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WEATHER EVENTS FORECASTING IN KOTA KINABALU USING A FUZZY RULE-BASED SYSTEM

Suzelawati Zenian and Amirah Ramizah Bibi Abdul Rasheed

Mathematics with Computer Graphics, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.

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ABSTRACT. *A weather forecast is a prediction of weather phenomena in the future by collecting as much data as possible. Major worldwide climate studies include the breakthrough and interpretation of complicated weather patterns in order to successfully forecast varied weather events. It is quite complex to screen so many parameters from several factors to discover precise weather conditions. In this paper, a fuzzy rule-based system (FRBS) is applied for weather forecasting in Kota Kinabalu. There are 234 fuzzy rules being developed as the FRBS are constructed along and successfully implemented in MATLAB. Based on the results, the comparison between actual and forecast data shows moderate precision as the accuracy level is higher than the level of error analysis.*

KEYWORDS. Weather events, fuzzy rule-based system, forecasting, fuzzy set.

INTRODUCTION

Malaysia is an Asian country situated north of the equator and is geographically located in between two large oceans which are the Pacific Ocean to the east and the Indian Ocean to the west (Malaysia Meteorological Department, 2016). There is no dry season in Malaysia because it is near the equator, which is also surrounded by oceans. In general, as is the case in tropical countries, Malaysia experiences a rainy season which is relatively unpredictable every year. The study area is Kota Kinabalu, Sabah, one of Malaysia's states. The selected location for this study will be southwest of Kota Kinabalu city. The existing weather forecasting research is performed within the same area using a soft computing technique (Mojiol, 2006). There are data sets from January 2019 to December 2019 on probability distribution for the development of weather forecasts. This region has a typical moist continental climate. The conditions are regularly hot and cool, with strong rainfall typically in the afternoon and highly unchanging all year long.

Weather forecast is a significant issue that must be considered because of the variability of human activities which will eventually regulate the weather in a region of a country. All human activities such as the variations in land refuge and the burning of fossil fuels, are alleged to be one of those contributions to this issue of constant changes in the weather. Fuzzy logic stipulates an effective technique to relate to the weather parameter and the weather events. To complete the research, a software called MATLAB will be used to implement the generated FRBS by using certain MATLAB functions (Moler & Little, 2020). Khatua *et al.* (2020) showed that in order to investigate the impact of global warming, water pollution, and harvesting of juvenile fishes on the production of mature Hilsa fishes, a mathematical model is developed using fuzzy inferences. Cihan (2020) implemented FRBS to forecast the number of verified cases in the Covid-19 outbreak in Turkey.

Fuzzy logic is also used to forecast relative humidity because fuzzy logic can manage weather uncertainty and complexities despite dealing with major mathematical terms. Fuzzy logic is a simple but effective technique for solving problems with comprehensive applications. Fuzzy logic can be used to provide alternatives for unclear, inaccurate, and ambiguous issues. Fuzzy logic is another of those logical or expert systems, the purpose where it is to use the expertise and experience acquired over a period to achieve a human expert level (Ross, 2010; Zadeh, 1975).

This paper focuses on the implementation of FRBS in forecasting the weather events in Kota Kinabalu based on the data collection from the Meteorology Forecasting Department in Kota Kinabalu. In this paper, the observation of daily weather events will include temperature, relative humidity, atmospheric pressure, and precipitation. Then these weather observations will be used as parameters related to forecast the selected weather events such as rain, thunderstorm, rain-thunderstorm, cloudy and sunny.

Hence, a mapping of the weather parameters onto weather events has to be developed in order to be able to predict the weather event. This can be done by implementing FRBS in the MATLAB software by undergoing a few processes such as fuzzification, rule generation, rule-based reduction and inferencing. Then the forecasted weather events will be compared with the actual data to clarify the differences in order to determine the precision of accuracy and error analysis. As a result, forecasting the weather event can be accomplished because the fuzzy logic stipulates an effective technique to relate to weather parameters and weather events as it is fuzzy in nature. Thus, this can contribute more to the meteorology field.

MATERIALS AND METHODS

To develop the FRBS in forecasting weather events, there are a few processes in developing the fuzzy rules shown in the experimental setups (Sharma *et al*., 2014). There are eight steps to be implemented whereby the performances will be compared according to the monthly forecast data which will then determine the accuracy and error analysis. The measures engaged are summarized in the remaining discussion for this section.

The process segment can be extended in detail as the steps in conducting these processes are dependent on each other. Firstly, it is the development of FRBS by applying the data set. Secondly, the results of monthly data of the original weather events and the forecasted weather events would be measured in a plot to display the inconsistency between them and evaluate the precision for accuracy analysis and error analysis. Ultimately, a summary will be included in the last stage which is the conclusion to summarize the important elements. There are eight steps opted in developing the fuzzy rules in this experimental setup as illustrated in Figure 1.

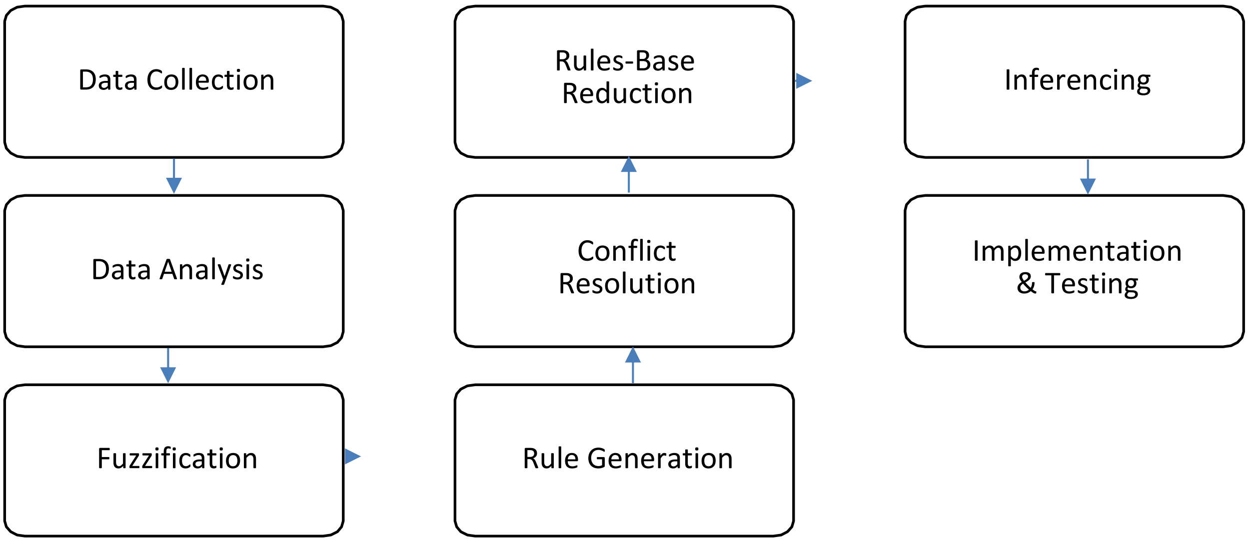

Figure 1. Methodology for developing the FRBS

A. Data Collection

Daily weather observations from January 2019 to December 2019, a total of one year of weather parameters such as temperature, humidity, precipitations and atmospheric pressure. The data collected are from the Malaysia Meteorology Department (2016).

B. Data Analysis

Data are collected to determine if the extreme data exist, the errors collection and the sample size of data included in this weather forecasting can be recognized. Due to the common occurring weather events in Malaysia, there are five forms of weather events preferred in forecasting the weather which are the "Rain", "Rain-Thunderstorm", "Thunderstorm", "Cloudy" and "Sunny" weather events. There are four types of weather observation which are atmospheric pressure, precipitation, humidity, and temperature which have been gathered for data analysis.

C. Fuzzification of input/output

The fuzzification will assign a range of linguistic variables that define the various input and output parameters of the system. Fuzzification is the step by which the crisp values are fuzzified into membership levels associated with the fuzzy sets. A triangular shape membership function has been selected as the input variable ranges from 0 to 1 in a specified discourse universe. The linguistic variables which are applied are "very low", "low", "medium", "high" and "very high" along with the four-input variable which are atmospheric pressure, precipitation, humidity, and temperature. The range for the weather parameters is defined by determining the maximum and minimum numerical value of each weather parameter.

D. Rule Generation

Through engaging MATLAB rules editor, the rules are incorporated into the fuzzy inference system. The automatic generating of rules is utilized to generate the automatic specific rules by applying an algorithm based on the collected weather data to produce the data extraction. Apart from that, the engagement with human specialists relying on their perspectives, heuristic based and preferences resulting in a standardized rule set.

E. *Conflict Resolution*

The indicator of conflict resolution is a decoding process of outputs called defuzzification whereby the multiple fuzzy rules were compared and cancelled. The conflict resolution is accomplished by carrying out in the fuzzy rule-based system by initial classification of the generic and specific rules that are created followed by removing the inconsistent and redundant rules before ultimately aggregation of rules is performed.

F. *Inferencing*

The Mamdani inference framework is used in the forecasting system. The application of Mamdani inference framework is required to develop the dynamic fuzzy sets as the output product membership functions. Following the aggregation method, for every output variable, a fuzzy set exists which needs to undergo defuzzification process. A list of sample fuzzy rules is shown in Table 1.

Table 1. Developed fuzzy rules

Rules	IF (antecedent)	THEN (consequence)
1	(TodayTemp is low) and (YestTemp is high) and (TodayPressure is low) and (YestPressure is medium)	forecast is cloudy
2	(TodayTemp is high) and (YestTemp is high) and (TodayPressure is medium) and (YestPressure is medium)	forecast is clear
3	(TodayTemp is high) and (YestTemp is high) and (TodayHumidity is low) and (YestHumidity is low)	forecast is sunny
4	(TodayTemp is high) and (YestTemp is high) and (TodayPressure is medium) and (YestPressure is low)	forecast is thunder
5	(TodayTemp is low) and (YestTemp is medium) and (TodayHumidity is VHigh) and (YestHumidity is VHigh)	forecast is rain
6	(TodayTemp is high) and (YestTemp is high) and (TodayPressure is VLow) and (YestPressure is low)	forecast is rain-thunder

G. *Implementation & Testing*

To show the output of the outcome for forecasting weather events, this system will be implemented in MATLAB R2018 software which is the key factor for this weather forecast. The rules editor in MATLAB is used to apply specific and generic rules. The implementation of FIS is described as the shaping of the consequence part (Then) based on the antecedent part (If) and the inputs are fuzzy subsets. To conclude briefly regarding the fuzzy RBS in the experimental setup, it will have the following basic characteristics for this methodology as shown in Table 2.

Table 2. Basic characteristics

Linguistic Labels (Input)	4
Number of outputs	8
Number of rules	234
Inferencing Method	Forward Chain
Inference model	Mamdani
Aggregation Operator	“MIN”

H. Determine Precision

The experimental setup findings above could be used to improve weather prediction accuracy based on the statistics obtained. Generally, experiments require a precision analysis or error analysis in order to correlate the usual outcome and evaluate the accuracy and the error analysis in percentage. The formulae applied throughout this paper to determine the precision by calculating the error analysis and the predictive accuracy analysis are shown as follows (Sharma *et al.*, 2014).

$$\text{Relative Error} = \frac{\text{Absolute Error}}{\text{Actual Value}} = \frac{\text{Actual Value - Observed Value}}{\text{Actual Value}} \quad (1)$$

$$\text{Error Analysis} = \text{Percentage relative error} = \text{Relative error} \times 100\% \quad (2)$$

$$\text{Accuracy analysis} = \text{Percentage accuracy} = 100\% - \text{Error analysis} \quad (3)$$

DESIGN AND IMPLEMENTATION

This section outlines the fuzzy logic toolbox as the system implementation which are effective in helping user step-by- step in developing a system design of fuzzy inference system. Fuzzy Logic Toolbox comprises several MATLAB features, tools, and a Simulink framework for analyzing, constructing, and modelling systems based on fuzzy logic. In fuzzy logic toolbox there are five main components which consist of Fuzzy Logic Designer, Surface Viewer, Rule Editor, Membership Function Editor and Rule Viewer which will be explained in further details. There are directions, stages and usage for each of the boxes which are relevant to the information of a system to be designed (Agboola, 2013, Awan & Awais, 2011, Hemayatkar, 2018).

A. Input

The input is the weather event data.

B. Process

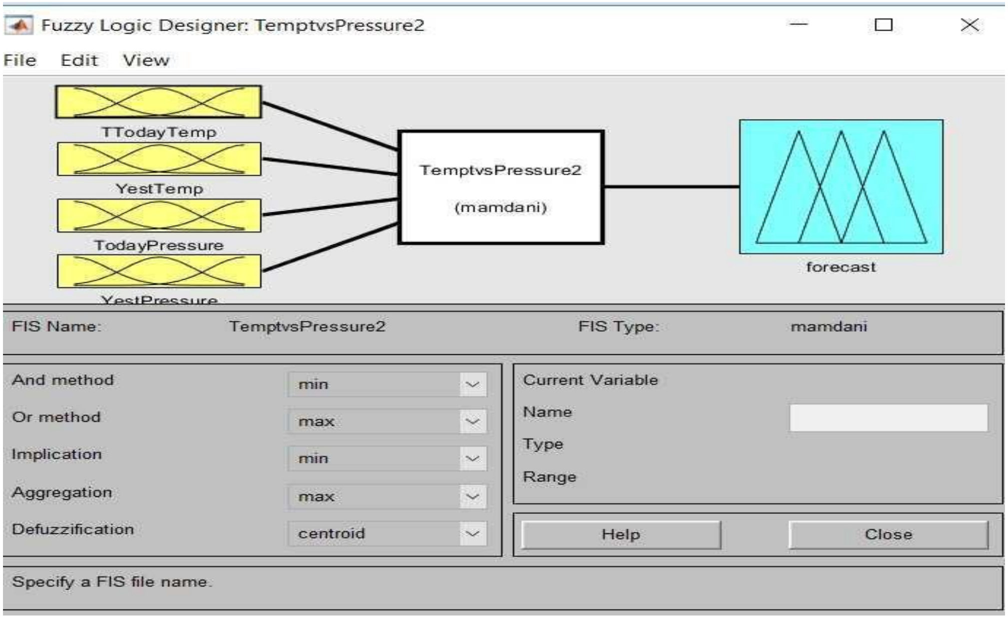

Figure 2. Fuzzy Logic Designer

User can build and evaluate fuzzy inference system for modelling a complex system behavior with the aid of fuzzy logic designer application (see Figure 2). There is no limited number of data entry in the fuzzy logic designer. If the data entry and membership function are high, it will be a problem in interpreting the outcomes for an inference system. Moreover, user can modify and build an appropriate model inference system using this fuzzy logic designer display box.

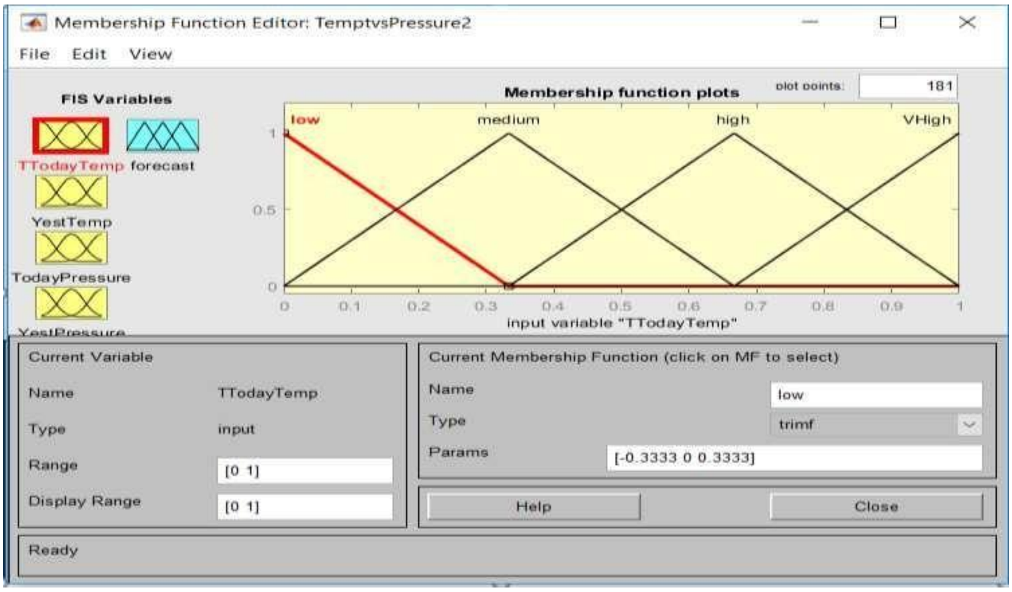

Figure 3. Membership Function Editor

The membership function editor is a method for viewing and modifying all membership features associated and enables a user to manipulate input and output data for entire fuzzy inference system. Users can also view the membership function plots which are shown in Figure 3 above for the variable which are selected.

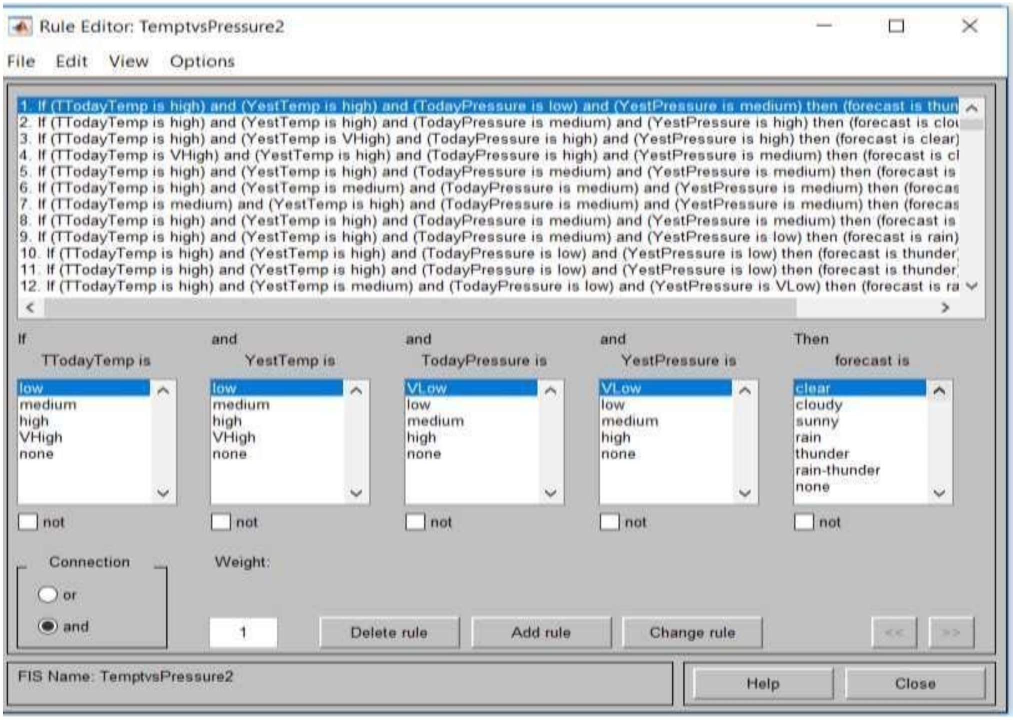

Figure 4. Rule Editor

The rule editor box is widely used to create an IF-THEN network. This is because the rule editor allows the user to build the rule statements. A collection of rules can be generated automatically depending on the input variable which is set in the box as shown in Figure 4.

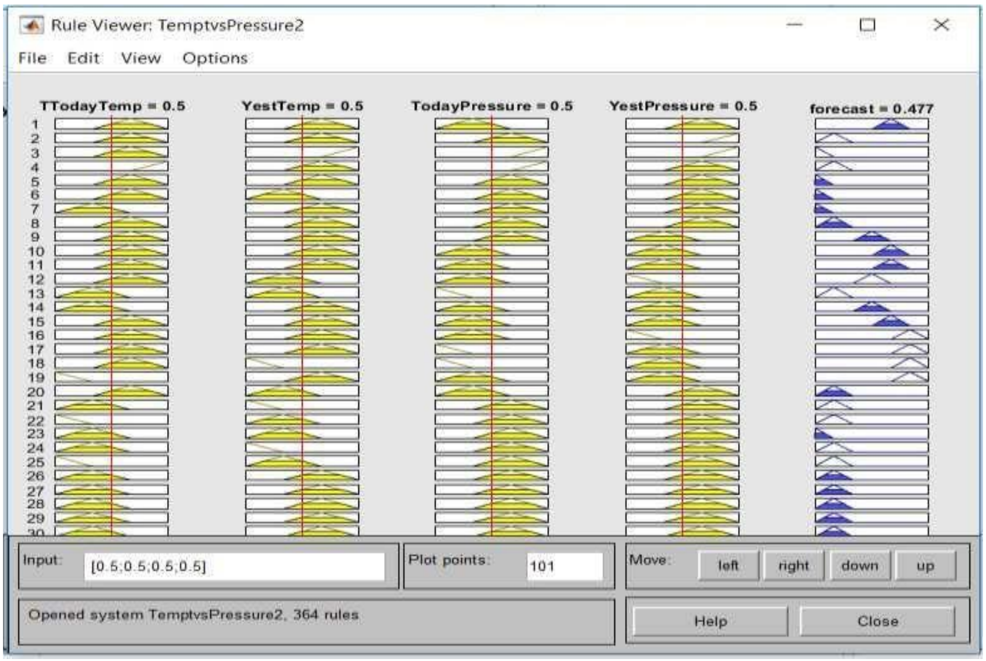

Figure 5. Rule Viewer

The overall results of the fuzzy inference process will be shown in the rule viewer section. Users can observe a new screen of a diagram pop-up with numerous graph plots embedded within it. The rule viewer will illustrate and shows a set of membership function in every column (see Figure 5).

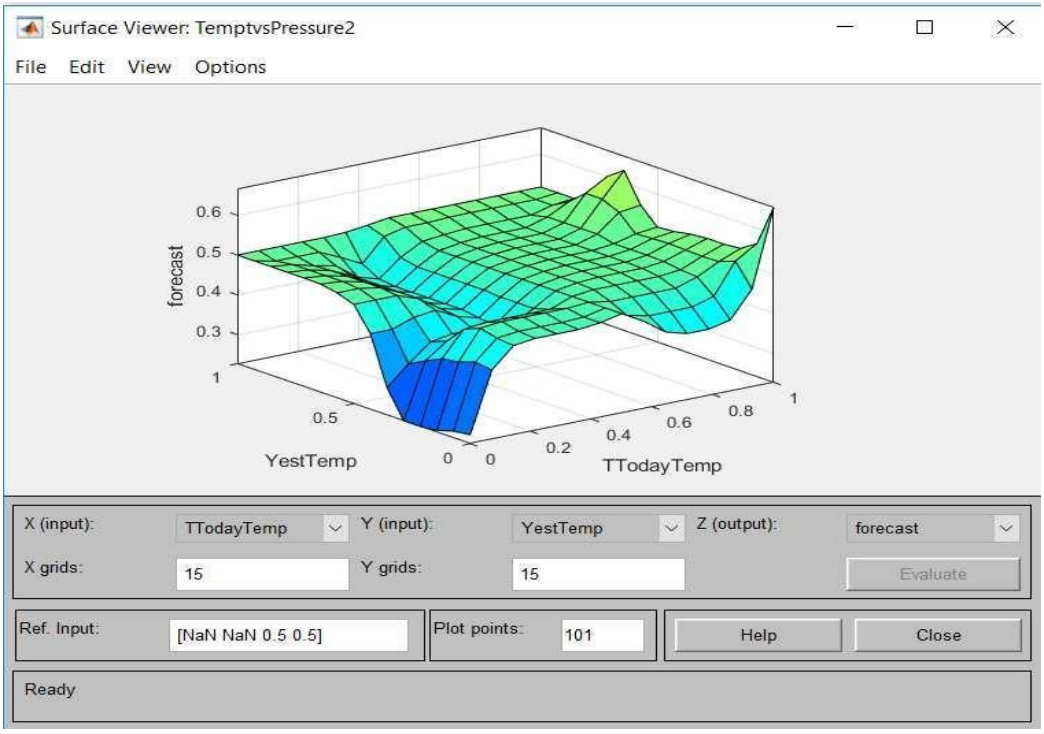

Figure 6. Surface Viewer

In the surface viewer (see Figure 6), it will display the surface that represents the mapping of the membership function where the three-dimensional of *x* is for input, *y* is for input and *z* is for the output.

C. Output

The output will be used as parameters related to forecasting the selected weather events such as rain, thunderstorm, rain-thunderstorm, partly cloudy and sunny. Hence, the mapping of weather parameters onto weather events must be developed to obtain the forecasted weather events. In this study, a comparison of the forecast events will be made to display the wider view of forecasting data of the fuzzy rules and the data accuracy will be calculated to increase the accuracy of forecasting data of the fuzzy rules.

RESULTS AND DISCUSSION

The results are conducted by implementing MATLAB software and will be discussed in detail. Besides, the accuracy of the forecasting will be examined. There are 234 sets of rules which are successfully developed by focusing on the data and the weather event in the year 2019. The successfully developed rules consist of 29 rules for cloudy weather events, 42 rules for sunny weather events, 20 rules for thunderstorm weather events, 63 rules for rain weather events, and 80 rules for rain- thunderstorm weather events.

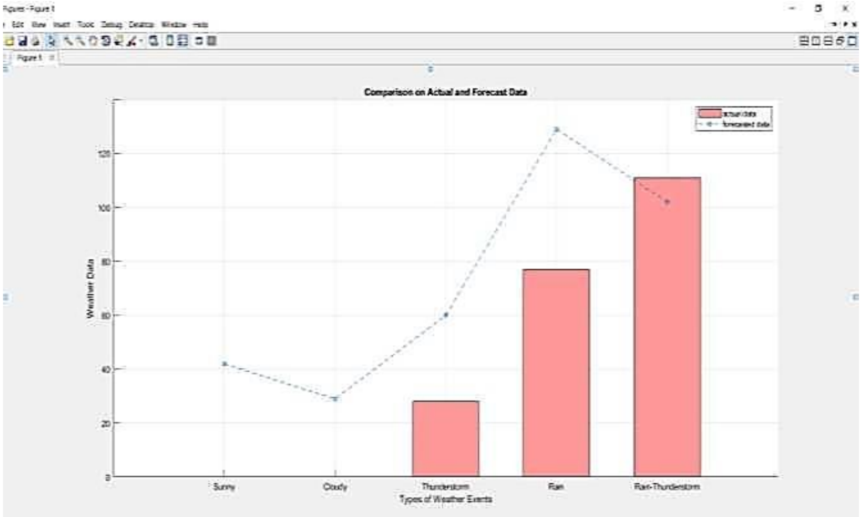

Figure 7. Comparison of actual and forecasted data

Figure 7 portrays the comparison in total number of forecasted data which have moderate precision of accuracy with the actual weather events in days using graph plotting. The actual data are represented using the bar chart graph whereas the forecast data are represented by the line graph plotting. It is clearly illustrated that the forecast data exceeded the actual data value for "Thunderstorm" and "Rain" weather events. Moreover, there are no actual data for "Sunny" and "Cloudy" weather events, so the data could not be compared with the forecast data. Thus, the plotting indicates that the forecast data is higher in majority weather event as compared to actual data which contain some missing value.

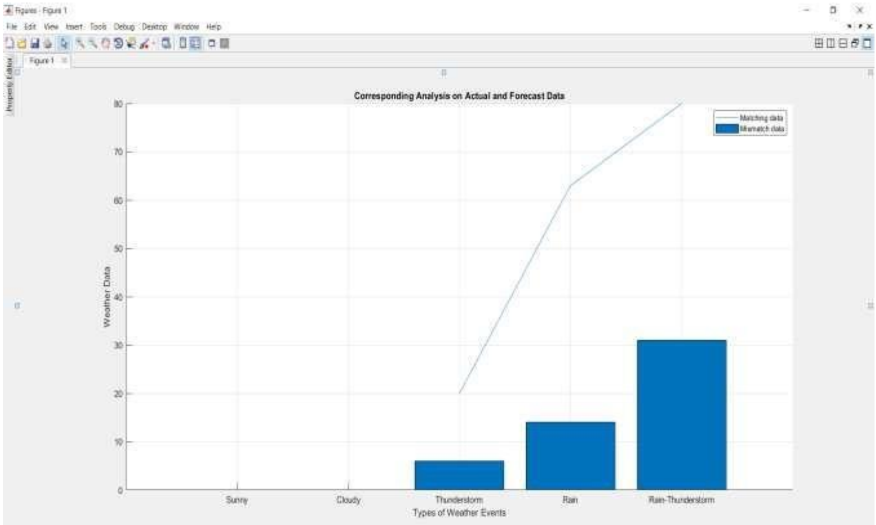

Figure 8. Corresponding analysis of match and mismatched data

Figure 8 portrays the corresponding data between matching and mismatched data for the actual and forecast weather event. This clearly illustrated that the matching data are higher than the mismatch data in total for the year 2019. The highest matching data are for "Rain- Thunderstorm" weather event with 80 matching data corresponding to actual and forecast weather events. Apart from that, for "Rain" weather event, there are 63 matching data which marked the second highest matching data whereas as much as 20 matching data for "Thunderstorm" weather event corresponds to actual and forecast weather events.

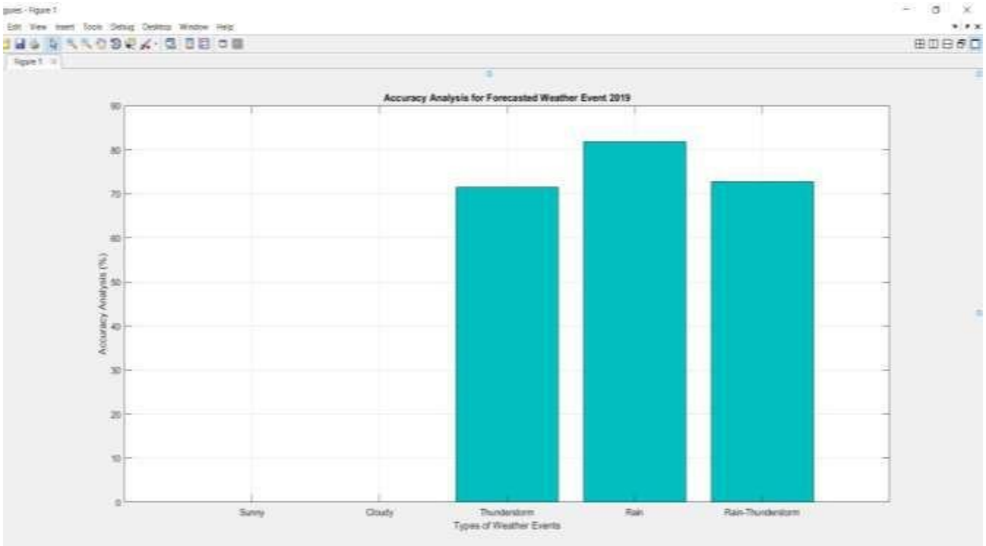

Figure 9. Accuracy analysis for forecasted weather event

Figure 9 portrays the precision of accuracy for forecasted weather events in percentage using bar graph plotting. The overall precision of accuracy is obtained by 75.5% for all three weather events. There are three weather events data been plotted which are “Rain”, “Thunderstorm” and “Rain-Thunderstorm”. Among the three, only “Rain” weather event managed to achieve the highest precision of accuracy compared to the other two weather events.

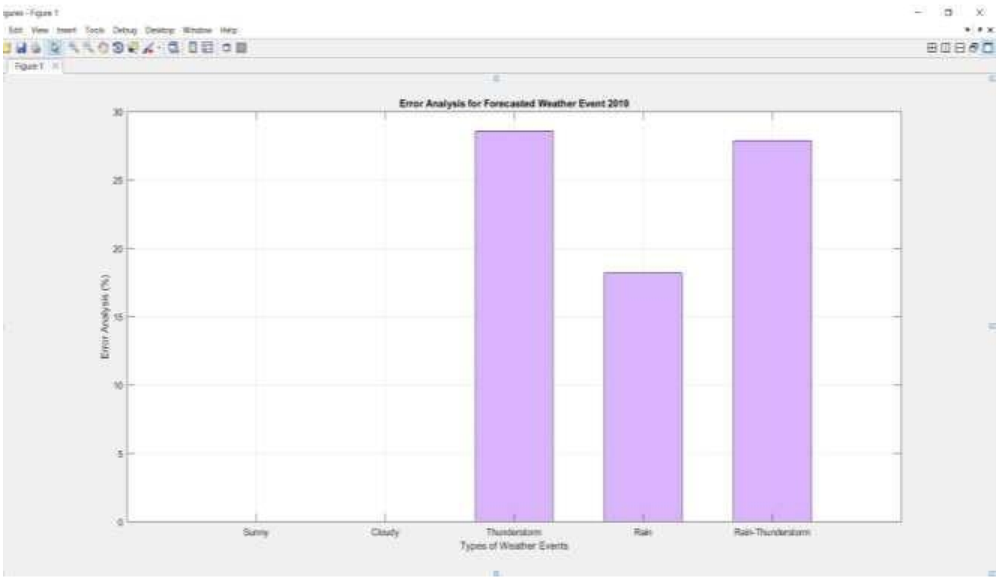

Figure 10. Error analysis for forecasted weather event

Figure 10 illustrates the error analysis for the three weather events resulting in a total error analysis of 23.6%. Among the weather events there are two weather events with high error analysis which are ‘Rain-Thunderstorm” and “Thunderstorm”. Nevertheless, compared to the three-weather event, the lowest error analysis is the “Rain” weather event resulting in 18.2%. However, there is no outcome for the "Sunny" and "Cloudy" weather events because there is no actual data available.

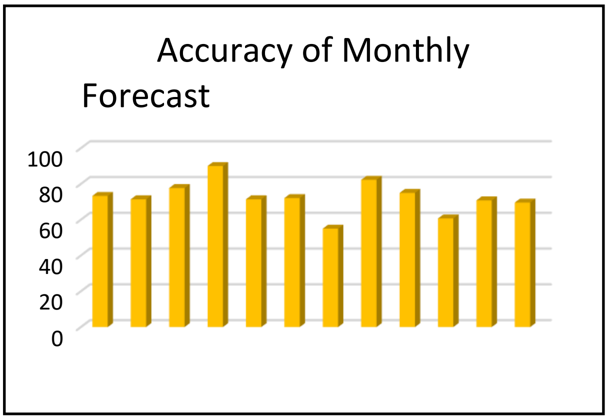

Figure 11. Monthly forecast of accuracy analysis

To sum up, an overall plotting of graph has been performed to show the differences in terms of months for the precision of accuracy for the forecasting weather events. The month which has the highest precision of accuracy is in April with approximately 90% accuracy and followed by March, August and September with approximately 70% to 80% accuracy. However, there were two months which marked the lowest precision of accuracy. They are the month of July and October with approximately 55% and 65% respectively. The obvious low accuracy of the forecast weather is due to scarcity of a rule that could be developed including the existence of several missing events that could contribute to low accuracy.

CONCLUSION

This paper has discussed in detail regarding the method of a fuzzy rule-based system in developing the rules for forecasting weather events. The implementation of FRBS have been positively accomplished by utilizing the software which is MATLAB R2018a. In particular, this paper is executed for several reasons in order to track and determine the weather event in Kota Kinabalu, Sabah. It is quite a beneficial and effective method to achieve the objective of this experiment. Another success is when 178 fuzzy rules were developed based on the actual weather data by using two days scenario to forecast the third day weather event.

This study has accomplished the contribution as the fuzzy rule-based system is being implemented successfully in Matlab to perform weather event forecasting. Precision, reliability and consistency have been improved in order to determine and analyze meteorological forecasts. This also suggests that on the weather forecasting data a fuzzy inference method can be implemented as well. It is indeed evident from the result that the fuzzy method of inference is an effective climate modeling technique. A weather forecasting system can be developed by FRBS and the use of FIS can allow the user to produce a better outcome than the preceding one.

Although some techniques and concepts in forecasting weather events are a contribution to the paper, there are some modifications that should be introduced to boost potential efficiency in the future. These suggestions are to enhance the method that has been implemented in this work. The few aspects which need to be enhanced are the usage of data and parameters, the development of new effective techniques and many more.

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