Fuzzy Logic

Assignment 1

Technical report

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MSc Intelligent Systems and Robotics

Instructor: Dr.Sarah Greenfield

Student: Ibrahim Ahmethan

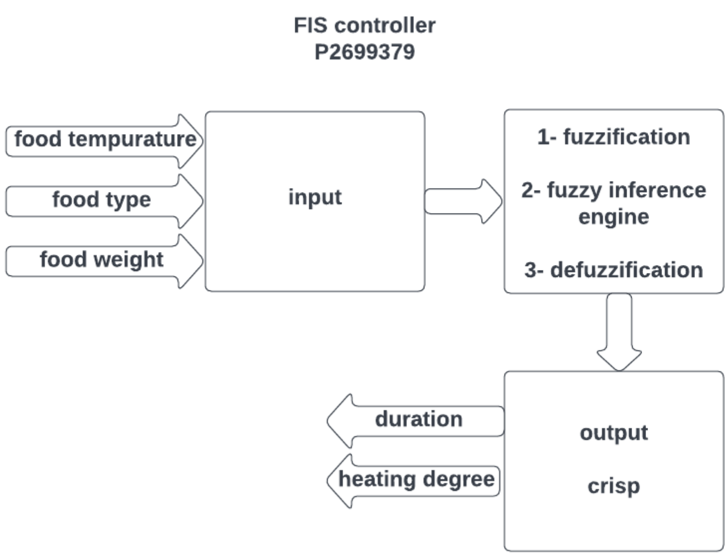
P2699379

Introduction

Fuzzy logic control is a type of control system that uses fuzzy logic, a mathematical method for dealing with uncertainty, to produce control decisions. Unlike traditional binary control systems, which operate on crisp (i.e., precise) input/output values, fuzzy logic controllers use linguistic variables and fuzzy sets to represent and manipulate the uncertainty in the system being controlled. The output of a fuzzy logic controller is a mapping from the linguistic inputs to a control action, which can be a continuous or discrete control signal. Fuzzy logic controllers have proven to be effective in a wide range of control applications due to their ability to handle imprecise or uncertain input data and their ability to provide a simple and interpretable control rule base[1].

Microwave ovens are one of the most frequently used home appliances, The amount and kind of food that are placed in the oven determine the time and temperature at which each food item should be cooked. Traditionally, the cooking parameters such as cooking time and temperature in a microwave oven are determined by the user, hence the cooking parameters are adjusted manually by the user's experience.

This report demonstrates the application of fuzzy inference systems (FIS) built to automate and regulate the proper oven parameters required to reheat or cook foods and liquids. The report explains how the Mamdani controller is utilized to apply the proposed FIS by turning fuzzy linguistic statements into crisp outputs. The proposed FIS controller has three inputs and two outputs, the inputs are food weight, initial food temperature and type of food (liquid/ semi-liquid / solid), meanwhile, the FIS controller has two outputs, duration and heating temperature. The duration is responsible for long the food will be heated, on the other hand, the heating temperature adjusts the proper temperature while cooking. The three inputs play an important and crucial role to determine the values of the outputs. Therefore, the aim of this assignment is to design a fuzzy controller for microwave ovens to automate the process of cooking or heating without the need for human commands or instructions.



Flowchart of the proposed FIS controller

Methodology and design

The design of a fuzzy controller started with identifying crisp input variables, In this study the three inputs of FIS as follows, the category of food, the weight of food and the temperature of food. The input parameters were determined and defined after a long discussion with my mom since she is a housewife and experienced in working with ovens. User experience and translating linguistic terms to machine-understandable language were essential to design such the proposed rule-based controller. The Mamdani fuzzy inference systems were utilized to design the controller. The implementation of the proposed controller included 6 steps: steps as the following [1].

1- **Step 1:** Determining the set of fuzzy rules, since the proposed FIS controller has 3 inputs, the combination of the three inputs resulted in 27 different rules. The antecedents (input parameters) of the rules are connected with AND operator. The following example shows some samples of the rules.

   - If (Food_Temp is very_cold) and (physics_of_food is liquid) and (wight_of_food is light) then (duration_(Min) is short)(heat_degree_(Celsius) is medium_heat) (1)

   - If (Food_Temp is cold) and (physics_of_food is liquid) and (wight_of_food is light) then (duration_(Min) is medium)(heat_degree_(Celsius) is low_heat) (1)

   - If (Food_Temp is normal) and (physics_of_food is liquid) and (wight_of_food is light) then (duration_(Min) is short)(heat_degree_(Celsius) is low_heat) (1)

   Notice that the antecedent is used to determine the degree of truth or relevance of the fuzzy rule based on the current input values, furthermore, since the proposed design has 2 outputs, the duration and heat degree, it is obvious in the above rules that the antecedent plays crucial rule to determine the values of the outputs [2].

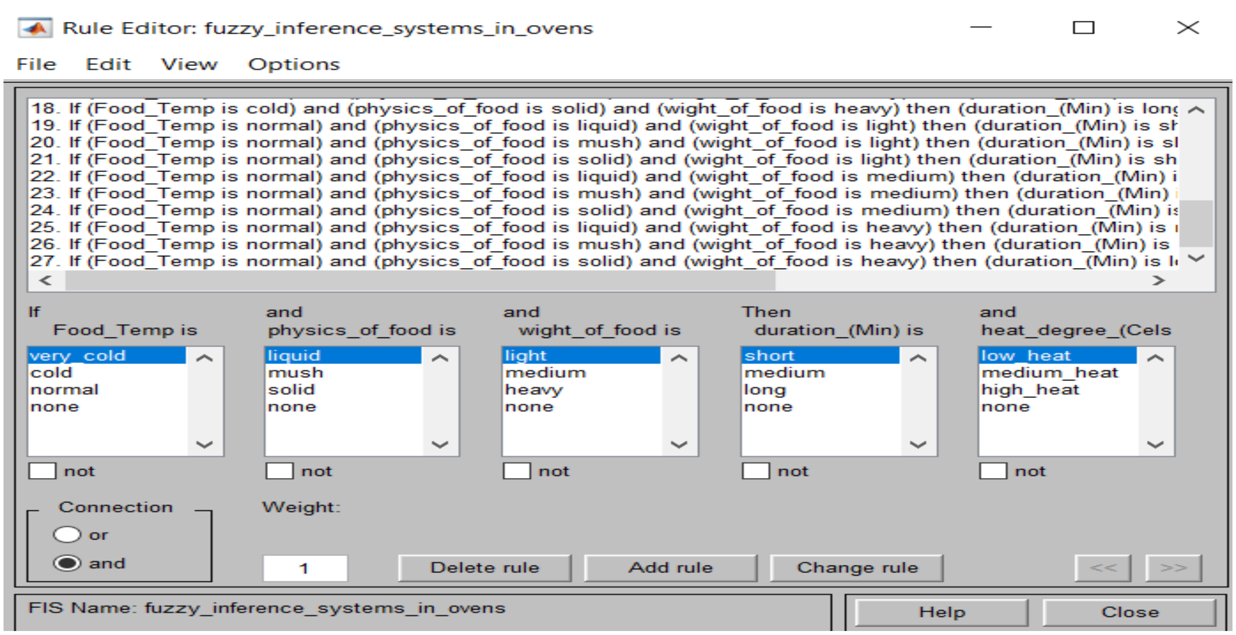


Figure 1. Reasoning process of FIS

2- **Step 2:** Fuzzification, where the input variables are converted into fuzzy sets using membership functions. Depending on the type of input, each input has a different range of fuzzy sets. The shape of the membership function is triangular for all the inputs [3]. the following table shows the linguistic terms and ranges of fuzzy membership functions for each input.

- **Inputs of FIS controller**

Inputs	**Linguistic term**	**Range of membership function**
Food temperature In Celsius (C°)	Very cold Cold Normal	[0 - 34] C°
Physical property of food	Liquid Semi liquid solid	[0 - 110]
Wight of food In gram (g)	Light Medium Heavy	[0 - 1200] gm

the above table summarizes the input type and the range of corresponding membership functions, in the following section, the membership functions and their graphs are shown.

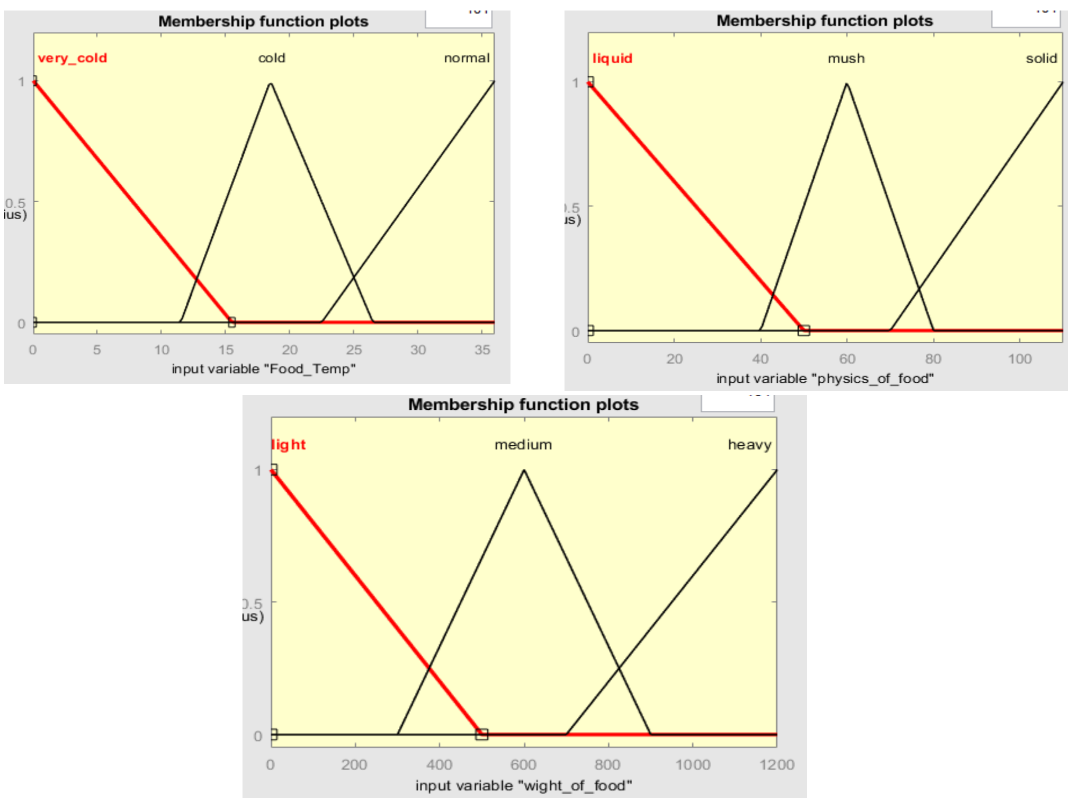


Figure 2. Inputs membership function of the proposed FIS

- **Outputs of FIS controller**

Outputs	Membership function	Range of membership function
Duration In (min)	Short Medium long	[0 - 16] min
Temperature In Celsius (C°)	Low heat Medium heat High heat	[0 - 200] C°

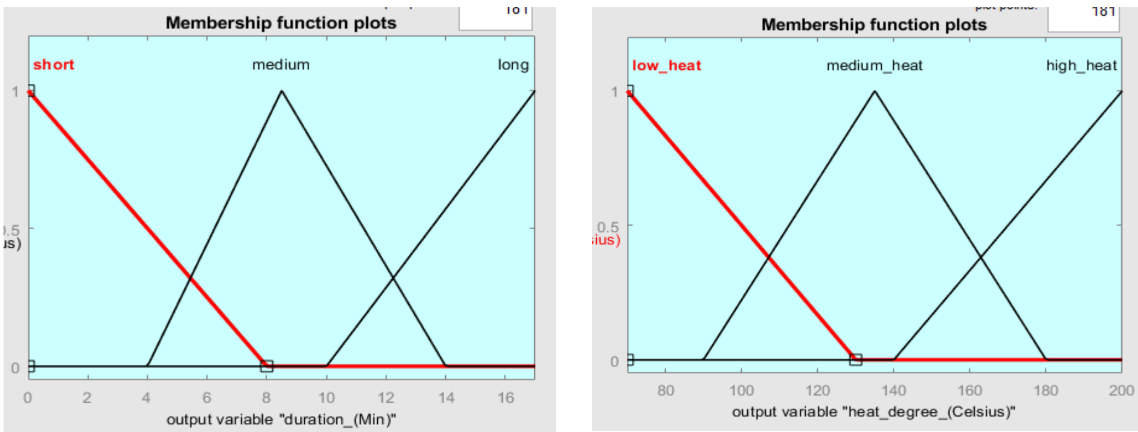


Figure 3. Outputs membership functions of the proposed FIS

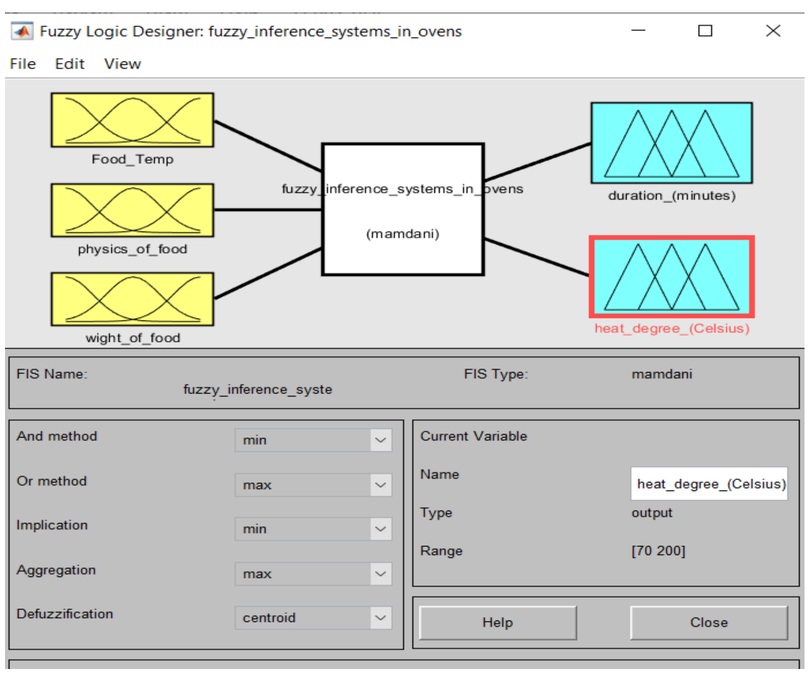


Figure 4. Overview of the proposed Mamdani FIS

3- **Step 3:** Fuzzy operation, establishing a rule strength by combining the fuzzified inputs in accordance with the fuzzy rules, the fuzzy operation method implemented is AND operator, furthermore, the AND corresponds to the Min operator. The following example demonstrates the fuzzy operation with AND method.

If (Food_Temp is cold) **and** (physics_of_food is liquid) **and** (wight_of_food is light) then (duration_(Min) is medium) (heat_degree_(Celsius) is low_heat) (1)

Input 1: Food_Temp is cold
Input 2: physics_of_food is liquid
Input 3: wight_of_food is light

Output 1: duration_(Min) is medium
Output 2: heat_degree_(Celsius) is low_heat

Therefore, the fuzzy operation can be summarized as the following.

- Input 1 **and** Input 2 **and** Input 3 **then** Output 1 Output 2

4- **Step 4:** Implication, in fuzzy inference systems, implication refers to the process of determining the degree of truth of the consequent (output) of a fuzzy rule, based on the degree of truth of the antecedent (input). This process is also known as "fuzzy implication" or "fuzzy inference." The implication operator is used to calculate the degree of truth of the consequent, given the degree of truth of the antecedent and the fuzzy rule. In this FIS the implication operator used is the "minimum" operator, which produces the minimum value of the antecedent and the rule's implication function [4].

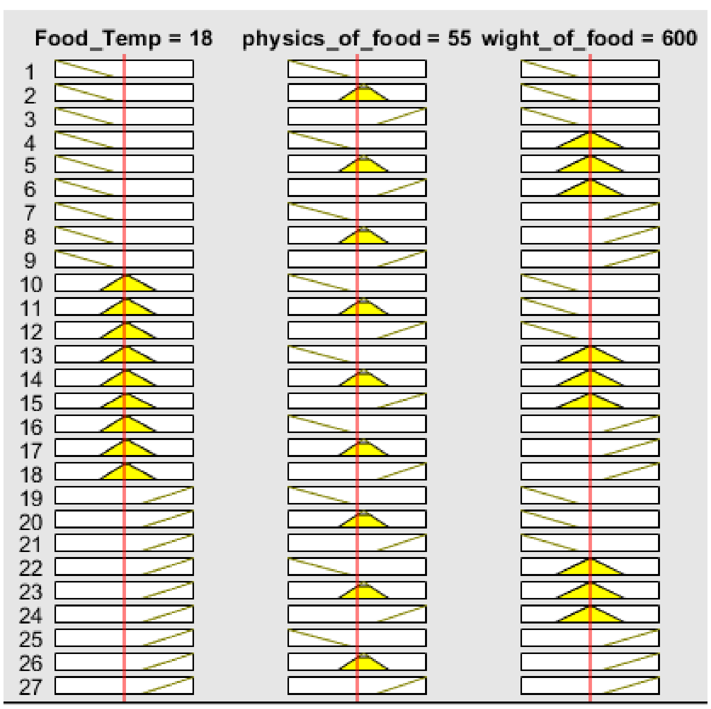


Figure 5. Min operator implication

5- **Step 5**: Aggregation, in fuzzy logic, aggregation refers to the process of combining multiple fuzzy sets or fuzzy rules to form a single fuzzy set or rule. This process is also known as "fuzzy integration" or "fuzzy combination"[5].

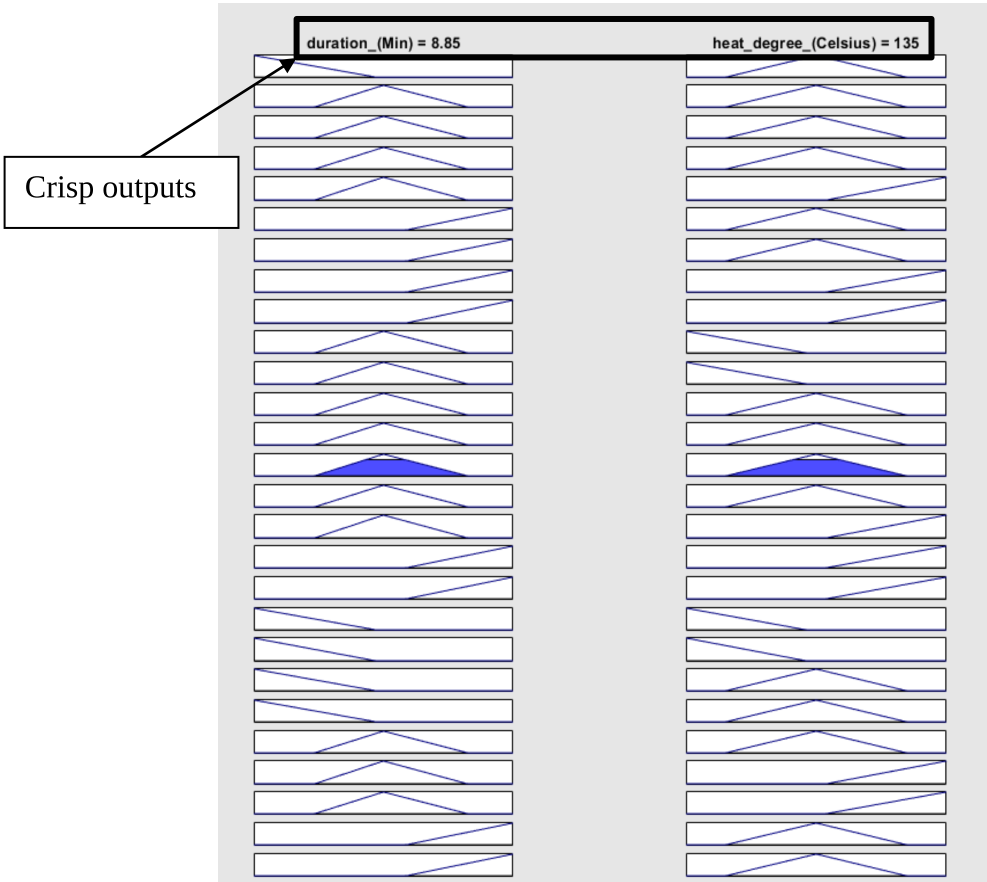


Figure 6. Max operator aggregation

6- **Step 6:** Defuzzification, this step is the process of converting a fuzzy set, which is a set of values that have different degrees of membership in a certain category or group, into a crisp value that belongs to that category or group. The defuzzification is done by using a technique called the center of gravity method(centroid), which calculates the weighted average of the values in the fuzzy set based on their degree of membership. The result of defuzzification is a single, clear (crisp) value that represents the most likely or representative value of the fuzzy set [6]. Figure 4 demonstrates the crisp output values of the proposed FIS.

All types of membership functions, operators and defuzzification methods are assigned and utilized after carefully reviewing the recent studies in oven FIS controllers and analyzing the microwave oven manufacturer's cooking advice and instructions [7][8][9], furthermore, different operators and defuzzification approaches implemented (demonstrated in the appendix section), the obtained results did not satisfy the desired outputs.

Experimental results

In this assignment, MATLAB programming language is used to build and test the proposed controller, furthermore, the fuzzy toolbox is utilized to implement the Mamdani FIS considering the controller design. The graphical and surface representation of the result from the MATLAB software's inference system for determining microwave oven cooking time and proper temperature alongside the cooking factors is shown in the following figure.

Figure 7. Inputs and Outputs of the proposed Mamdani FIS

In the sample example above figure 7, the food temperature is 18 C°, which indicated that the food is colder than the room temperature, the physical property of the food is 57.9, according to the range of member function for the physical property, the food is considered to be semi-liquid in this case. Furthermore, the weight of the food is 600 grams (0.6 kg), this amount of food (600 g) is roughly enough to feed 3 adults, which means that the amount is considerably high to be consumed by an adult. According to the previous inputs and after the defuzzification process, the suggested duration by the proposed FIS is 8.84 which approximately corresponds to 8 minutes and 40 seconds (8:40 min), while the suggested heating degree is 135 C°. The outcomes of suggested output duration and heating degree by taking into account the values of the inputs were shared and discussed with the expert (my mom), as a result, the suggested crisp outputs are examined and concluded that the proposed FIS controller succeeded to achieve results near to the expected results by the expert. Further testing with different input values and defuzzification methods is represented in the appendix section of this report.

Conclusion

The FIS controller proposed a successful fuzzy model based on rules to control the heating time and temperature of a microwave oven for different kinds of foods, taking into account three input factors, which are the initial food temperature, the physical property of food and the weight of food. Furthermore, research showed that incorporating fuzzy logic in microwave ovens to calculate cooking time results in reduced cooking time and energy consumption, as well as preservation of food quality. Despite the presence of many advanced microwave oven technologies, our proposed model could achieve higher accuracy if further developed and improved by incorporating advanced rules and methods to automate the cooking process. According to user experience and literature review, it's clear that the three factors considered are the most crucial and have a significant impact on the oven cooking or heating process.

Appendix

- **The parameters of desired FIS controller with its values**

parameter	method
Implication	min
Aggregation	max
Defuzzification	centroid
Membership function	triangular
Total number of rules	27 (all possible input combinations)

- **Different output results for different inputs of the desired FIS controller**

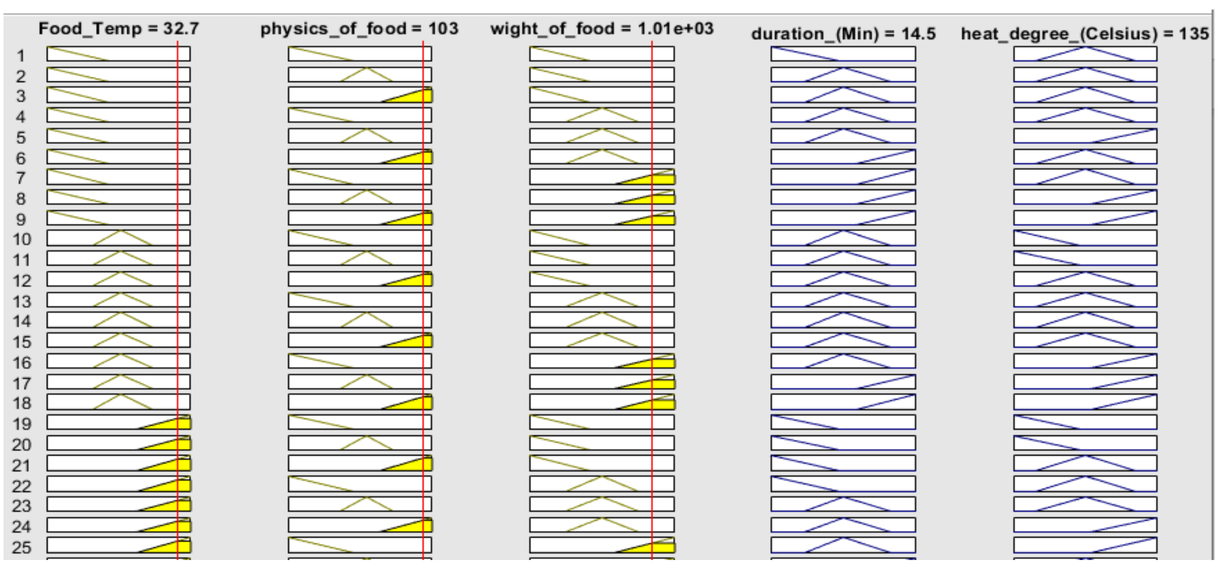


Figure 8. FIS (a)

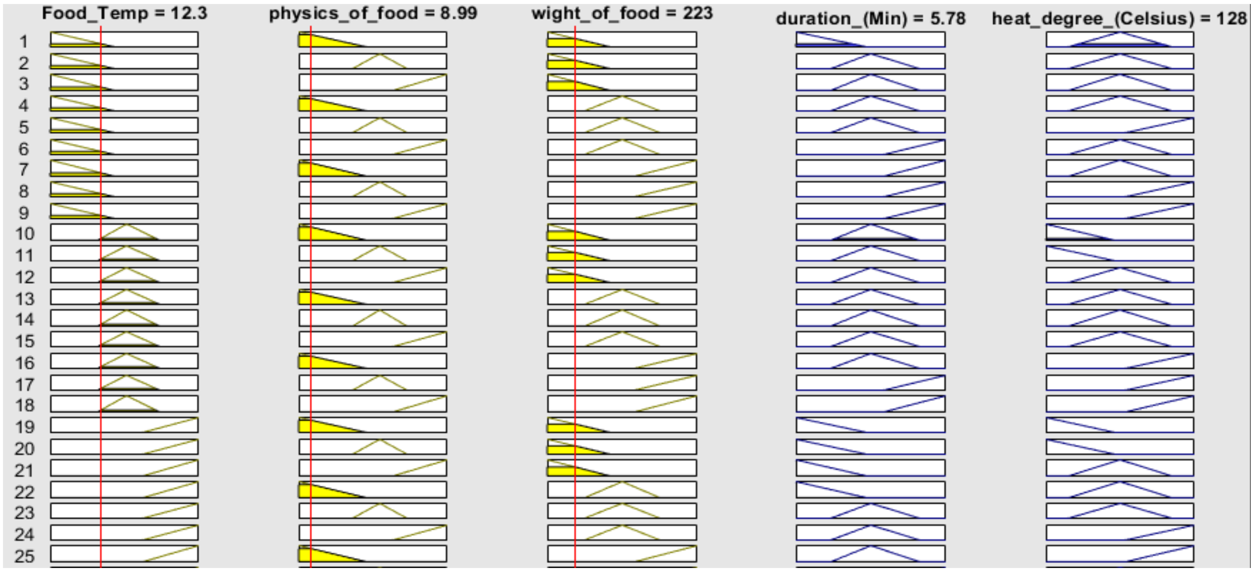


Figure 8. FIS (b)

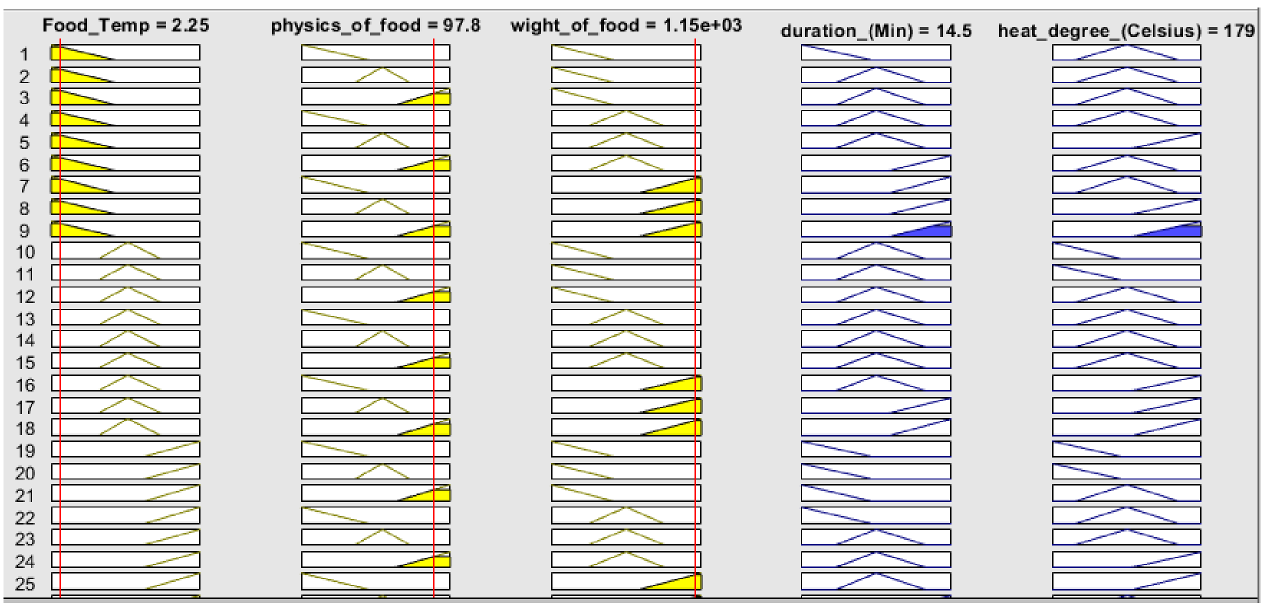


Figure 8. FIS (c)

	Food temperature C°	Physical properties of food	Weight of food	Duration	Heat degree
Figure 8 FIS (a)	32.7 C°	103 (solid)	1.01 kg	14.3 min	135 C°
Figure 8 FIS (b)	12.3 C°	8.9 (liquid)	0.223 kg	5.20 min	128 C°
Figure 8 FIS (c)	2.25 C°	97.8 (solid)	1.15 kg	14.25 min	179 C°

As shown in the table above, different values of inputs resulted in different duration and heat degrees, for instance, figure (a) and figure (c) both almost have the same weight and physical properties, however, the temperature in figure (c) is considerably colder than the one in figure (a), therefore, although figure (a) and (c) have the same duration time, the heat degree of figure (c) is much higher than the heat degree of the figure (a) since figure (b) is colder than (a), hence higher temperature rate must be applied to be able to cook the food placed in properly. Furthermore, it is worth noting that in figure (b) the physical property is liquid and the weight is 0.223 kg, therefore the suggested duration and heat degree are much lower than the ones in Figures (a) and (b). it is clear that the system's suggestions make complete sense since we all are dealing or had to deal with microwave ovens at some point in our life.

- **The following figures show the surface graph of the proposed FIS**

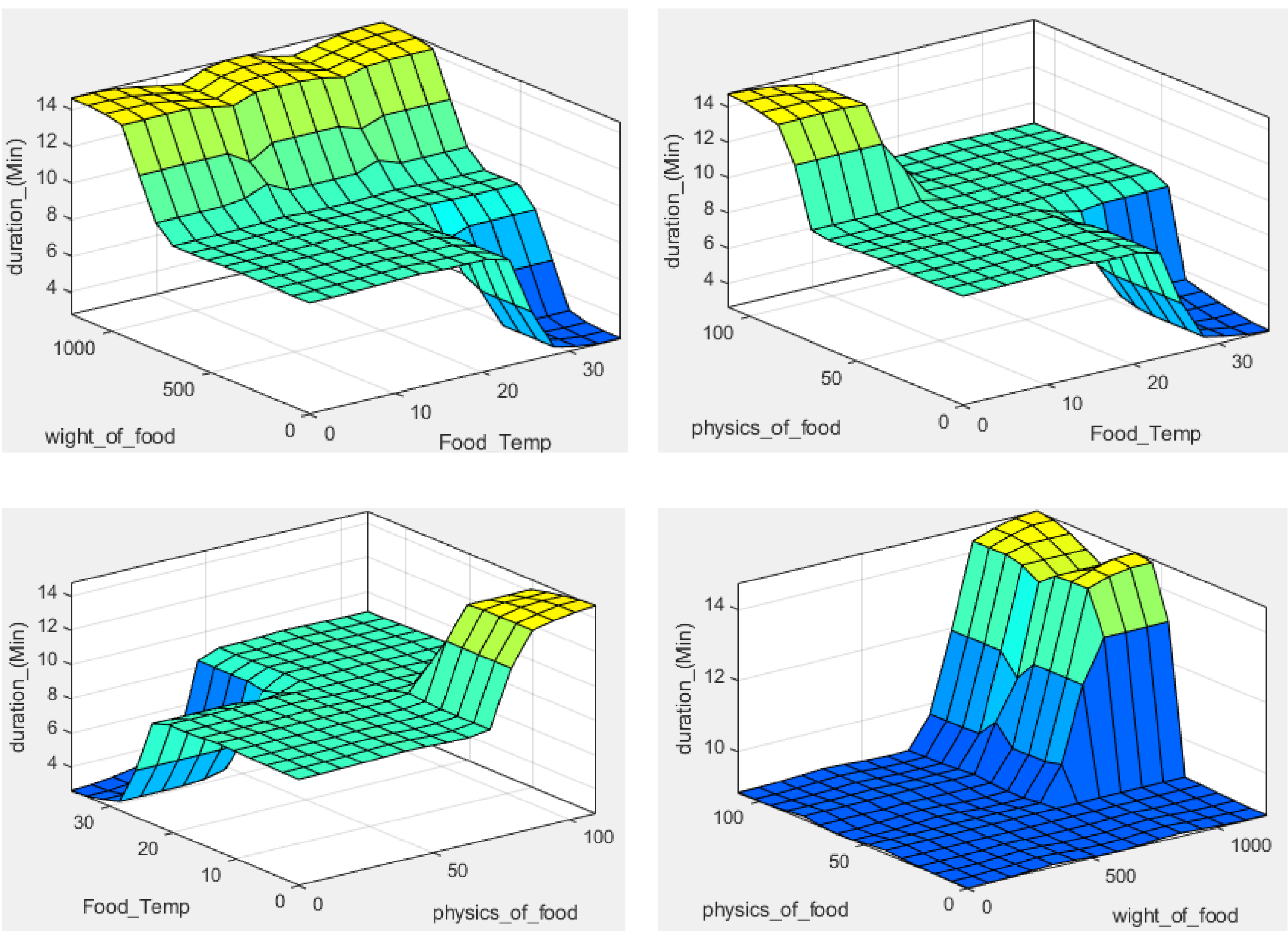


Figure 9. Surface view of the proposed FIS model

- **Different defuzzification method**

Various defuzzification methods are tested for the previous model in figure 8 (b)

Figure 8 FIS (c)	2.25 C°	97.8 (solid)	1.15 kg	14.25 min	179 C°

Sample: figure 9 (b)	**Centroid**	**Bisector**	**Lom**	**Som**	**Mom**
duration	14.25 min	14.5 min	17 min	15 min	16 min
Heat degree	179 C°	179 C°	200 C°	182 C°	191 C°

As shown in the table above, different types of defuzzification methods are implemented to the sample of figure 8 (b). it is obvious that the centroid and bisector defuzzification methods almost have the same outcomes, where the Lom and Mom defuzzification methods resulted in much higher suggested temperature and longer duration comparing to the centroid and bisector. Therefore, the centroid method is more guaranteed approach to be the safest choice in terms of avoid burning or over cooking the food.

References

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