function in the fuzzification process. Also, each data point is fuzzified against two intervals according to the factors, hence two degrees of membership is contained in each linguistic value. Consequently, HFSS is formed from the fuzzification of each factor with uniform and non-uniform subintervals, respectively and the average temperature factor (Y) formed is shown in Table VI.

Furthermore, the HFSS of the data point in each linguistic value is aggregated using the operator in equation (1). Also, the weight of each subinterval is firstly gotten using equation (7), before performing the aggregation calculations. The largest aggregation is defined as the fuzzification location of the data points and is used to form a fuzzy logic relationship order 3. These numbers indicates the order of the time series influencing the data value in the t-period.

TABLE VII
FUZZY LOGIC RELATIONSHIP ORDER 3

Date	Order 3 $(t-3), (t-2), (t-1)$	t
01-04-21	-	-
02-04-21	-	-
03-04-21	-	-
04-04-21	(H4, H17, H22, H34),(H5, H17, H24, H32),(H5, H15, H24, H37)	H5
05-04-21	(H5, H17, H24, H32),(H5, H15, H24, H37),(H5, H17, H21, H34)	H5
06-04-21	(H5, H15, H24, H37),(H5, H17, H21, H34),(H5, H17, H22, H32)	H7
...	...	...
29-08-21	(H3, H11, H25, H34),(H1, H11, H26, H34),(H1, H14, H25, H34)	H4
30-08-21	(H1, H11, H26, H34),(H1, H14, H25, H34),(H4, H13, H21, H34)	H5
31-08-21	(H1, H14, H25, H34),(H4, H13, H21, H34),(H5, H11, H27, H34)	H5

TABLE VI
HESITANT FUZZY SOFT SET FOR Y-FACTOR

Data	H1	H2	H3	H4	H5	H6	H7
26,1	{0, 0.124}	{0, 0}	{0, 0}	{0.640, 0}	{0, 0}	{0, 0}	{0, 0}
26,7	{0, 0}	{0, 0}	{0, 0}	{0, 0}	{0.799, 0}	{0, 0}	{0, 0.231}
26,5	{0, 0}	{0, 0}	{0, 0}	{0, 0}	{0.319, 0}	{0, 0}	{0, 0.068}
…	…	…	…	…	…	…	…
25,9	{0, 0.246}	{0, 0}	{0, 0}	{0.880, 0}	{0, 0}	{0, 0}	{0, 0}
26,8	{0, 0}	{0, 0}	{0, 0}	{0, 0}	{0.962, 0}	{0, 0}	{0, 0.313}

26,7	{0, 0}	{0, 0}	{0, 0}	{0, 0}	{0.799, 0}	{0, 0}	{0, 0.231}

The aggregation of each data point is used as input in the defuzzification process and the crisp value of each linguistic is calculated using equations (8) and (9). The results obtained for the average temperature factor are as follows:

crisp(H1)=25.150; crisp(H2)=24.187; crisp(H3)=25.142; crisp(H4)=25.993; crisp(H5)=26.779; crisp(H6)=27.496; crisp(H7)=27.266

The defuzzification for the average humidity are:

crisp(H11)=78.502; crisp(H12)=78.072; crisp(H13)=80.747; crisp(H14)=83.968; crisp(H15)=87.364; crisp(H16)=85.337; crisp(H17)=88.637

The defuzzification for the duration of solar radiation are as follows:

crisp(H21)=2.546; crisp(H22)=3.556, crisp(H23)=3.049; crisp(H24)=5.409; crisp(H25)=7.569; crisp(H26)=9.509; crisp(H27)=9.299

The defuzzification for the average wind speed are:

crisp(H31)=0.358; crisp(H32)=0; crisp(H33)=0; crisp(H34)=0; crisp(H35)=0; crisp(H36)=2; crisp(H37)=2

Forecasting results are calculated based on the fuzzy logic relationship formed and also from the crisp value of each linguistic for all factors. The 4-factor FTS forecasting of order 3 is calculated using equation (10), and the results are shown in the following table.

TABLE VIII
ACTUAL DATA AND FORECASTING RESULTS

Date	Actual Data	Forecasting Results of Order 3
01-04-21	26.1	-
02-04-21	26.7	-
03-04-21	26.5	-
04-04-21	27	26.377
05-04-21	26.5	26.629
06-04-21	27.2	26.456
....	....	....
29-08-21	25.9	25.151
30-08-21	26.8	25.151
31-08-21	26.7	25.773

Besides tabulation form, the results of 4-factor FTS forecasting are also represented in the following graph.

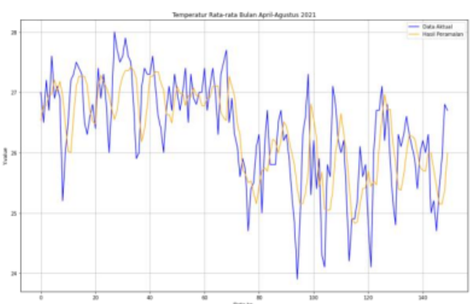

Fig. 1. Comparison of 4-factor FTS forecasting results and actual data on average temperatures in Sleman Regency in April-August 2021.

The error of the forecasting results is calculated using equation (2) and the MAPE value is 2.1%. Therefore, this value shows that the accuracy of 4-factor FTS to predict the temperature in Sleman Regency for April-August 2021 is 97.9%.

V. Conclusion

In conclusion, the 4-factor fuzzy time series forecasting of order 3 has a high accuracy to predict the average temperature in Sleman Regency by considering the factors of average humidity, duration of solar radiation, and wind speed. This is reflected from the MAPE value obtained as 2.1%, meaning that the forecasting accuracy is 97.9%. Also, the results show that the implementation of clustering and hesitant fuzzy soft sets helps to obtain high forecasting accuracy.

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