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Design and Development of Coffee Machine Control System Using Fuzzy Logic

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Abstract: The food and beverage industry is currently rife in urban and outside cities. Many locations are used as places to sell drinks, especially coffee which is a native plant of Indonesia. Nowadays, coffee compounding requires good technology. There are many coffee processing machines on the market. The coffee machine is capable of making expresso coffee, latte coffee and others. This coffee machine also combines coffee ingredients, sugar and milk as a carrier for a delicious aroma. In addition, the water pressure from the coffee machine heating boiler, the strong pressure of the coffee machine piston also affects the results of making a cup of coffee, the stronger the pressure, the thicker the coffee produced and the slower the flow of water in the coffee machine. glass of water because basically the stronger the pressure applied to it. the coffee grounds, the tighter and tighter the gaps that the water itself will pass, as well as the thickness of the resulting coffee water will be more concentrated. With Fuzzy Inference, it is possible to determine the optimal pressure to be exerted by the coffee machine piston based on the weight of the coffee grounds (grams) on the coffee machine piston and the specifications of the type of coffee machine used. Determining the optimal pressure on the coffee grounds will affect the taste of the coffee water produced and the speed of making a cup of coffee. This study uses the optimal pressure on the piston using the fuzzy inference method. The purpose of this research is to create a simulation for evaluating the performance of a coffee machine using fuzzy logic to solve the problem of damage to the piston. The fuzzy approach in this research uses the fuzzy Takagi Sugeno Kang method.

Keywords: Coffee Machine; Fuzzy Logic; Inference Method; Fuzzy Inference; Fuzzy Takagi Sugeno Kang Method;

INTRODUCTION

Culinary is a business that is in great demand. It's only natural because everyone needs food and drink. One of them is by opening a coffee shop that has sprung up a lot in line with the current lifestyle trends that are being loved by millennials. One of the main roles in opening a coffee shop is the coffee machine which is very influential in creating the taste of the coffee itself apart from the type of coffee chosen. There are some of the most important things in a coffee machine to create flavor in a cup of coffee, including temperature, coffee machine water pressure, the amount of coffee grounds, the fineness of the coffee grounds and the coffee machine piston pressure. The increasing level of coffee consumption is also inseparable from the lifestyle of urban people who like to gather. From these two factors, it can be said that the prospect of a coffee shop business in the future is still very promising. However, is this really going to last for a long time or is it just a trend that will last a few years? For this reason, the taste of coffee itself has a role in the trend that still persists to this day.

Compounding and serving a cup of coffee requires special treatment, so that until now coffee blends, commonly called Baristas, are competing to carry out experiments to produce a taste of coffee water that can be enjoyed in various variations, ranging from mixing it with a mixture of other ingredients or in terms of how it is served. In this era of increasingly advanced technological developments, there are many solutions that can solve human problems. Problems that arise due to limited human skills or other factors, are now gradually making coffee machines that previously used manual machines have switched to automatic coffee machines with computer-based control systems. By using a computer-based control system, it is hoped that it can help Baristas to present a coffee taste that is always standard both in terms of size and taste.

The settings on computer-based automatic coffee machines are now more sophisticated, unlike manual coffee machines that use human hands to apply pressure to the coffee grounds when making a cup of coffee.

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With automatic coffee machines, it is now possible to adjust how much pressure the machine can put on the coffee grounds to be processed. With the automatic coffee machine, it does not require special skills on the Barista to make a cup of coffee. One way to get optimal pressure is to make a device that can control the piston pressure based on the amount of coffee grounds used to make a cup of coffee. But before the process of making a tool, it is necessary to do a computer-based simulation in order to minimize the difference in taste for each cup of coffee making and as a reference for making tools. Meanwhile, one method of optimizing the coffee machine piston pressure is using the Fuzzy Inference method. By using this Fuzzy Inference method, it can be determined the optimal pressure that will be carried out by the piston based on the weight of the coffee grounds.

The fuzzy method is part of Artificial Intelligence. Artificial intelligence, one of which also discusses machine learning and deep learning. Deep learning, one of which also discusses image processing as object detection. In its application Deep Learning for hotel reviews by using image as input (Sze, Santoso, et al., 2022). In addition, Deep Learning is used to detect malware in smartphones (Hindarto & Santoso, 2022). Detecting vehicle plates using Deep Learning Agorithms (Hindarto & Santoso, 2019).

This fuzzy logic method has several advantages, one of which is its easy use and in the process of producing decisions that are more in line with the human condition. Fuzzy Logic can model intuition or feelings by converting CRISP (Shakouri G. & Nadimi, 2013) values into linguistic values with fuzzification and then entering them into rules that are made based on knowledge. The next advantage is that Fuzzy logic (Hasan et al., 2022) is suitable for use in most problems that exist in the real world. Problems in the real world are usually or mostly non-binary and non-linear, so fuzzy logic is suitable for use because it uses non-linear linguistic values. Fuzzy logic can also express concepts that are very difficult to formulate, such as optimal piston pressure (Masoumi et al., 2020). The use of membership functions allows fuzzy logic to be used to make objective observations of subjective values. Furthermore, these membership functions can also be combined to make a clearer concept disclosure. Based on the explanation above, in this research, a simulation of the piston pressure control system (Coffee Machine) (Barella et al., 2013) will be made to determine the optimal pressure based on fuzzy logic. The problem that occurs is that many coffee machines are broken and many of the owners do not know. The state-of-the-art in this research detects the damage caused by the thick coffee liquid. With the thicker the piston movement becomes slower due to the viscosity of the coffee liquid pressure and causes damage if preventive maintenance is not carried out. The purpose of this research is to monitor the piston function using fuzzy logic using the Takagi Sugeno Kang (Yazid et al., 2019) (TSK) method.

LITERATURE REVIEW

Previous research that has discussed the fuzzy methodology has been widely carried out, along with the research that underlies the use of fuzzy. There are several existing fuzzy methods, such as the Sugeno fuzzy method, the Mamdani fuzzy and the Tsukamoto fuzzy method. This research does not intend to find the shortcomings of previous research but to contribute ideas by using the fuzzy Takagi Sugeno Kang (TSK) method.

Research entitled Application of Fuzzy Logic Sugeno Method for Optimizing Export Value of Tuna Fish Hs 160414 to Italy (Luthfia Rohimah, Sinta Rukiastiandari, 2022). This research is good at solving problems using fuzzy. The weakness of the fuzzy method with Sugeno is not explained in more detail where the calculation in the formula is not explained, giving rise to different meanings.

Student Performance Simulation Using Sugeno's Fuzzy Inference Method Using Matlab Application (Mukminna et al., 2017). This research makes a simulation of student performance assessment using fuzzy logic to solve student evaluation problems. Because the special system has not been able to optimize support for teachers in conducting evaluations. The method used is the Sugeno method, which in this research shows manual calculations with calculations using Matlab. Weaknesses have not shown research with the aim of evaluating student performance.

Research with the title Comparative Analysis of Fuzzy Mamdani and Fuzzy Sugeno Methods for Determining the Quality of Instant Concrete Casting (Batubara, 2017). Research on concrete uses a comparison of Mamdani and Sugeno as an advantage in this research. However, the research does not explain the formulation of the Matlab software, but only displays images.

Research Comparative Study of Mamdani-type and Sugeno-type Fuzzy Inference Systems for Coupled Water Tanks (Mudia, 2020). This research discusses the problem of water tanks discussing and doing a comparison between the Mamdani method and the Sugeno method. However, when discussing the comparison of the Mamdani method and the Sugeno method, a striking difference in the results between the two methods must be made, so that the difference between Mamdani and Sugeno is clear.

In previous studies that have discussed the fuzzy logic method using Mamdani or Sugeno, there has been a lot of talk about the problems solved by Matlab software. But it does not discuss the meaning or explain how Matlab works. The state-of-the-art of this research is to explain about fuzzy design using Matlab by providing

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technical concepts from the Sugeno fuzzy method. This research is not only looking for the weaknesses of previous research, but also as a complement for future research that discusses the fuzzy method.

METHOD

Fuzzy Set, to understand fuzzy logic, it is necessary to know about fuzzy sets (fuzzy sets) (Setiawan et al., 2018). Because fuzzy is vague, the fuzzy set is a set in which each element has its membership with unclear boundaries. This set is known as the classic set (crisp). Before the emergence of the fuzzy logic method, the first time there was logic, namely crisp logic which had a value of true or false, yes or no, 1 or 0, was a classical set. For example: the classical set A for real numbers greater than 9 can be expressed in the equation:

$$A = \{x \mid x > 9\} \quad (1)$$

The classical set is realized by defining characteristic function for each element of the set the classic. For example, for the classic set A, (x, 0) or (x, 1) indicates x is a member of the set A ($x \in A$) or x is not a member of the set A ($x \notin A$). Unlike the classical set, fuzzy set using degrees to assess membership of an element in a set. If x is a collection of objects with element x membership in them which is called the universe of speech, then the set A in X is defined as the set can be expressed (Kusumadewi, 2006) in Fig 1.

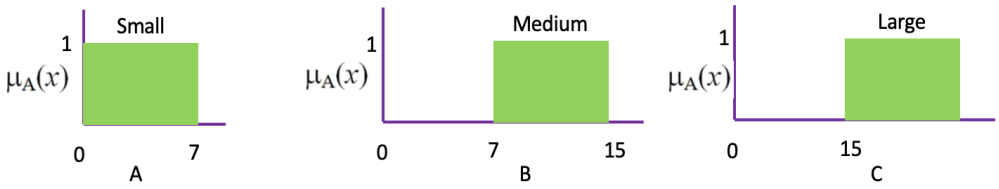

Fig. 1 Classic Set

The fuzzy set is a simple extension of the classical set in which the characteristic function is possible to be between 0 and 1. If the value of the membership function A(x) is limited to 0 and 1, the fuzzy set is simplified into a classical set.

Explanation of Fig 2, it can be described:

- If the size is 7, it can be said to be Small (Small (7) = 1).
- If the size is 8, it can be said to be Not Small (Small (8) = 0).
- If the size is 8, it can be said Medium (Medium (8) = 1).

This condition causes a very significant difference if the value 8 has been included in the Medium classification, so that the firm set becomes less flexible in determining the category in a set.

Characteristics of fuzzy sets using values between 0 to 1, which indicates the value of the degree of membership of a elements in the fuzzy set. If x is a collection of objects with the membership of the element x in it which is referred to as universe of speech, then the fuzzy set A in X is defined as a set that can be expressed by the equation:

$$A = \{(x, \mu A\ (x)) \mid x \in X\} \quad (2)$$

The fuzzy method was introduced by a scientist named Takagi Segeno Kang (TSK). Actually this fuzzy method is similar to the Mamdani fuzzy method. The difference between this TSK method is that the output uses constants or linear equations. Fuzzy Mamdani in its output still uses or is in the form of fuzzy. In general, the Segeno-Order Zero fuzzy form is as follows:

$$\text{IF } (X_1 \text{ is } A_1) \circ (X_2 \text{ is } A_2) \circ \ldots\ldots\ldots\ldots\ldots (X_N \text{ is } A_N) \text{ THEN } z = k \quad (3)$$

Where A is the i-th fuzzy set as an antecedent, ° is a fuzzy operator (AND or OR), and k is a constant or firm as a consequent.

For Segeno Order 1 fuzzy as follows

$$\text{IF } (X_1 \text{ is } A_1) \circ (X_2 \text{ is } A_2) \circ \ldots\ldots\ldots\ldots\ldots (X_N \text{ is } A_N) \text{ THEN } z = ax + by + c \quad (4)$$

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Where A is the i-th fuzzy set as an antecedent ° is a fuzzy operator (AND or OR), and ax + by + c is a linear equation as a consequent.

The input process using fuzzification starts from the input then the fuzzification process is carried out then inference logic is carried out. The inference logic step is to enter the rules and then do the aggregation. The final step is to carry out the defuzzification process.

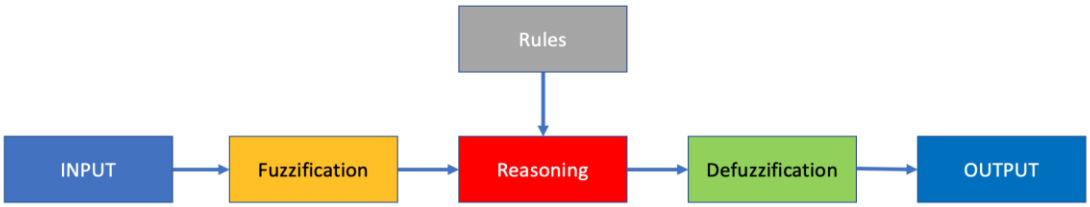

Fig. 2 Block Fuzzy Logic Method
Source: (Setiawan et al., 2018)

In fig 2, explains the steps of the block diagram of the fuzzy logic method. So this method is similar to that used by all fuzzy processes.

- Fuzzification, Fuzzification is a process of converting existing firm values into membership functions.
- Reasoning (Inference Machine) (YAO et al., 2022), The reasoning engine is the implication process in reasoning the input value in order to determine the output value as a form of decision making. One reasoning model that is widely used is maxmin reasoning. In this reasoning, the first process that is carried out is to perform the min operation of the fuzzification layer output signal, which is continued with the max operation to find the output value which will then be defuzzified as an output form.
- Rule Based (Pandey & Parhi, 2014), The basic rule (rule based) on fuzzy logic control is a the form of the "If-Then" or "if-then" relation rules as follows: if x is A then y is B where A and B are the linguistic values that defined in the range of variables X and Y. The statement “x is A” is called the antecedent or premise. The statement "y is B" is called the consequent or conclusion.
- Defuzzification (Wang et al., 2021), The input of the defuzzification process is a fuzzy set obtained from the composition of fuzzy rules, while the resulting output is a number in the domain of the fuzzy set. So if given a fuzzy set within a certain range, it must be able to take a certain crisp value. Much of the commercial success of fuzzy logic in fuzzy logic systems is due to the extrinsic nature of fuzzy logic itself. Success in controlling and modeling applications is largely due to systems with defuzzification (Teodorescu, 2010).

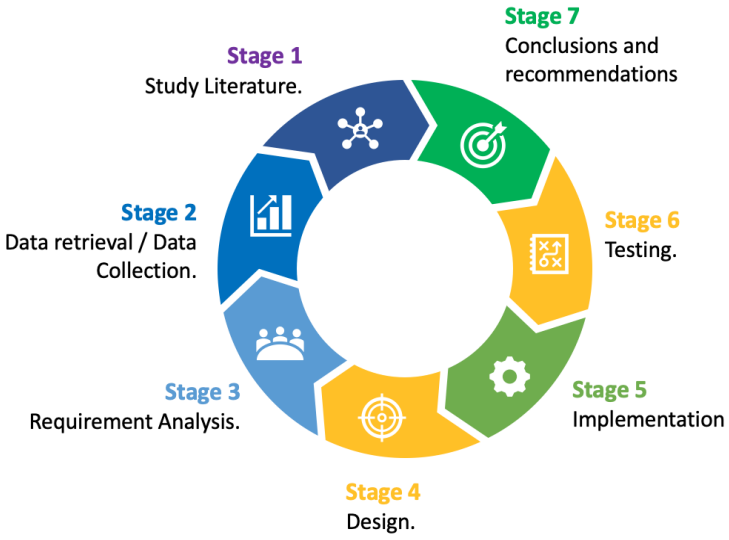

Fig. 3 Proposed method
Source: Researcher Property

This research proposes as in Fig. 3 to examine the performance of the piston in a coffee machine. The process will start with Stage 1, with literature study. The process is to look for references on fuzzy logic and several journals that have discussed coffee machine problems. Stage 2, by collecting data that will be used in fuzzy parameters. Because the data is very important, the completeness of the data is a priority before the fuzzification process is carried out. Stage 3, after getting all the system requirements, then do a needs analysis.

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This is important to do because the needs analysis will make the system designed to produce the expected performance. Stage 4, designing a fuzzy system where the input parameters will be used in the fuzzification process. Stage 5, Implementation using Matlab 2022 software to perform simulations on Membership Function Piston Status, Membership Function (Jeong et al., 2018), (Cazarez-Castro et al., 2010) Coffee Powder, Output Speed Piston. Stage 6. Testing, this stage is a test of membership input, rules and output, whether it is in accordance with what is expected. The purpose of this method is to conduct trials to find out the results, which can then be used as the first step of preventive maintenance on coffee machines. Stage 7 conclusions and recommendations, this stage is the stage to draw conclusions from design, implementation, testing. The results of this test will later be used to justify the rules, membership input and output, so that later if this system is used to control the coffee machine, the correct results will be obtained. This fuzzy method can actually be implemented using a micro-controller such as an arduino or raspberry. Many studies use Arduino as a control sensor such as a proximity sensor that uses an ultrasonic sensor (Sze, Hindarto, et al., 2022).

RESULT

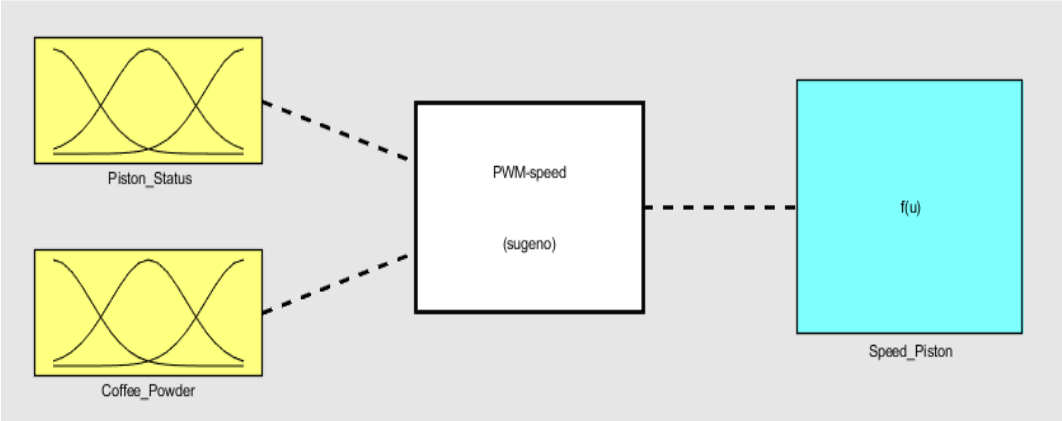

Fig. 4 Fuzzy Sugeno Method in Matlab
Source: Researcher Property

In fig 4, it is a display of the Sugeno method using the 2022 version of the Matlab software (Griffis et al., 2021). Actually, manual solutions can also be done. But in this research using Matlab software to make it easier. In addition to the Sugeno method, there is the Mamdani method and the Tsukamoto method, each of which still has advantages and disadvantages. Matlab is a programming language high-level language that specializes himself for the needs of technical computing, visualization and programming such as mathematical computing, data analysis, algorithm development, simulation and modeling and calculation graphs. Matlab comes with different colors different. This is because matlab brings special features in math, physics, statistics, and visualization functions. Matlab was developed by MathWorks, which originally created to provide easy access to data matrix on the LINPACK and EISPACK projects. Currently Matlab has many functions that can be used as a problem solver ranging from simple problems to complex problems from various disciplines (Setiawan et al., 2018).

There are two input or membership functions, namely Piston Status and Coffee Powder. The output is Speed Piston for speed. The following is the input table for Piston status and Coffee Powder.

Table 1. Piston Status and Coffe Powder

No	Piston_Status	Value	No	Coffee_Powder	Value
1	Clean	12.5 - 20	1	Fine	12.5 - 20
2	Medium	25 - 35	2	Medium	25 - 35
3	Dirty	30 - 50	3	Rude	30 - 50

Table 2. Piston Status and Coffe Powder

No	Speed Piston	Value
1	Slow	100
2	Medium	250
3	Fast	500

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In fig 5, Membership for Piston_status, for Piston_status = Clean, then the trapezoidal formula can be used.

$$\mu \text{ Clean (x)} = \begin{cases} 1, & x \leq 12{,}5 \\ \frac{20-x}{20-12{,}5}, & 12{,}5 < x < 20 \\ 0, & x \gg 20 \end{cases}$$

Membership for Piston_status, for Piston_status = Medium, then the triangle formula can be used.

$$\mu \text{ Medium (x)} = \begin{cases} 0, & x \leq 30 \\ \frac{x-15}{25-15}, & 15 < x < 25 \\ \frac{35-x}{35-25}, & 25 < x < 35 \end{cases}$$

Membership for Piston_status, for Piston_status = Dirty, then the trapezoid formula can be used.

$$\mu \text{ Dirty (x)} = \begin{cases} 0, & x \leq 15 \; OR \; x \gg 35 \\ \frac{50-x}{50-30}, & 30 < x < 50 \\ 1, & x \gg 37{,}5 \end{cases}$$

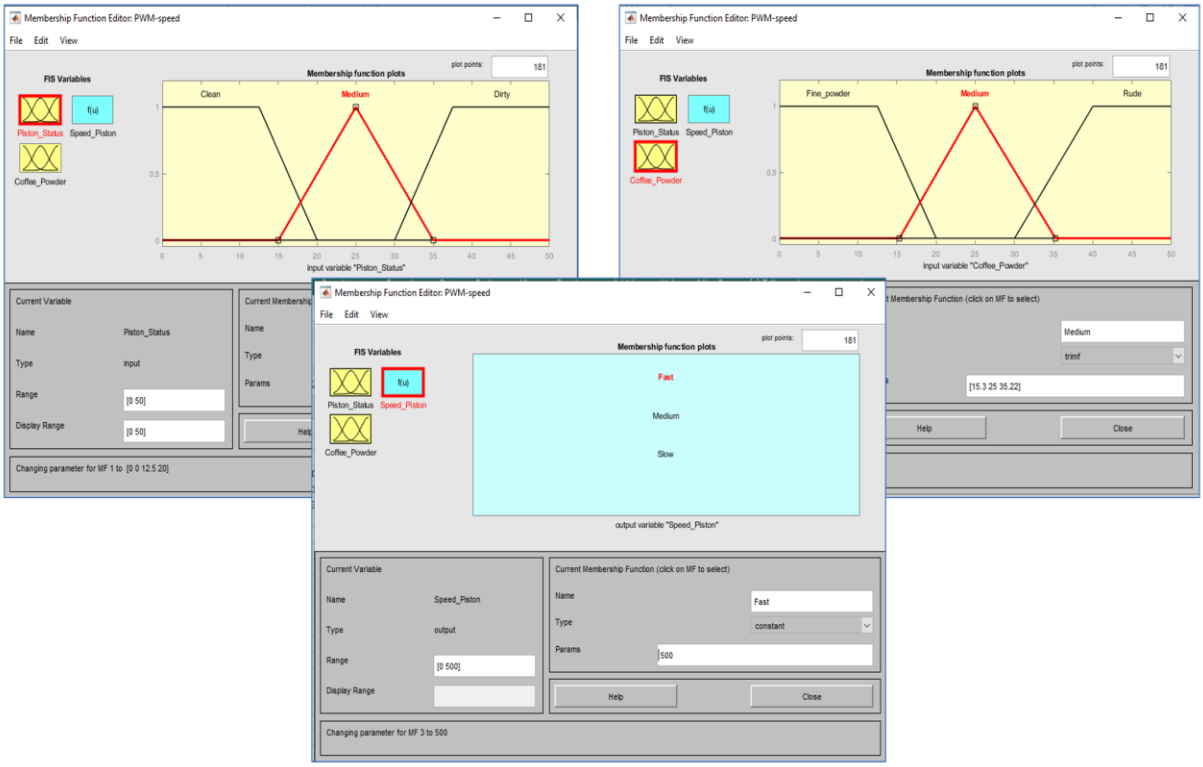

Fig. 5 Parameter Fuzzy (Membership Function Input and Output) in Matlab
Source: Researcher Property

In fig 5, Membership for Coffee_Powder = Fine, then the trapezoid formula can be used.

$$\mu \text{ Fine (x)} = \begin{cases} 1, & x \leq 12{,}5 \\ \frac{20-x}{20-12{,}5}, & 12{,}5 < x < 20 \\ 0, & x \gg 20 \end{cases}$$

Membership for Coffee_Powder = Medium, then the triangle formula can be used.

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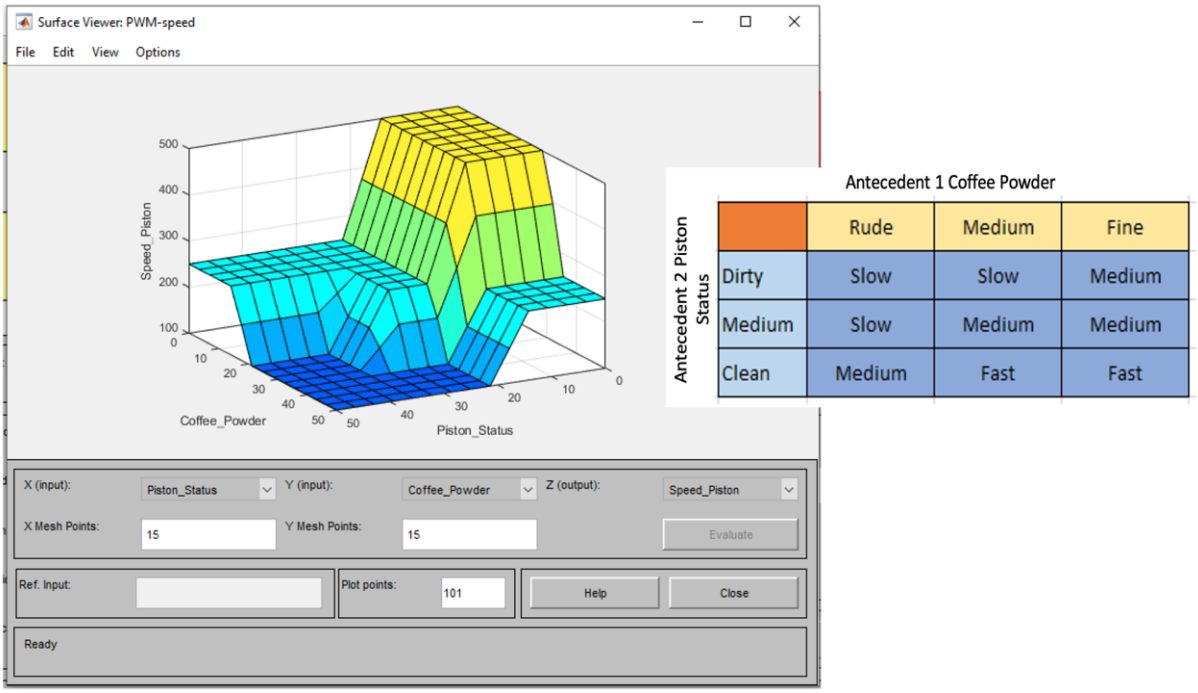
$$\mu \text{ Medium (x)} = \begin{cases} 0, & x \leq 30 \\ \frac{x-15}{25-15}, & 15 < x < 25 \\ \frac{35-x}{35-25}, & 25 < x < 35 \end{cases}$$

Membership for Coffee_Powder = Rude, then the triangle formula can be used.

$$\mu \text{ Rude (x)} = \begin{cases} 0, & x \leq 15 \; OR \; x \gg 35 \\ \frac{50-x}{50-30}, & 30 < x < 50 \\ 1, & x \gg 37{,}5 \end{cases}$$

The rules in fuzzy Sugeno, as follows:
1. IF Piston_Status = Clean AND Coffee_Powder = Fine THEN Speed is Fast.
2. IF Piston_Status = Clean AND Coffee_Powder = Medium THEN Speed is Fast.
3. IF Piston_Status = Clean AND Coffee_Powder = Rude THEN Speed is Medium.
4. IF Piston_Status = Medium AND Coffee_Powder = Fine THEN Speed is Medium.
5. IF Piston_Status = Medium AND Coffee_Powder = Medium THEN Speed is Medium.
6. IF Piston_Status = Medium AND Coffee_Powder = Rude THEN Speed is Slow
7. IF Piston_Status = Dirty AND Coffee_Powder = Fine THEN Speed is Medium
8. IF Piston_Status = Dirty AND Coffee_Powder = Medium THEN Speed is Slow
9. IF Piston_Satus = Dirty AND Coffee_Powder = Rude THEN Speed is Slow.



Antecedent 1 Coffee Powder

Antecedent 2 Piston Status	Rude	Medium	Fine
Dirty	Slow	Slow	Medium
Medium	Slow	Medium	Medium
Clean	Medium	Fast	Fast

Fig. 6 Surface Viewer in Matlab
Source: Researcher Property

As in fig 6, Antecedent 1 (Coffee Powder) and Antecedent 2 (Piston Status) are formed, which form the antecedent table, the experts who already know about coffee machine knowledge are thinking. So this research does not even discuss the knowledge of the coffee machine. The surface of the rule forms a 3D plot, Coffee powder, Piston status and Speed Piston.

The next step is defuzzification, which is to form a fuzzi condition into a CRISP or firm form. The process is to do a composition, namely aggregating the clipping results from the results of the fuzzy rules so as to get a single fuzzy set result. A suitable defuzzification for the Sugeno method is Weighted Avarage. This method takes the average by using weighting in the form of membership degrees. So it can be formulated as follows:

$$y^* = \sum \frac{\mu(y)y}{\mu(y)} \qquad (5)$$

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where y is the CRISP value and (y) is the degree of membership of the CRISP y value.

DISCUSSIONS

From the explanation of this research that the fuzzy method uses Sugeno, it is discussed explicitly. Unlike the Mamdani method. The output is still linguistic. For the Sugeno method, the output is using constants for zero order and linear equations for first order. Because of this, this method is good for control machines, because the output clearly uses constants. Preventive Maintenance is an effort to prevent damage to the machine, meaning that the method used is a method of guarding before more severe damage occurs. The coffee machine can operate better if the user knows about the condition of the machine and the coffee grounds. Minor damage or machine service is carried out quickly, if preventive maintenance is carried out. Standard Operating Procedures should be carried out in machine operation. Preventive Maintenance of coffee machines is carried out once a month to maintain the durability of the machine. Machines that move slowly will result in decreased performance of the coffee machine. Besides, the piston feels heavy and it is easy to loosen and cause the engine to be hot and damaged.

CONCLUSION

Based on the results of the discussion presented earlier, the following conclusions can be drawn: The simulation of the piston pressure control system using fuzzy logic has been successfully created by making membership degrees in order to determine the optimal pressure. By using the fuzzy logic method, the required weight of coffee is obtained to optimize the viscosity of coffee water. The system designed and simulated is more effective in reading the piston pressure classification, because with fuzzy clustering logic, piston pressure readings in theory and application can be done.

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