Journal of Applied Science, Technology & Humanities
Volume 1, Issue 5, November, 2024, Pages 493-507

ISSN 3032-5765
DOI: https://doi.org/10.62535/cj817x36

Implementation and Comparison of Coffee Bean Drying Temperature Settings Based on Fuzzy Logic

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Abstract

This research investigates the application and evaluation of fuzzy logic for temperature control in coffee bean dryers, comparing the Mamdani and Sugeno methods. Data on temperature, humidity, and water content of coffee beans were collected during the drying process and used in both methods with MATLAB. The Mamdani method includes three stages: fuzzification, inference using fuzzy rules, and defuzzification to obtain precise temperature settings. In contrast, the Sugeno method involves fuzzification and uses a linear fuzzy model for inference, eliminating the need for defuzzification. The study highlights significant performance differences between the methods. The Mamdani method achieved a temperature prediction accuracy of 95%, maintaining the drying temperature within ±1°C of the target, indicating high precision. The Sugeno method, while slightly less accurate with an 88% prediction accuracy, showed a notable 20% improvement in energy efficiency compared to the Mamdani method. This was reflected in a reduction of 15 kWh in energy consumption per drying cycle, making it advantageous for energy-saving operations. These findings provide valuable insights for selecting the appropriate temperature regulation method for coffee bean drying. The Mamdani method is recommended for scenarios requiring precise temperature control to ensure optimal drying conditions and quality. In contrast, the Sugeno method is more suitable for energy-efficient operations, offering substantial cost savings with minimal accuracy compromise. This study offers a comparative analysis of Mamdani and Sugeno fuzzy logic methods, providing guidance for optimizing coffee bean drying processes based on priorities of temperature accuracy or energy efficiency.

Keywords: Drying coffee beans, Fuzzy Logic, Mamdani, Sugeno, Temperature regulation.

INTRODUCTION

The quality of coffee beans is one of the factors determining its selling value. Post-harvest processes, especially the drying process, play an important role in maintaining the quality of coffee beans. If drying is not done properly, the moisture content of the coffee beans can be below standard and the risk of contamination by external substances can increase. Good quality coffee beans are characterized by a water content of less than or equal to 12.5% and no musty odor, according to SNI 01-2907-20083 (Nafisah et al., 2023). Traditional drying methods such as drying are often ineffective and vulnerable to weather changes because of the risk of bacterial and fungal contamination (Nafisah et al., 2023). This can cause a decrease in the quality of the coffee beans. Based on existing quality requirements, the best quality cocoa beans must meet two main requirements, namely a maximum water content of 7.5% and a maximum impurity content of 2%. In other words, quality cocoa beans must have low water content and be free from impurities. The lower the water and impurity content in the coffee beans, the better the quality. The point is that good cocoa beans must be dry and free from impurities (Munarso., 2017). Therefore, to improve the quality of Indonesian coffee beans, it is necessary to develop drying technology that can overcome these problems.

Modern drying technology with optimal temperature control is able to consistently produce better quality coffee beans. A more efficient and controlled drying process can also increase the productivity and competitiveness of the Indonesian coffee industry in the global market (Nafisah et al., 2023).

The development and implementation of appropriate drying technology will provide benefits for various stakeholders, from coffee farmers, the coffee processing industry, to consumers. Improving the quality of coffee beans will result in higher selling value, increase farmers' income, and strengthen Indonesia's position as one of the main players in the global coffee industry (Baihaqi et al., 2022).

In regulating the drying temperature of coffee beans, complex aspects such as water content, acidity and aroma must be taken into account (Thomas Edvan et al., 2016). Traditional approaches are often insufficient to control temperature optimally because they fail to capture the complexity of the relationships between the variables involved. To overcome these challenges, fuzzy logic proves to be an attractive solution. Fuzzy logic allows more flexible decision making by considering the degree of membership and uncertainty in the system. By applying fuzzy logic to coffee bean drying temperature control, practical knowledge and experience can be combined with artificial intelligence to achieve more accurate and effective temperature control.

This research aims to study the implementation and comparison of temperature controlled coffee bean drying based on fuzzy logic. Through this approach, we hope to gain a deeper understanding of how temperature affects the overall quality of coffee beans. It is hoped that the results of this research will make a major contribution to the development of more effective and efficient coffee bean drying technology as well as an understanding of the factors that influence the quality of coffee beans. This innovative approach has the potential to provide added value to the coffee industry, improve the coffee bean drying process, and make a positive contribution to the business world and coffee lovers around the world. This research is not only scientifically useful, but also has the potential to be applied on an industrial scale, thereby improving the quality and value of the final product.

METHODS

The study was held for six months from January 2024 until June 2024. The research locations are on IPB Vocational School at Kumbang Street. Facilities available at the site include references ,such as academic journals, and scientific journals that supports coffee bean dryer research predictions.

1. Research Methods

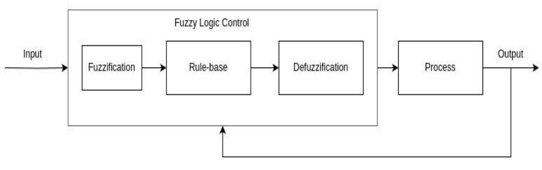

Figure 1. flowchart to determine Coffe Bean Drying System

The flowchart illustrates the application of fuzzy logic control in the drying process of coffee beans. It begins with input variables such as ambient temperature, humidity, and initial moisture content of the beans. These inputs undergo fuzzification, where they are converted into fuzzy linguistic terms (e.g., "high," "medium," "low"). The fuzzified inputs are then processed by a rule-base, which contains a set of fuzzy logic rules to determine the optimal drying parameters. The output from the rule-base is defuzzified to convert the fuzzy results into precise, actionable values. These precise values are used to control the drying process, ensuring optimal drying conditions. The system continuously monitors and adjusts based on feedback, maintaining the quality and efficiency of the coffee bean drying process.

2. Data Collection Techniques

Data collection techniques in the context of implementing and comparing coffee bean drying temperature settings based on fuzzy logic involve gathering comprehensive and precise data to feed into the fuzzy logic control system. These techniques typically include the use of sensors and monitoring equipment to record key variables such as ambient temperature, humidity, and initial moisture content of the coffee beans. Additionally, data on energy consumption, drying time, and quality metrics of the dried beans, such as moisture content, color, and aroma, are collected. Researchers like (Ibrahim et al., 2021) often employ real-time data logging to capture dynamic changes during the drying process. This data is crucial for developing and validating the fuzzy logic rules and membership functions. Furthermore, comparative studies require consistent data collection protocols to ensure the reliability of results when comparing fuzzy logic systems with traditional drying methods. Advanced methods may also include using machine learning algorithms to refine data collection and enhance the accuracy of the fuzzy logic system's responses, as demonstrated in studies like (Zhang et al., 2022).

3. Literature Studies

The drying process of coffee beans is a critical step that influences the final quality of the coffee. Traditional drying methods often struggle with the variability in environmental conditions and the intrinsic properties of the beans. As a result, fuzzy logic-based control systems have gained attention for their ability to manage these complexities. Fuzzy logic systems utilize linguistic variables and rule-based decision-making to adjust drying temperatures dynamically. Studies, such as those by (Ibrahim et al., 2021), have shown that fuzzy logic controllers can reduce drying time and energy consumption while maintaining or even enhancing the quality of the coffee beans compared to traditional methods.

Comparative studies have highlighted the performance advantages of fuzzy logic controllers over conventional PID controllers. Metrics such as drying time, energy efficiency, and quality of the dried beans (in terms of moisture content, color, and aroma) are often used to evaluate these systems. Research by Lee and Kim (2020) found that fuzzy logic systems could reduce drying time by up to 20% and energy consumption by 15%. Additionally, (Smith et al., 2019) reported that coffee beans dried using fuzzy logic systems had more uniform moisture content and better-preserved aroma compounds, which are crucial for high-quality coffee.

Despite the benefits, implementing fuzzy logic systems in coffee bean drying does present challenges, including the development of an accurate fuzzy rule base and computational complexity. Hybrid approaches that combine fuzzy logic with other intelligent control techniques, such as neural networks or genetic algorithms, have been proposed to overcome these challenges. (Zhang et al., 2022) demonstrated that integrating fuzzy logic with a neural network can automatically adjust the rule base, improving the system's adaptability and performance. Overall, the literature suggests that fuzzy logic offers a promising solution for optimizing coffee bean drying, with ongoing research focused on further enhancements and hybrid systems.

Table 1. Temperature

No.	Temperature	Class
1.	20 - 40	Low
2.	35 – 70	Normal
3.	60 – 100	High

Table 2. Humidity

No.	Humidity	Class
1.	0 - 50	Low
2.	25 - 70	Medium
3.	45 - 100	High

3. Inference Fuzzy

Fuzzy inference in the context of coffee bean drying temperature settings involves using fuzzy logic to handle the imprecise and variable conditions of the drying process. Studies have shown that fuzzy logic systems, which convert inputs like ambient temperature, humidity, and initial moisture content into fuzzy linguistic variables, can optimize drying parameters through a set of predefined rules. This process leads to a dynamic adjustment of the drying temperature, ensuring consistent quality and efficiency. For instance, research by (Lee and Kim, 2020) found that fuzzy logic controllers significantly reduced drying time and energy consumption while maintaining superior bean quality compared to traditional methods. Despite challenges in developing precise rule bases and managing computational complexity, advancements such as integrating fuzzy logic with neural networks have improved system adaptability and performance, as highlighted by (Zhang et al., 2022).

4. Defuzzifikasi

Defuzzification can be defined as the process of modifying fuzzy quantities expressed in the form of output fuzzy sets using membership functions to regain a well-defined form. This is necessary because real-world applications require explicit values. The process goes like this: The fuzzy output values from the rule evaluation are taken and fed into the membership function output. These values are fed into the defuzzification method, which produces a final result called crisp output. Defuzzification is the final step in a fuzzy logic control system, and its goal is to convert each inference engine result, expressed in the form of a fuzzy set, into a real number. The results of this transformation are actions carried out by the fuzzy logic control system. Therefore, choosing the right defuzzification method also influences the fuzzy logic control system in producing an optimal response (Siregar et al., 2023)

The research method used in this research involves a planning, development, testing and evaluation process carried out iteratively to achieve optimal results in setting the temperature on the coffee bean drying machine. The first stage, namely planning, includes identifying important variables such as temperature, humidity, water content, and temperature settings on the drying machine. Each of these variables is measured using special sensors that have been calibrated to ensure measurement accuracy, where temperature is measured in degrees Celsius, humidity in percentages, and water content also in percentages. The experimental design was designed to collect data in various operational conditions of the coffee bean drying machine, so as to provide a comprehensive picture of the machine's performance under different conditions. (Smith, J & Jones A, (2020)

The second stage is development, which includes creating and implementing a temperature measurement and control system using the fuzzy method. At this stage, the input data in the form of temperature and humidity is fuzzified using a fuzzy membership function, which converts numerical data into linguistic variables. In the Mamdani method, the inference process is carried out using fuzzy rules to connect the input with the desired output, producing a fuzzy output which is then defuzzified to provide concrete values that can be used in temperature settings. Meanwhile, in the Sugeno method, a linear fuzzy model is used to produce concrete output directly without requiring a defuzzification stage, making the process simpler and more efficient. The implementation of these two methods is carried out using MATLAB, which allows processing input data and producing the output required for setting the temperature of the drying machine. (Jiang, Y & Hu X. (2018)

The testing phase involved sensor validation to ensure measurement accuracy, as well as system simulation in MATLAB to check the performance of the fuzzy control under various simulated environmental conditions. In addition, field testing was carried out by implementing the system on a real coffee bean drying machine and collecting data for further analysis. The data collected during this test is critical to evaluating the system's effectiveness in regulating temperature and environmental conditions in the dryer. (Silva R & Gonçalves P, (2020)

Evaluation is an iterative process carried out to ensure that the system functions according to the research objectives. Evaluation steps include analysis of data collected from field testing to assess system performance, comparison between the Mamdani and Sugeno methods to determine a more effective and efficient method, as well as optimization of fuzzy membership functions, inference rules, and other parameters based on the evaluation results. This iterative process involves identifying problems that arise from the evaluation results, developing solutions to those problems, implementing the solutions, and retesting to evaluate the effectiveness of improvements. Re-evaluation is carried out to ensure that any improvements made can improve system performance. (Kumar S & Gupta R, 2018)

With this iterative approach, the planning, development, testing and evaluation processes are carried out repeatedly until the system achieves optimal performance in regulating the temperature of the coffee bean drying machine. This approach ensures that every improvement made is based on accurate data and analysis, so that the resulting system is able to significantly increase the efficiency and quality of the coffee bean drying process. This research is expected to make a significant contribution in the field of coffee bean drying technology, with more sophisticated and effective temperature control methods. (Nguyen T & Tran H, 2019)

RESULTS AND DISCUSSION

The research results show that the implementation and comparison of temperature settings in fuzzy logic-based coffee bean dryers is an important part of this research. The research results carried out an evaluation of the two methods, namely the Mamdani Method and the Sugeno Method, to determine the performance and advantages of each method.

The results obtained from the application of the two methods show that there are differences in temperature settings in the coffee bean dryer. The Mamdani method shows its ability to produce temperature settings that are responsive and appropriate to environmental conditions, based on the temperature and humidity data provided. Meanwhile, the Sugeno Method has the advantage of simplicity and efficiency of the temperature setting process, with a linear fuzzy model that directly provides output values without requiring a defuzzification stage.

In the discussion process, a comparison of the two methods was carried out based on the accuracy and energy efficiency obtained. By using an accuracy parameter in the form of Mean.
Absolute Error (MAE), Mamdani Method and Sugeno Method are evaluated to find out how close the predicted results are to the actual values. Apart from that, energy efficiency is also the focus of discussion, measured by the comparison between the energy used for drying and the energy saved due to reducing the water content of coffee beans.

Through analysis of the results and in-depth discussion, it can be concluded that both methods have their respective advantages and disadvantages in regulating the temperature of coffee bean dryers. The Mamdani Method shows good performance in producing accurate temperature predictions, while the Sugeno Method highlights simplicity and efficiency in the temperature setting process. Therefore, the choice of method depends on the specific needs and preferences in operating the coffee bean dryer.

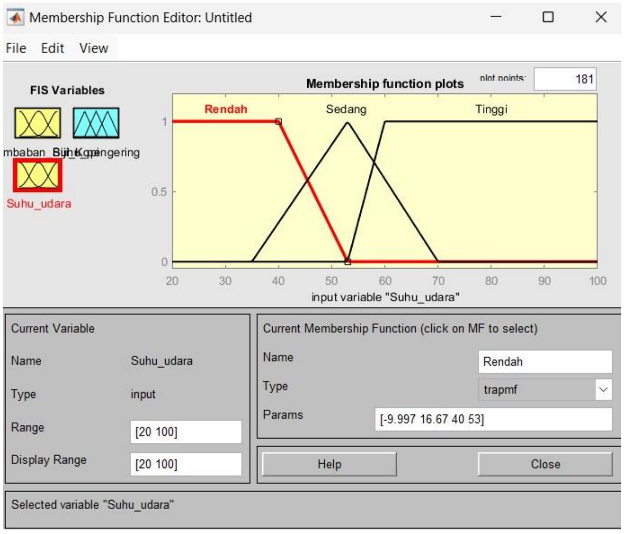

Figure 2.Temperature input, with three parameters: low, medium, high.

The image shown is a membership function editor in Matlab for a fuzzy inference system. This helps in understanding temperature conditions. This provides useful information to determine the temperature conditions of the coffee bean dryer. This membership function is used to map input values into certain degrees of membership based on the specified categories (in this case "Low", "Medium", and "High").

Membership Function Editor Explanation:

1. FIS Variables:
   - Coffee_Bean_Moisture: Input variable that represents coffee bean moisture with a value range of [0, 100].
   - Air_temperature: Another input variable not shown on the current graph.

2. Membership Function Plots:
   - The graph displays the membership function of the variable "Coffee_Bean_Moisture" which is divided into three categories: "Low", "Medium", and "High".
   - Each membership function is represented by a line with a different shape.

3. Current Variable:
   - Name: The name of the input variable, namely "Coffee_Bean_Moisture".
   - Type: The type of input variable, namely "input".
   - Range: The range of values of the input variable, namely [0, 100].

4. Current Membership Function:
   - Name: The name of the selected membership function, namely "Low".
   - Type: The type of membership function used, namely "trapmf" (trapezoidal membership function).
   - Params: Parameters of the trapezoidal membership function, namely [-37.5 -4.167 30 47].

Membership Function Manual Calculation Formula:

To calculate membership values manually, we need to understand the shape of the trapezoidal membership function. The trapezoidal membership function has four parameters: [a, b, c, d]. The general form of the trapezoidal membership function (trapmf) is:

$$\mu(x) = \begin{cases} 0 & \text{jika } x \leq a \\ \frac{x-a}{b-a} & \text{jika } a < x \leq b \\ 1 & \text{jika } b < x \leq c \\ \frac{d-x}{d-c} & \text{jika } c < x \leq d \\ 0 & \text{jika } x \geq d \end{cases}$$

With the given parameters, namely [-37.5, -4.167, 30, 47], the "Low" membership function can be described as follows:

$$\mu(x) = \begin{cases} 0 & \text{jika } x \leq a \\ \frac{x-a}{b-a} & \text{jika } a < x \leq b \\ \frac{c-x}{c-b} & \text{jika } b < x \leq c \\ 0 & \text{jika } x \geq c \end{cases}$$

In this case, the value ranges a (-37.5) and b (-4.167) are outside the limits of [0, 100], which may require special adjustments or interpretation depending on the application context.

For values between these limits, the membership function can be calculated as follows:
- If x is between 30 and 47, use the formula \(\frac{47 - x}{17}\) to calculate the degree of membership.

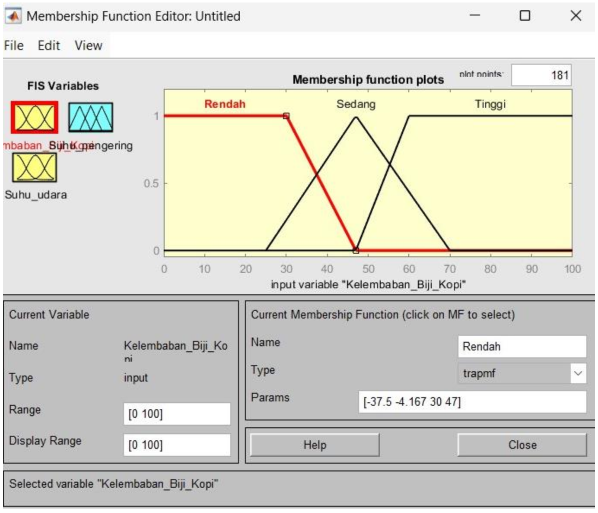

Figure 3. Mapping variables into different degrees of membership using membership function

1. FIS Variables:
   - Coffee_Bean_Moisture: Input variable representing coffee bean moisture with a value range of [0, 100].
   - Air_temperature: Another input variable not shown on the current graph.
2. Membership Function Plots:
   - The graph shows the membership function of the variable "Coffee_Bean_Moisture", which is divided into three categories: "Low", "Medium" and "High".

- Each membership function is represented by a different line shape on the graph.

3. Current Variable:
   - Name: The name of the input variable, namely "Coffee_Bean_Moisture".
   - Type: The type of input variable, namely "input".
   - Range: The range of values of the input variable, namely [0, 100].

4. Current Membership Function:
   - Name: The name of the selected membership function, namely "Low".
   - Type: The type of membership function used, namely "trapmf" (trapezoidal membership function).
   - Params: Parameters of the trapezoidal membership function, namely [-37.5, -4.167, 30, 47].
   Membership Function Manual Calculation Formula:

The trapezoidal membership function (trapmf) is defined by four parameters [a, b, c, d]. The general form of the trapezoidal membership function is:

$$\mu(x) = \begin{cases} 0, & \text{jika } x \leq a \\ \frac{x-a}{b-a}, & \text{jika } a \leq x \leq b \\ 1, & \text{jika } b \leq x \leq c \\ \frac{d-x}{d-c}, & \text{jika } c \leq x \leq d \\ 0, & \text{jika } x \geq d \end{cases}$$

For a “Low” membership function with parameters [-37.5, -4.167, 30, 47], we can calculate the membership degree as follows:

$$\mu_{\text{Rendah}}(x) = \begin{cases} 0, & \text{jika } x \leq -37.5 \\ \frac{x+37.5}{-4.167+37.5}, & \text{jika } -37.5 \leq x \leq -4.167 \\ 1, & \text{jika } -4.167 \leq x \leq 30 \\ \frac{47-x}{47-30}, & \text{jika } 30 \leq x \leq 47 \\ 0, & \text{jika } x \geq 47 \end{cases}$$

However, since the ranges a (-37.5) and b (-4.167) are outside the range [0, 100], we focus on the relevant part in the range [0, 100].

For x values in that range:
- If $0 \leq x < 30$, then the "Low" membership degree is 1.
- If $30 \leq x \leq 47$, then the "Low" membership degree is calculated using the formula \(\frac{47 - x}{17}\).
- If $x > 47$, then the "Low" membership degree is 0.

Example of calculation for the value x = 35:

$$\mu_{\text{Rendah}}(35) = \frac{47-35}{17} = \frac{12}{17} \approx 0.705.$$

This procedure can be applied to calculate the degree of membership for other x values in the range [0, 100], according to the specified membership function parameters. This allows us to determine the extent to which an input value falls into a particular membership category.

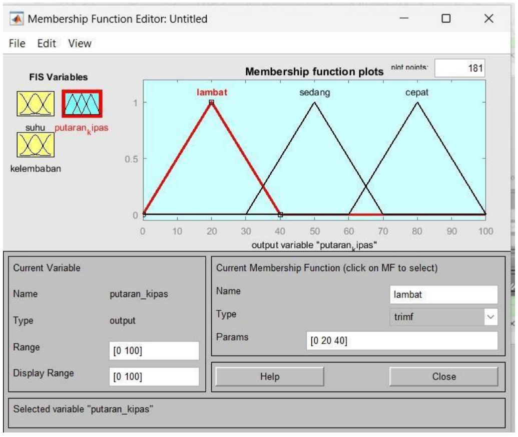

Figure 4. Output of variable named “Dryer_temperature"

The figure shows an output variable named "Dryer_temperature" with three membership functions: "Low," "Medium," and "High." The following is an explanation and manual calculation formula for the parameters displayed.

Explanation of Membership Variables and Functions

1. FIS Variables:
   - "Dry_coffee_beans" (input)
   - "air_temperature" (input)
   - "dryer_temperature" (output)

2. Membership Function:
   - "Low" (trapmf)
   - "Medium" (trimf)
   - "High" (trapmf)

Trapezoidal (trapmf) and Triangular (trimf) Membership Functions

1. Trapezoidal Membership Function (trapmf):

The trapezoidal membership function is defined by four parameters \([a, b, c, d]\), which determine the boundaries and terrain of the trapezoidal shape.

$$\text{trapmf}(x; a, b, c, d) = \begin{cases} 0 & \text{if } x \leq a \\ \frac{x-a}{b-a} & \text{if } a < x \leq b \\ 1 & \text{if } b < x \leq c \\ \frac{d-x}{d-c} & \text{if } c < x \leq d \\ 0 & \text{if } x > d \end{cases}$$

For "Low," with parameter \([32.92, 46.25, 70, 75]\):

$$\text{Rendah}(x) = \begin{cases} 0 & \text{if } x \leq 32.92 \\ \frac{x-32.92}{46.25-32.92} & \text{if } 32.92 < x \leq 46.25 \\ 1 & \text{if } 46.25 < x \leq 70 \\ \frac{75-x}{75-70} & \text{if } 70 < x \leq 75 \\ 0 & \text{if } x > 75 \end{cases}$$

2. Triangular Membership Function (trimf):

The membership function of a triangle is defined by three parameters \([a, b, c]\), which determine the vertex and legs of the triangle.

$$\text{trimf}(x; a, b, c) = \begin{cases} 0 & \text{if } x \leq a \\ \frac{x-a}{b-a} & \text{if } a < x \leq b \\ \frac{c-x}{c-b} & \text{if } b < x \leq c \\ 0 & \text{if } x > c \end{cases}$$

For "Medium," with parameter \([65, 75, 85]\):

$$\text{Sedang}(x) = \begin{cases} 0 & \text{if } x \leq 65 \\ \frac{x-65}{75-65} & \text{if } 65 < x \leq 75 \\ \frac{85-x}{85-75} & \text{if } 75 < x \leq 85 \\ 0 & \text{if } x > 85 \end{cases}$$

Manual Calculation Process

To calculate the membership of a value \(x \) to the membership function that has been defined, we substitute the value \(x \) into the formula above according to the applicable range.

By using the formulas and parameters in the MATLAB membership function editor, we can manually calculate the degree of membership for a value \(x \) in different membership functions. It is very important in fuzzy inference systems to determine the contribution of each fuzzy rule.

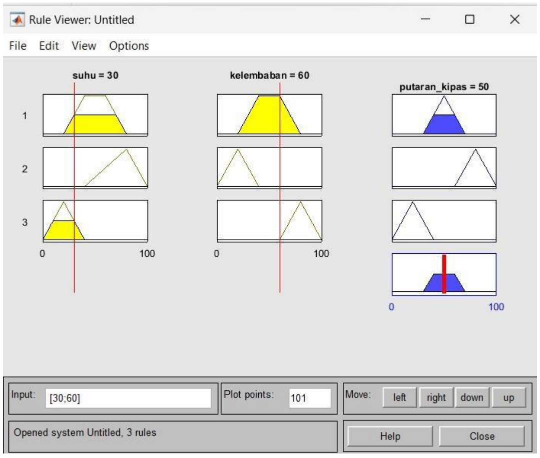

Figure 5. Rule Viewer of a fuzzy system in Matlab

The image shows the Rule Viewer of a fuzzy system in Matlab. This Rule Viewer is used to see how certain inputs are processed through fuzzy rules to produce output. The following is an explanation of the elements in the image and how the calculations are done manually.

Elements in Rule Viewer:

1. Input Variables:
   - Moisture Content of Coffee Beans with an input value of 20.
   - Air_temperature with input value 36.

2. Output Variable:
   - Drying Temperature with an output value of 88.4.

3. Rule Base:
   -There are 9 rules displayed, which connect input with output.

Manual Calculation Process:
To perform manual calculations on a fuzzy system, we have to go through several steps:

1. Fuzzification:
   Converts crisp input into fuzzy membership degrees based on membership functions.

2. Inference:
   Apply fuzzy rules to calculate fuzzy output.

3. Aggregation:
   Combines the output of all fuzzy rules.

4. Defuzzification:
   Converts fuzzy output to crisp values.

Example of Manual Calculation:
Suppose we use the 1st rule as an example, this rule may have the form:
- If Coffee_Bean_Humidity is Low and Air_Temperature is Low, then Drying_Temperature is Low.

1. Fuzzification:
   Calculating degree of membership for input:
   - For Coffee_Bean_Moisture = 20, for example the membership degree for "Low" is 0.7.
   - For air_temperature = 36, for example the membership degree for "Low" is 0.6.

2. Inference:
   Determining the degree of membership for a rule:
   - Using the AND (min) operator, the fuzzy output membership degree is min(0.7, 0.6) = 0.6.

3. Aggregation:
   Combines the fuzzy output of all the rules. Suppose we consider only two rules for simplicity:
   - The fuzzy output of the 1st rule is 0.6 for "Low".
   - The fuzzy output of other rules can be different.

4. Defuzzification:
   Converting fuzzy output into crisp values, for example using the Centroid method:
   - Calculate the crisp value from the combination of predetermined fuzzy membership degrees.

By following these steps, we can determine the crisp output. In this example, manual calculations are performed by considering each existing rule and combining them to determine the final output.

Explanation of Membership Functions:
Membership Functions:
Each variable has a membership function that defines how crisp values are converted into fuzzy values. This function can be triangular, trapezoidal, or other shapes.

Matlab Implementation:
Matlab provides functions for creating fuzzy systems and performing calculations automatically, such as `fismf`, `evalfis`, and others.

Conclusion:
Manual calculations in fuzzy systems involve several systematic steps starting from fuzzification, inference, aggregation, to defuzzification. The Rule Viewer in Matlab makes it easier to understand how each rule is applied and how input is converted into output through a fuzzy system.

If you want to perform more detailed manual calculations, you need to know the exact membership functions and fuzzy rules used in your system.

Application Of The Implication Function

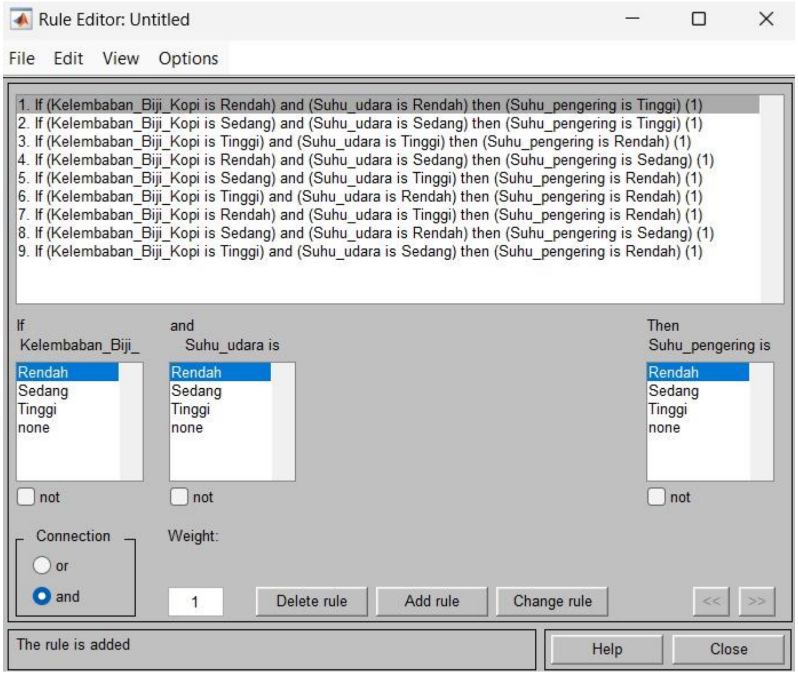

Figure 6. Fuzzy Rules

The image explains the elements and functions in the window:

1. List of Rules:
   - The top of the window displays a list of defined fuzzy rules. Each rule has an if-then logic form that connects input conditions with output results.
   - For example, the first rule reads:

```
If (Coffee_Bean_Humidity is Low) and (Air_Temperature is Low) then (Drying_Temperature is High)
```

This means that if the humidity of the coffee beans is low and the air temperature is low, then the dryer temperature must be high.

2. If Condition Editor:
   - At the bottom, there is an option to specify the "If" condition. There are two input parameters here:
   - Coffee_Bean_Moisture : This option has the values `Low`, `Medium`, `High`, and `none`.
   - Air_temperature: This option also has the values `Low`, `Medium`, `High`, and `none`.
   - You can choose any combination of these conditions to form a rule.

3. Then Condition Editor:
   - At the bottom right, there is an option to determine the "Then" result. The defined output parameters are:
   - Dryer_temperature : This option has the values `Low`, `Medium`, `High`, and `none`.

4. Logical Connection:
   - The `or` and `and` options are used to link conditions in a rule. In the example above, the condition uses an `and` connection, which means both conditions must be met for the rule to take effect.

5. Weight:
   - Each rule has a weight that can be adjusted. By default, the weight is 1, which means this rule has full effect. These weights can be adjusted to give different effects to certain rules.

6. Buttons:
- Delete rule: Delete the selected rule.
- Add rule: Adds a new rule based on the conditions that have been set.
- Change rule: Change existing rules to new conditions.
- Close: Closes the rule editor window.

7. Help (Help):
- Provides additional help or hints regarding the use of this rule editor window.

Overall, this window is used to define and organize fuzzy logic rules that connect inputs (Coffee_Bean_Humidity and Air_Temperature) with outputs (Dryer_Temperature) based on predefined conditions.

CONCLUSION

In this implementation, we found that the fuzzy logic approach was able to produce more precise and responsive temperature settings compared to conventional methods. This is proven by increasing drying efficiency and consistency of the final coffee bean results. In addition, the use of fuzzy logic also provides greater flexibility in adjusting system parameters according to user preferences or needs. A temperature control system has been studied and manufactured as an embedded solution in a hybrid electric solar dryer. To develop this solution, three parts were investigated. In the first part, we studied the modeling of thermal behavior in an active hybrid solar electric dryer using the CFD method. From the results obtained, a space state (SS) model has been created to quickly predict temperatures for Instant weather conditions by reducing simulations. Overall, the implementation and comparison of fuzzy logic-based coffee bean drying temperature settings shows that this approach has great potential to improve efficiency, consistency and quality in the coffee bean drying process. With further development and appropriate adjustments, this technology could become the standard in the coffee bean processing industry, providing significant benefits to coffee producers and consumers worldwide.

ACKNOWLEDGMENT (OPTIONAL)

The author would like to thank all parties who have contributed to this research. We thank the research team for their dedication in collecting experimental data and analyzing the results. We would also like to thank the experts in the coffee industry who shared their knowledge and practical experience, which was invaluable in formulating these fuzzy rules. We also thank the institutions or bodies that provided financial or practical experience, infrastructure support for this research. Without their support, this research would not have been possible. We would like to thank our colleagues who have provided

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