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Implementation of Fuzzy Logic to Determine the Doneness of Beef Steak

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Abstract

This study aims to implement fuzzy logic in determining the doneness level of beef steak based on the inputs of roasting time and roasting temperature. The output of the developed system is in the form of maturity levels in the categories of "rare", "medium rare", "medium", "medium well", and "well done". Data for this study were obtained through interviews with experienced beef steak sellers. This research method includes direct calculations as well as the use of MATLAB software to develop fuzzy logic systems. The results of the interview analysis are used as a basis for the formation of fuzzy rules for determining the degree of doneness of steaks. The results showed that in the example case with a roasting temperature of 300°C and a roasting time of 10 minutes, the resulting output value was 70, which placed the doneness of the steak in the "medium well" position. These results have been verified both through direct calculations and the use of MATLAB software. The study concluded that the implementation of fuzzy logic can help in determining the doneness level of beef steak, based on temperature variations and roasting time.

Keywords: Fuzzy logic, MATLAB, Steak doneness.

INTRODUCTION

Beef steak is a popular dish enjoyed all over the world. The degree of doneness of a steak is one of the important factors that determine its quality and enjoyment (Schmid & McGee, 1989). Steak is a long-known meal using simple spices and grilling using fire and charcoal (Pramita, 2018). The ripening process of meat causes several chemical changes that make it more tender and flavorful. Because meat is a vein of meat (muscle) attached to the skeleton but does not include veins on the lips, nose and ears that come from healthy animals when cut (Dharmayanti, 2013). Steak has a variety of cooking types, namely welldone, medium well, medium, and medium rare (Rangkuti, 2019). Consumers have different preferences regarding the level of doneness of steaks, ranging from rare (very red) to well done (very cooked). The determination of the right level of doneness for steak plays an important role in ensuring consumer satisfaction.

According to (Nofrianda, 2019), One of the important things in business is that it can build consumer satisfaction. Customers who are satisfied because their expectations are met by the products they believe in will create customer loyalty, which will later lead them to shop again or recommend new customers (Priambada et al., 2016). However, determining the degree of doneness of steak objectively and consistently can be challenging, especially due to factors such as individual variations in taste preferences and differences in measurement methods (Suryadi et al., 2022). Then, in the book entitled "Meat Processing Technology" the level of doneness of food ingredients such as beef depends on taste preferences. Traditionally, the degree of doneness of steaks is determined visually and manually by the cook. This can lead to inconsistencies and inaccuracies, as visual judgment can be affected by factors such as lighting, cooking experience, and cuts of meat.

Fuzzy logic is a method that allows for handling uncertainty and complexity in decision-making and allows for more flexible judgments than traditional methods. The fuzzy method is one of the concepts that has long existed, this concept will later be applied to control systems that use the fuzzy method (Prasetya et al., 2019). Fuzzy logic is a component that makes up soft computing and is widely used in various software. In fuzzy logic, a value can be true (1) or false (0) (Informatika & Indonesia, 2007). The main characteristic of using fuzzy logic is that it has a membership degree or membership function (Radja et al., 2020). This algorithm provides a solution to data processing problems that cannot be solved by traditional methods (Rizky Pahlevi1, Wahyu Oktri Widyarto2, 2013). Many control system applications use fuzzy systems because these control processes can be designed relatively easily and flexibly without requiring complex mathematical models of the system to be controlled (Sutikno, 2018).

Previous studies reviewed by (Siswoyo & Zaenal, 2018), The concept of fuzzy logic is relatively easy to understand and has advantages compared to other concepts because it is able to form a natural approach to solving problems. Its flexibility allows it to be built and developed easily without having to start from scratch. Fuzzy logic also provides tolerance for data uncertainty, which corresponds to situations that often occur in everyday life. In this case, the implementation of fuzzy logic can be an effective solution for determining the degree of doneness of beef steak. By taking into account various data variables that affect meat doneness, such as temperature and time to cook a steak, fuzzy logic can provide a more thorough and accurate approach. Fuzzy logic has the ability to map the input space to the output space in an accurate way (Paquin et al., 2015).

This study, entitled Implementation of Fuzzy Logic to Determine the Doneness of Beef Steak, presents the implementation of fuzzy logic to determine the level of doneness of beef steak. Unlike traditional methods that rely on visual observation and subjective touch, this method offers a more objective and scientific approach.

In research, fuzzy logic calculations to determine the level of doneness of this steak use direct calculations or using MATLAB software. The analysis in this article was done with the help of MATLAB software (Sutikno, 2018). MATLAB is used as a comparison tool with results carried out by direct calculations (Fatwa et al., 2022). Therefore, this study aims to develop a fuzzy system to determine the doneness level of beef steak automatically and accurately. This system is expected to assist cooks in serving steaks with a level of doneness that suits consumer preferences. Thus, this journal aims to explain the implementation of fuzzy logic in determining the degree of doneness of beef steak. Through this research, it is expected to develop methods that can make a significant contribution to the beef industry, especially in improving product quality and consumer satisfaction.

According (Kristianto & Wahyudi, 2019) service quality that meets customer expectations significantly affects customer satisfaction. In addition, research shows that high-quality customer service plays an important role in retaining customers, increasing loyalty, and encouraging positive recommendations to others. Consumers who are satisfied with the service provided will tend to come back (Veronika Nugraheni Sri Lestari et al., 2023)

Using a fuzzy inference system, the study was able to integrate various factors that influence steak maturity, such as the temperature of the stove and the length of cooking time. This enabled the creation of a system that could assess the steak's maturity rate more accurately and consistently. Another advantage of this method is its ease of use. The user only has to enter the stove temperature and cooking time data, and the system will automatically determine the level of ripeness. This opens up an opportunity for steak lovers to enjoy a steak with a level of maturity that suits their tastes without relying on professional expertise.

This research represents a significant step forward in the culinary field. The implementation of fuzzy logic to determine the doneness of beef steaks has never been done before and has the potential to revolutionize the way we enjoy steak. This research paves the way for a variety of potential future applications, such as the development of an automated steak grilling system that can produce steaks with the desired level of doneness or the development of a more objective and consistent steak scoring system for culinary competitions.

METHODS

Research Location and Time

This research was conducted on February 13, 2024 at one of the beef steak restaurants. with the main purpose of this research is to collect data to determine the level of maturity of beef steak based on stove temperature and length of cooking time.

Method of Collecting Data

Data collection is a data collection method carried out to ensure the accuracy of information related to the research, with the aim of obtaining accurate and relevant data in the research (Syahfitri et al., 2023). In the research method for determining the degree of doneness of beef steak includes:

1. Interview

On February 13, 2024, we decided to visit one of the leading steak grill restaurants to start the interview process. Our goal was to gain an in-depth understanding of steak cooking techniques and the factors that affect their doneness. One of the few employees we interviewed was an experienced cook at the restaurant. During the interview, we asked various questions related to the steak cooking process, including the desired level of doneness, the time required to reach that doneness, and the temperature required to cook the steak according to those preferences. The data obtained from this interview is an integral part of our research in developing a fuzzy logic model to determine the optimal doneness of steaks.

2. Study Literature

The data we obtained through interviews with various experts, as well as a thorough literature study on steak doneness, were crucial steps in preparation for the implementation of our planned fuzzy logic model. The interviews provided valuable insights into best practices in steak cooking, including key parameters such as the desired doneness level, time, and temperature required to achieve it. These data not only provide an in-depth understanding of the steak cooking process but also provide a solid foundation for the development of our fuzzy logic algorithm. Through a combination of empirical data from interviews and theoretical knowledge from the literature, we aim to create an accurate and reliable model for automatically determining steak doneness based on individual customer preferences.

In understanding steak doneness, factors such as temperature, time, and desired doneness play an important role. To implement an accurate and adaptive approach, we decided to use the Mamdani method in the development of fuzzy logic models. The Mamdani method allows us to describe the fuzzy rules clearly and intuitively, as well as take into account the uncertainty associated with the process of cooking steaks. Using the data we obtained through interviews and literature studies as a basis, we designed a series of fuzzy rules covering various scenarios in cooking steak. Through the defuzzification stage, our model will produce outputs that indicate an optimal maturity level based on temperature and time inputs. Thus, the implementation of fuzzy logic using the Mamdani method is expected to provide an accurate and adaptive solution for determining the doneness of steak according to customer preferences.

Data Analysis

The Mamdani method is one of the most common approaches in fuzzy logic, helping to overcome uncertainty in decision making (Ayuningtias et al., 2017). The mamdani method has proven to be very useful in the function and control approach (Izquierdo & Izquierdo, 2018). In the mamdani method, using several IF-THEN rules obtained from operators / experts who are experienced in their fields (Maryam et al., 2021). Fuzzy logic is a problem-solving control system methodology that is suitable for implementation on systems ranging from simple systems, small systems, embedded systems, PC networks, multi-channel or workstation-based data acquisition, and control systems. (Putri & Maulana, 2023).

According to (Sufarnap & Sudarto, 2019), The theories in the development of fuzzy logic show that in principle, fuzzy logic can be applied in modeling various systems. One of the advantages of fuzzy logic is its ability to establish relationships between inputs and outputs without overriding existing factors. Therefore, fuzzy logic is considered to have high tolerance and flexibility to the data used in its use. The use of fuzzy mamdani methods is similar to the use of statistical forecasting methods. Fuzzy-based analysis approach is more efficient in the use of data compared to forecasting methods. Statistical forecasting often results in greater errors than fuzzy approaches. By using a fuzzy approach, the results tend to be closer to the actual situation (Andani, 2013). Then, fuzzy logic is a form of multi-number logic that uses truth values that are between 0 and 1. In fuzzy logic, the truth value of a variable can be between 0 and 1, which is different from traditional logic which only has a truth value that is at 0 or 1(Mattos-Vela, 2021).

Fuzzy logic consists of four stages, namely membership functions, fuzzyfication, rule evaluation, and defuzzyfication. The fuzzyfication stage aims to convert assertive input data into fuzzy values in fuzzy sets for some input linguistic variable (Wicaksono Hadi & Setiawan, 2011).

1. **Fuzzification**

   Fuzzification is the technique of converting a definite (firm) value into a fuzzy (uncertain) value. In this process, inputs are entered into the fuzzy system by creating fuzzy sets and values. In this case, fuzzification has two input variables, namely stove temperature and cooking time (Haerani, 2014).

   The first step in this method is fuzzyfication, where crisp input variables are converted into fuzzy variables using membership functions. Later, fuzzy rules were created to link fuzzy input to fuzzy output, using linguistic terms such as "If... then...". After that,fuzzy inference is used to determine how strongly each rule applies and its implications on fuzzy output variables, often by using fuzzy logic operators such as AND, OR, and NOT (Simanjuntak & Fauzi, 2017).

2. **Membership Functions**

   The degree of membership is the degree at which the value expressly corresponds to the membership function, measured in the range from 0 to 1. This is also known as membership level, truth value, or fuzzy input. The next step is the rule evaluation, which aims to find the fuzzy value of the output from the fuzzy value of the input. The process involves using the fuzzy input value of the fuzzy process as input into the rules that have been created to produce the fuzzy output value. The final stage is the process of defuzzyfication, aimed at determining the unequivocal value of the output. The process involves taking fuzzy values of output from the evaluation of rules to produce firm values of output (Haerani, 2014).

3. **Inference Fuzzy (Rule Evaluation)**

   The next fuzzy calculation process is the reasoning (inference) stage, which aims to find the fuzzy output value from the fuzzy input. In this process, the fuzzy input values generated from fuzzification are inserted into the rules that have been created to produce fuzzy outputs. The reasoning stage involves three steps: applying fuzzy operators (aggregation), applying the implication method, and combining all outputs. This fuzzy system uses the MAX-MIN inference method, also known as MAMDAMI (Haerani, 2014).

4. **Defuzzyfication**

   The final step is defuzzyfication, where the fuzzy output is converted into crisp values using the corresponding membership function. Thus, the Mamdani method provides a powerful framework for integrating human knowledge with numerical data, enabling the system to take decisions in complex and uncertain situations. In conclusion, Mamdani's fuzzy logic is a logic system that can process uncertain information and make decisions using a scale of values between 0 and 1. This capability allows for more accurate and realistic decision making as it considers many factors and finds compromises among the various options available (Dary Daffa Haque, 2023).

In determining the degree of doneness of the steak, this approach can provide a more nuanced solution than conventional methods. First of all, we need to define the relevant variables, such as roasting time, temperature, cooking time, and doneness level preference. Each of these variables is then divided into fuzzy sets with corresponding membership functions, for example, "minimal", "medium", and "maximum" for temperature. Furthermore, fuzzy rules reflecting expert knowledge of the steak cooking process can be established. For example, "If the temperature is low and the roasting time is moderate, then the doneness level is low." Once these rules are defined, the output is defined in the form of fuzzy sets, such as "rare", "medium", and "well-done". Then, using fuzzy operating principles, such as fuzzy inference and defuzzyfication, we can produce more accurate and diverse levels of steak doneness.

Fuzzy logic makes it possible to take into account complex and non-linear factors (Kaur, 2012), seperti waktu pemanggangan steak daging sapi, yang sulit diwakili dalam model konvensional. Thus, the mamdani method in fuzzy logic offers a powerful and flexible approach in determining the degree of doneness of steaks, taking into account various variables and individual preferences.

Flowchart

A flowchart is a diagram that describes the steps in a process sequentially. This diagram consists of symbols that represent the steps in the process, and the relationships between steps are connected with lines and arrows. By using flowcharts, complex processes can be broken down into steps that are easier to understand and analyze (Roihan et al., 2019). Here is the flowchart for determining the level of beef steak doneness.

In determining the level of doneness of beef steak using Fuzzy Mamdani logic, here is a flowchart for the process of determining the level of doneness of steak. Based on the flowchart below, in determining the level of doneness of beef steak, it requires two inputs, namely the stove temperature and cooking time, where the temperature unit is in Celsius and the unit for time is minutes. Then, for the output itself is the level of doneness of the steak which consists of five levels of doneness, namely Rare, Medium Rare Medium, Medium Well, and Welldone. To determine the level of doneness of the steak, a fuzzy mamdani logic approach is used, which will later go through several stages and also use the Matlab application.

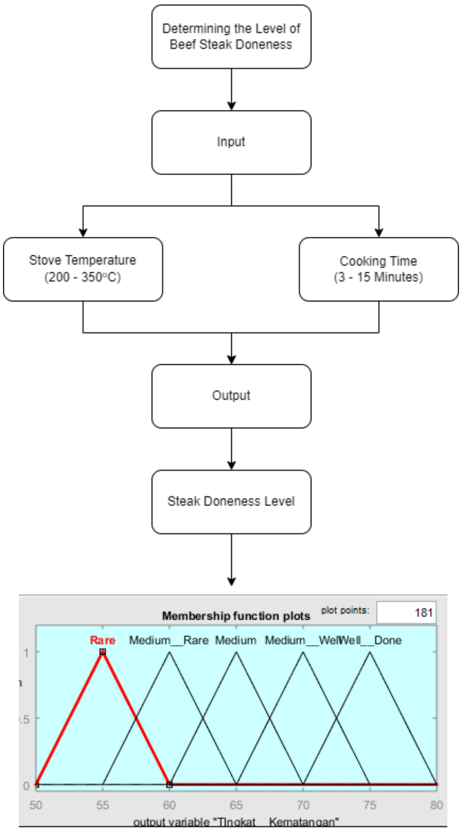

Figure 1. Flowchart for steak doneness process

The degree of membership is the degree at which the value expressly corresponds to the membership function, measured in the range from 0 to 1. This is also known as membership level, truth value, or fuzzy input. The next step is the reasoning process, which aims to find the fuzzy value of the output from the fuzzy value of the input. The process involves using the fuzzy input value of the fuzzy process as input into the rules that have been created to produce the fuzzy output value. The final stage is the process of defuzzyfication, aimed at determining the unequivocal value of the output. The process involves taking fuzzy values of output from the evaluation of rules to produce firm values of output (Haerani, 2014).

RESULTS AND DISCUSSION

Membership Function in Determining the Level of Doneness of Steak

A membership function is a curve that describes how input data points are mapped to their membership values, often referred to as membership degrees, with a range of values between 0 and 1. One commonly used method of deriving membership value is through a function approach (Haerani, 2014). Membership functions are typically used to describe the relationship between input values and the likelihood or high likelihood of an input value being a member of a fuzzy set (Sitohang & Denson Napitupulu, 2017). The most common examples of membership functions are triangular functions and trapezoidal functions. In this study using triangular membership function and trapezoidal function.

Furthermore, the following membership function graph is the result of data obtained during interviews with experts, namely chefs who usually cook beef steak. There are two input variables used, namely stove temperature and cooking time. Then for the output variable is the level of doneness of the steak and the following is a more complete explanation.

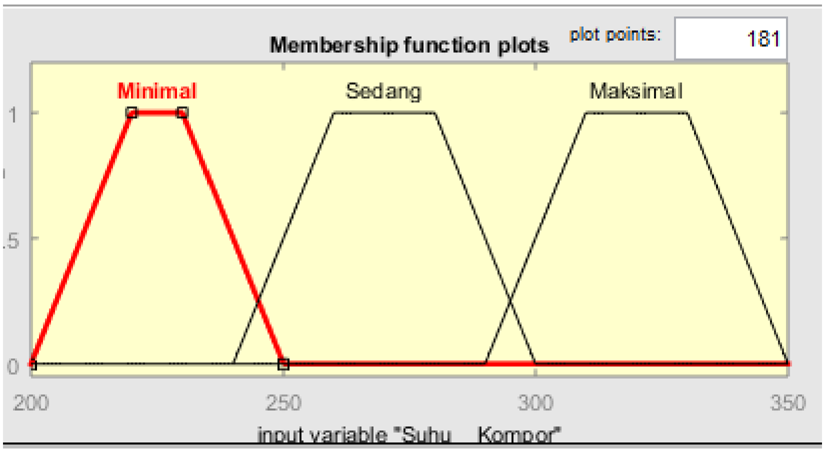

Figure 2. Graph of trapezoidal membership function variable input stove temperature

In the picture above is a membership function of one of the input variables, namely the stove temperature. The temperature variable is made with the Trapezoidal type and has a range of 200ºC to 350ºC with three parameters namely Minimum, Medium, and Maximum. It can be seen that the value of the Minimal parameter is [200 220 230 250]ºC with the peak point at 220ºC - 230ºC, the value of the Medium parameter is [240 260 280 300]ºC with the peak point at 260ºC - 280ºC , and the value of that Max parameter is [290 310 330 350]ºC with the peak point at 310ºC - 330ºC. In the next section, table below is a table that contains the parameter range values of the stove temperature input variable as explained in figure 2.

Table 1. Variable input stove temperature

Stove Temperature	Minimum	Medium	Maximum
Range(ºC)	[200 220 230 250]	[240 260 280 300]	[290 310 330 350]
Peak (ºC)	[220-230]	[260-280]	[310-330]

In the picture below is the membership function of the second input variable, which is cooking time. The variable cooking time is made with the Trapezoidal type and has a range from 0 to 15 minutes with three parameters, namely Short, Medium, and Long.

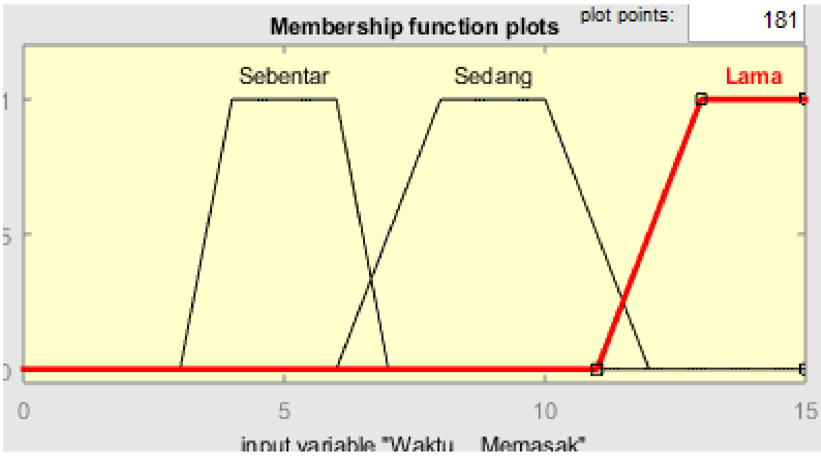

Figure 3. Graph of trapezoidal membership function variable input cooking time

It can be seen that the value of the Brief parameter is [3 4 6 7] minutes with its peak point of 4 - 6 minutes, the value of the Medium parameter it is [6 8 10 12] minutes with a peak point is 8 - 10 minutes, and the value of the long cooking parameter is [11 12 14 15] minutes with a peak point are 12 - 14 minutes. In the next section, the table below contains the value of the range parameter of the cooking time input variable, as explained in figure 3.

Table 2. Input variable cooking time

Cooking Time	Short	Medium	Long
Range(Minutes)	[3 4 6 7]	[6 8 10 12]	[11 12 14 15]
Peak (Minutes)	[4-6]	[8-10]	[12-14]

In the picture below is a membership function of the output variable, namely the maturity level. The maturity level variable is made with the Triangular type and has a range from 50% to 80% with 5 parameters, namely Rare, Medium Rare, Medium, Medium Well, and Welldone.

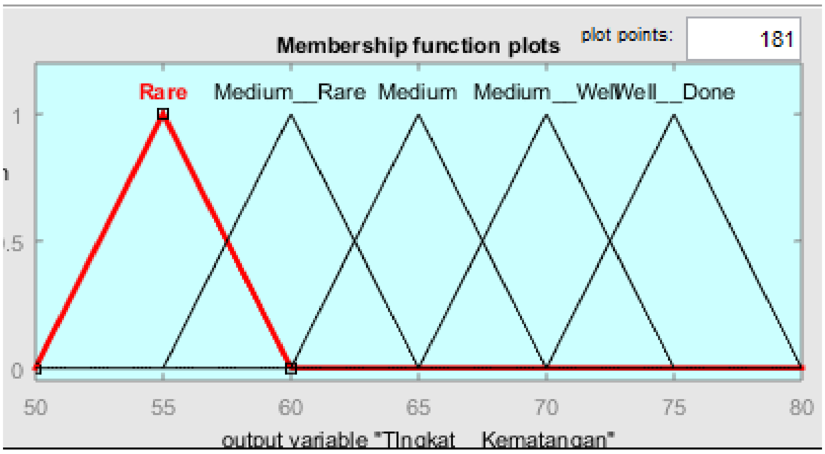

Figure 4. Graph of tringular membership function variable output maturity level

It can be seen that the Rare maturity level is 55% and the parameter value is in the range of [50 55 60]%, The maturity level of Medium Rare is 60% and the parameter value is with a range [55 60 65]%, The maturity level of the Medium is 65% and its parameter value with range [60 65 70]%, The maturity level of Medium Well it is 70% and its parameter value with range [65 70 75]%, and the maturity level of Welldone is 75% and its parameter value with range [70 75 80]%. In the next section, the table below contains the value of the range parameter of the output variable of steak doneness level, as explained in figure 4.

Table 3. Output variable of steak doneness level

Maturity Level	Rare	Medium Rare	Medium	Medium Well	Well Done
Range(%)	[50 55 60]	[55 60 65]	[60 65 70]	[65 70 75]	[70 75 80]

Membership Set

This fuzzy logic membership set is a range of values where each value has a membership degree (μx) between 0 and 1. In each parameter, the membership set will be determined to facilitate the determination and calculation of the membership degree to be sought. The following membership set is a membership set of input variables made based on interview data and adjusted to graphs created in the Matlab application and can later be used in calculating the level of steak doneness based on the range of each parameter to determine the value of the degree of membership (μx). Here's the function data for the membership set input variable.

To divide the membership set this is done based on the position of the variable value on a parameter with several formulas. Because this study uses a trapezoidal type fuzzy graph, the formula that can be used is:

1. Formula for calculating the value on the left side of the trapezoidal = $\frac{x-a}{b-a}$
2. 1 is the value of the variable that is in the range of the vertex of the trapezoid

3. Formula for calculating the value on the right side of the trapezoidal = $\frac{d-x}{d-c}$

Stove Temperature Input Variable Membership Set

$$Fx(Stove\ Temperatu) \begin{cases} \mu Minimum(x) = \begin{cases} \frac{x-200}{220-200} & : 200 < x < 220 \\ 1 & : 220 \le x \le 230 \\ \frac{250-x}{250-230} & : 230 < x < 250 \\ 0 & : x \le 200 \cup x \ge 250 \end{cases} \\ \mu Medium(x) = \begin{cases} \frac{x-240}{260-240} & : 240 < x < 260 \\ 1 & : 260 \le x \le 280 \\ \frac{300-x}{300-280} & : 280 < x < 300 \\ 0 & : x \le 240 \cup x \ge 300 \end{cases} \\ \mu Maximum(x) = \begin{cases} \frac{x-290}{310-290} & : 290 < x < 310 \\ 1 & : 310 \le x \le 330 \\ \frac{350-x}{350-330} & : 330 < x < 350 \\ 0 & : x \le 290 \cup x \ge 350 \end{cases} \end{cases}$$

Cooking Time Input Variable Membership Set

$$Fx(Cooking\ Time) \begin{cases} \mu Short(x) = \begin{cases} \frac{x-3}{4-3} & : 3 < x < 7 \\ 1 & : 4 \le x \le 6 \\ \frac{7-x}{7-6} & : 6 < x < 7 \\ 0 & : x \le 3 \cup x \ge 7 \end{cases} \\ \mu Medium(x) = \begin{cases} \frac{x-6}{8-6} & : 6 < x < 8 \\ 1 & : 8 \le x \le 10 \\ \frac{12-x}{12-10} & : 10 < x < 12 \\ 0 & : x \le 6 \cup x \ge 12 \end{cases} \\ \mu Long(x) = \begin{cases} \frac{x-11}{12-11} & : 11 < x < 13 \\ 1 & : 13 \le x \le 15 \\ 0 & : x \le 11 \cup x > 15 \end{cases} \end{cases}$$

Based on the membership set data, we perform calculations to determine the level of doneness of steak with temperature 300ºC (within the Maximum parameter range) and cooking time for 10 minutes (within the Medium parameter range). From the experiment, a degree of membership was obtained(µx) from temperature 300ºC is 0,5 and the membership degree(µx) of 10 minutes time is 1. Here is the calculation of the membership degree of the input variable:

$$\mu\mathbf{StoveTemperature} = \frac{x-a}{b-a} = \frac{300-290}{310-290} = \frac{10}{20} = \mathbf{0\ \ 5}$$
$$\mu\mathbf{CookingTime} = \mathbf{10} = \mathbf{1}$$

The next step is to create rules to be used as rules later in the process towards defuzzyfication. This rule is created by multiplying the number of parameters on two or more input variables.

The input variables here each have 3 parameters, therefore the rules that can be created are 3x3 = 9 rules. Here are the rules that we have defined based on the input variable data and the output variable:

1. If (Suhu__Kompor is Minimal) and (Waktu__Memasak is Sebentar) then (Tingkat__Kematangan is Rare) (1)
2. If (Suhu__Kompor is Minimal) and (Waktu__Memasak is Sedang) then (Tingkat__Kematangan is Medium__Rare) (1)
3. If (Suhu__Kompor is Minimal) and (Waktu__Memasak is Lama) then (Tingkat__Kematangan is Medium__Rare) (1)
4. If (Suhu__Kompor is Sedang) and (Waktu__Memasak is Sebentar) then (Tingkat__Kematangan is Medium__Rare) (1)
5. If (Suhu__Kompor is Sedang) and (Waktu__Memasak is Sedang) then (Tingkat__Kematangan is Medium) (1)
6. If (Suhu__Kompor is Sedang) and (Waktu__Memasak is Lama) then (Tingkat__Kematangan is Medium__Well) (1)
7. If (Suhu__Kompor is Maksimal) and (Waktu__Memasak is Sebentar) then (Tingkat__Kematangan is Medium__Rare) (1)
8. If (Suhu__Kompor is Maksimal) and (Waktu__Memasak is Sedang) then (Tingkat__Kematangan is Medium__Well) (1)
9. If (Suhu__Kompor is Maksimal) and (Waktu__Memasak is Lama) then (Tingkat__Kematangan is Well__Done) (1)

Figure 5. Rules

From the experiments we did, the temperature 300ºC (Maximum) and 10 minutes (Medium) are included in the 8th rule, namely "If the Maximum Stove Temperature and Cooking Time are Medium, the Doneness level is Medium Well" from these rules, fuzzy operators are used as follows:

$$\alpha_8 = \mu_{\mathbf{StoveTemperatureMax}} \cap \mu_{\mathbf{MediumCookingTime}}$$
$$\alpha_8 = \boldsymbol{Min}(\mu_{\mathbf{StoveTemperatureMax}(300)} ; \mu_{\mathbf{MediumCookingTime}(10)})$$
$$\boldsymbol{\alpha_8 = Min(0\ 5 ; 1)}$$
$$\boldsymbol{\alpha_8 = 0\ 5}$$

Because in this case using the AND operator, the smallest membership degree value between the two input variables is taken to later determine the Implication Function which is to calculate the value x_1 and x_2 in the output variable. Since this is the fuzzy mamdani method, the next step is to calculate the value x_1 and x_2 on the output graph, determine the set of membership of the output variable, area, and moment equation in the defuzzyfication process.

Defuzzyfication

The defuzzyfication process with the center of area (COA) method involves the use of moment values and area values on output variables based on the fuzzy operators used. In COA, the formulation of the method is to find the center point of the area under the curve of the output variable membership function defined by the fuzzy rules that have been applied (Santosa et al., 2022).

In this defuzzyfication process, the first is to determine the implication function, which is to find the values of x_1 and x_2 from the previously calculated data. These x_1 and x_2 values are taken and determined from the graph of the output variable and based on the rules used. In this calculation, the values of x_1 and x_2 are taken in the range of Medium Well parameters and then obtained the value of $_{x1}$ is 67.6 and the value of x_2 is 72.5 based on the following calculation:

$$0\ 5 = \frac{x_1 - a}{b - a}$$
$$0{,}5 = \frac{x_1 - 65}{70 - 65}$$
$$0{,}5 = \frac{x_1 - 65}{5}$$
$$x_1 - 65 = 0\ 5\ x\ 5$$
$$\boldsymbol{x_1 = 65 + 2\ 5 = 67\ 5}$$

$$0\ 5 = \frac{c - x_2}{c - b}$$
$$0\ 5 = \frac{75 - x_2}{75 - 70}$$
$$0\ 5 = \frac{75 - x_2}{5}$$
$$0\ 5\ x\ 5 = 75 - x_2$$
$$\boldsymbol{x_2 = 75 - 2\ 5 = 72\ 5}$$

Then from the results of the values x_1 and x_2 above, the area can be calculated and a membership set is formed on the output variable as follows:

$$\boldsymbol{LD_1} = \frac{axt}{2} = \frac{(67{,}5 - 65)\ x\ 0{,}5}{2} = \boldsymbol{0{,}625}$$

$\boldsymbol{LD_2} = \text{p x l} = (72{,}5 - 67{,}5)\ x\ 0{,}5 = \mathbf{2{,}5}$
$\boldsymbol{LD_3} = \frac{axt}{2} = \frac{(75 - 72{,}5)\ x\ 0{,}5}{2} = \mathbf{0{,}625}$

Output function membership set

$$Fx(a,b,c)\begin{cases} 0 & : x \leq 65 \\ \frac{x-65}{75-70} & : 60 < x < 67{,}5 \\ 0{,}5 & : 67{,}5 \leq x \leq 72{,}5 \\ \frac{75-x}{75-70} & : 72{,}5 < x < 75 \\ 0 & : x \geq 75 \end{cases}$$

Counting Moment

$M_1 = \frac{x-65}{70-65} = \frac{x-65}{5} = 0{,}2x - 13$
$M_2 = 0{,}5$
$M_3 = \frac{75-x}{75-70} = \frac{75-x}{5} = 15 - 0{,}2x$

$\mathbf{Moment} = \int_a^b \boldsymbol{F(x)x\,.\,dx}$

Moment Set 1

$M_1 = \int_{65}^{67{,}5}(0{,}2x - 13)x\ dx\ \rightarrow\ \int_{65}^{67{,}5} 0{,}2x^2 - 13x\ dx\ \rightarrow\ \int_{65}^{67{,}5} 0{,}067x^3 - 6{,}5x^2 dx$
$M_1 = [0{,}067(67{,}5)^3 - 6{,}5(67{,}5)^2] - [0{,}067(65)^3 - 6{,}5(65)^2]$
$M_1 = [20.605{,}640 - 29.615{,}625] - [18.399{,}875 - 27.462{,}5]$
$M_1 = [-9.009{,}985] - [-9.062{,}625]$
$\boldsymbol{M_1} = \mathbf{52{,}64}$

Moment Set 2

$M_2 = \int_{67{,}5}^{72{,}5} 0{,}5x\ dx \rightarrow \int_{67{,}5}^{72{,}5} 0{,}25x^2 dx$
$M_2 = [0{,}25(72{,}5)^2 - 0{,}25(67{,}5)^2]$
$M_2 = [1.314{,}0625 - 1.139{,}0625]$
$\boldsymbol{M_2} = \mathbf{175}$

Moment Set 3

$M_3 = \int_{72{,}5}^{75}(15 - 0{,}2)x\ dx \rightarrow \int_{72{,}5}^{75} 15x -\ 0{,}2x^2\ dx \rightarrow \int_{72{,}5}^{75} 7{,}5x^2 - 0{,}067x^3 dx$
$M_3 = [7{,}5(75)^2 - 0{,}067(75)^3] - [7{,}5(72{,}5)^2 - 0{,}067(72{,}5)^3]$
$M_3 = [42.187{,}5 - 28.265{,}625] - [39.421{,}875 - 25.532{,}23]$
$M_3 = [13.921{,}875] - [13.889{,}645]$
$\boldsymbol{M_3} = \mathbf{32{,}23}$

From all the data obtained, namely Regional Area (LD) and also Moments (M), the last stage is the Defuzzyfication process by dividing the total moments by the total Area.

$Z^* = \frac{\sum M}{\sum LD}$
$Z^* = \frac{M_1 + M_2 + M_3}{LD_1 + LD_2 + LD_3}$
$Z^* = \frac{52{,}64 + 175 + 32{,}23}{0{,}625 + 2{,}5 + 0{,}625}$
$Z^* = \frac{259{,}87}{3{,}75} = 69{,}2989 = 69{,}3 = 70$

From the results of the defuzzyfication process, a final value of 70% was obtained with a margin of error of 0.7% and this 70% value is a percentage for the maturity level of "Medium Well" in this case proving that the calculation carried out is in accordance with the rules that have been used, namely "If the Maximum Stove Temperature and Cooking Time are Medium, the Maturity level is Medium Well".

To prove that the calculation is accurate, we conducted a test on the Matlab application with stove temperature input = 300^{o}C and cooking time = 10 minutes and obtained 70% results according to the calculations that have been done with the output results in the Matlab application:

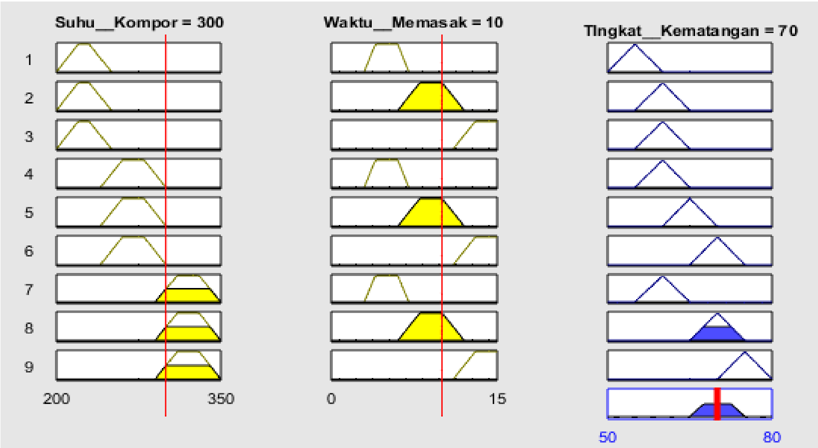

Figure 6. Output results in matlab applications

CONCLUSION

This study adopts the Fuzzy Mamdani logical approach to determine the level of beef steak doneness. The process of determining the level of maturity is carried out through several stages described in detail in the flowchart. In this process, two main inputs are required, namely stove temperature (in degrees Celsius) and cooking time (in minutes), with output in the form of five levels of steak doneness, namely Rare, Medium Rare, Medium, Medium Well, and Welldone. The stages of determining the maturity level start from determining the degree of membership, making rules, and then moving on to the defuzzification stage.

The defuzzification process, using the Center of Area (COA) method, calculates the output value based on the fuzzy rules applied. This involves determining the values of x1 and x2 from the output graph and the rules used. These values are then used to calculate the area equation and moments for the output variable, facilitating the determination of the final output value.

The membership function graphs for input variables, such as stove temperature and cooking time, are designed based on data from an interview with a chef skilled in cooking beef steak. The stove temperature is divided into three parameters, namely Minimum, Medium, and Maximum, while the cooking time is divided into three parameters, namely Brief, Medium, and Long. Additionally, membership function graphs for the output variable, i.e., the maturity level, have also been created with corresponding parameters.

It is expected that this research can contribute significantly to improving product quality and consumer satisfaction in the beef industry by speeding up the cooking process and maintaining the consistency of beef doneness levels. Additionally, the use of fuzzy logic methods is expected to increase efficiency in the cooking process by reducing the risk of unevenly cooked or overcooked meat.

This research also provides a basis for the development of automation systems in the culinary industry, particularly in steak cooking, where intelligent systems can automatically adjust stove temperature and cooking time based on desired doneness preferences, enhancing efficiency and consistency in food production processes.

By utilizing trapezoidal and triangular membership functions to map input variables and employing fuzzy rules and defuzzification processes, this study provides a systematic approach to decision-making in cooking processes. The validity of calculations was verified through testing in MATLAB, confirming the accuracy of the results obtained.

In this specific case, with a stove temperature of 300°C (Maximum) and a cooking time of 10 minutes (Medium), the calculated membership degrees were 0.5 and 1, respectively. By applying fuzzy rules and defuzzification, the final output value for the beef doneness level was determined to be 70%, indicating "Medium Well" doneness.

Overall, this study successfully demonstrates the effectiveness of applying fuzzy logic in determining the level of beef steak doneness based on stove temperature and cooking time, making a significant contribution to the development of technology in the food and beverage industry and providing a better understanding of fuzzy logic application in the culinary context, particularly in steak cooking.

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REFERENCES

Andani, S. R. (2013). Fuzzy Mamdani Dalammenentukan Tingkat Keberhasilan Dosen mengajar. *Seminar Nasional Informatika 2013*, *2013*(semnasIF), 57–65.

Ayuningtias, L. P., Irfan, M., & Jumadi, J. (2017). Analisa Perbandingan Logic Fuzzy Metode Tsukamoto, Sugeno, Dan Mamdani. *Jurnal Teknik Informatika*, *10*(1), 9–16.

Dharmayanti, L. (2013). Pengetahuan Bahan Makanan 2. *Bahan Ajar SMK Program Keahlian Tata Boga*, *021*, 178.

Haerani, E. (2014). Analisa Kendali Logika Fuzzy Dengan Metode Defuzzifikasi Coa (Center of Area), Bisektor, Mom (Mean of Maximum), Lom (Largest of Maximum), Dan Som (Smallest of Maximum). *SITEKIN: Jurnal Sains, Teknologi dan Industri*, *10*(2), 245–253. https://ejournal.uin-suska.ac.id/index.php/sitekin/article/view/543

Informatika, J. T., & Indonesia, U. I. (2007). *(Taufiq Hidayat ST ^ MCS)*.

Izquierdo, S. S., & Izquierdo, L. R. (2018). Mamdani fuzzy systems for modelling and simulation: A critical assessment. *Jasss*, *21*(3). https://doi.org/10.18564/jasss.3660

Kaur, S. (2012). *Two Inputs Two Output Fuzzy Controller System Design using MATLAB*. *2*(3), 209–218.

Kristianto, A. D., & Wahyudi, T. A. (2019). Pengaruh citra merek, persepsi kualitas produk dan persepsi harga pada kepuasan pelanggan serta dampaknya terhadap loyalitas pelanggan. *Jurnal Manajemen Strategi dan Aplikasi Bisnis*, *2*(2), 117–126. https://doi.org/10.36407/jmsab.v2i2.74

Maryam, S., Bu'ulolo, E., & Hatmi, E. (2021). Penerapan Metode Fuzzy Mamdani dan Fuzzy Tsukamoto Dalam Menentukan Harga Mobil Bekas. *Journal of Informatics, Electrical and Electronics Engineering*, *1*(1), 10–14. https://djournals.com/jieee/article/view/54%0Ahttps://djournals.com/jieee/article/download/54/164

Mattos-Vela, M. A. (2021). Open access. *British Dental Journal*, *231*(4), 207. https://doi.org/10.1038/s41415-021-3384-2

Nofrianda, H. (2019). ANALISIS PENGARUH KUALITAS PRODUK, KUALITAS LAYANAN DAN HARGA TERHADAP KEPUASAN KONSUMEN (Studi Kasus Pada Konsumen Industry/ Toko Bakery di Kota Bengkulu). *Managament Insight: Jurnal Ilmiah Manajemen*, *13*(1), 71–85. https://doi.org/10.33369/insight.13.1.71-85

Paquin, F., Rivnay, J., Salleo, A., Stingelin, N., & Silva, C. (2015). Multi-phase semicrystalline microstructures drive exciton dissociation in neat plastic semiconductors. *J. Mater. Chem. C*, *3*(2), 10715–10722. https://doi.org/10.1039/b000000x

Pramita, V. D. (2018). Karakterisasi Steak Daging dengan Substitusi Texturized Vegetable Protein (TVP) Modified Legume Flour (Molef) Koro Pedang (Canavalia ensiformis L.). *Jawa*, 1–119.

Prasetya, B., Boedi Setiawan, A., & Febrinda Hidayatulail, B. (2019). Fuzzy Mamdani Pada Tanaman Tomat Hidroponik (Mamdani Fuzzy on Hydroponics Tomato Plants). *JEEE-U (Journal of Electrical and Electronic Engineering-UMSIDA)*, *3*(2), 228.

Priambada, S., Suyadi, I., Yulianto, E., & Susilo, H. (2016). Pentingnya Customer Relationship Management (CRM) Untuk Meningkatkan Loyalitas Pelanggan Di KPRI-UB. *Conference: Seminar Nasional Sistem Informasi Indonesia (SESINDO), November*, 437–444.

https://www.researchgate.net/publication/322500219_PENTINGNYA_CUSTOMER_RELATIONSHIP_MANAGEMENT_CRM_UNTUK_MENINGKATKAN_LOYALITAS_PELANGGAN_DI_KPRI-UB

Putri, A. D., & Maulana, A. (2023). Penerapan Metode Mamdani Fuzzy Logic untuk Menentukan Pembelian Alat Berat dalam Proyek Migas di PT SMOE Indonesia. *Jurnal Desain Dan Analisis Teknologi*, *2*(2), 138–149. https://doi.org/10.58520/jddat.v2i2.32

Radja, M., Londa, M. A., & Sara, K. (2020). Penerapan Metode Logika Fuzzy dalam Evaluasi Kinerja Dosen. *Matrix : Jurnal Manajemen Teknologi dan Informatika*, *10*(2), 78–86. https://doi.org/10.31940/matrix.v10i2.1841

Rangkuti, M. G. (2019). Pengolahan Citra Identifikasi Kematangan Tenderloin Steak Menggunakan Metode Ekstraksi Ciri Statistik. *Majalah Ilmiah INTI*, *6*, 51–54.

Rizky Pahlevi1, Wahyu Oktri Widyarto2, T. A. M. P. (2013). Implementasi Fuzzy Mamdani untuk Penentuan Pengadaan Kartu Operator pada Distributor Kartu Perdana PT . XYZ. *Prosiding Seminar Nasional Industrial Services (SNIS) III*, 2013–2016.

Roihan, A., Kusumah, H., & Permana, A. (2019). Prototype Fast Tracking of Detection Offenders Smoking Zone Berbasis Internet of Things. *Informatika Mulawarman : Jurnal Ilmiah Ilmu Komputer*, *13*(2), 111. https://doi.org/10.30872/jim.v13i2.1304

Santosa, S. H., Hidayat, A. P., & Siskandar, R. (2022). Raw material planning for tapioca flour production based on fuzzy logic approach: a case study. *Jurnal Sistem dan Manajemen Industri*, *6*(1), 67–76. http://dx.doi.org/10.30656/jsmi.v6i1.4594

Schmid, R., & McGee, H. (1989). On Food and Cooking: The Science and Lore of the Kitchen. In *Taxon* (Vol. 38, Nomor 3). https://doi.org/10.2307/1222284

Siswoyo, B., & Zaenal, A. (2018). Model Peramalan Fuzzy Logic. *Jurnal Manajemen Informatika (JAMIKA)*, *8*(1), 1–14. https://doi.org/10.34010/jamika.v8i1.897

Sitohang, S., & Denson Napitupulu, R. (2017). Fuzzy Logic Untuk Menentukan Penjualan Rumah Dengan Metode Mamdani (Studi Kasus: Pt Gracia Herald). *Jurnal ISD*, *2*(2), 91–101.

Sufarnap, E., & Sudarto, S. (2019). Penerapan Metode Fuzzy Mamdani dalam Penentuan Jumlah Produksi. *Seminar Nasional Sains dan Teknologi Informasi (SENSASI)*, *Juli*, 379–382. https://s.id/1SHDL

Suryadi, A., Putri, M. V., & Febrianti, E. L. (2022). Pengolahan Citra Digital Dan Logika Fuzzy Dalam Identifikasi Tingkat Kematangan Buah. *Journal of Science and Social Research*, *5*(2), 187. https://doi.org/10.54314/jssr.v5i2.863

Sutikno. (2018). Perbandingan Metode Defuzzifikasi Sistem Kendali Logika Fuzzy Model Mamdani Pada Motor Dc. *Indra Waspada Jurnal Masyarakat Informatika*, *2*(3), 27–38. https://media.neliti.com/media/publications/112322-ID-perbandingan-metode-defuzzifikasi-sistem.pdf

Syahfitri, A., Ibnutama, K., & Suherdi, D. (2023). Mendeteksi Tingkat Kesegaran Daging Sapi Menggunakan Metode Transformasi Ruang Warna HIS (Hue, Intensity, dan Saturation). *Jurnal Sistem Informasi Triguna Dharma (JURSI TGD)*, *2*(6), 923. https://doi.org/10.53513/jursi.v2i6.9040

Veronika Nugraheni Sri Lestari, Cindy Arivia, Nurmawati, N., & Dwi Cahyono. (2023). Pentingnya Customer Service Terhadap Permintaan dan persepsi Pelanggan Cafe Life Style Hotel Surabaya. *PaKMas: Jurnal Pengabdian Kepada Masyarakat*, *3*(1), 67–73. https://doi.org/10.54259/pakmas.v3i1.1640

Wicaksono Hadi, R., & Setiawan, I. (2011). Perancangan Alat Pendeteksi Kualitas Daging Sapi Berdasar Warna dan Bau Berbasis Mikrokontroler Atmega32 Menggunakan Logika Fuzzy. *Jurnal TRANSMISI*, *13*(1), 21–26. http://ejournal.undip.ac.id/index.php/transmisi