Fuzzy calculator for healthy amount of calories for adults

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Contents

Abstract

Nowadays weight control is an issue for many individuals. An appropriate amount of calories specific to an individual's lifestyle is necessary for a healthy life. There are two antithetic situation when the intake of calories has drastic impacts over people. While some people do not take into account how many calories they have per day and their weight is above normal limits, other people have drastic diets and reduce the calories intake extremely for achieving a desired weight. Both these situations have serious effects: from a poor health condition to organs failure. Since humans have particularities and our bodies do not respond identically in similar conditions, there is no perfect recipe for a healthy life. Using a fuzzy inference system, this paper aims to present a fuzzy calculator of the necessary amount of calories for a healthy life of an individual. For this, particularities such as weight, height (covered by the body mass index), age and lifestyle will be taken into account.

1 Introductive notions

1.1 Risks

According to Young and Benton [1] obesity is one of the human's greatest issue. Among multiple conditions (e.g. gout, breathing issues, some types of cancer, diabetes etc.), it prones the individual to lower life expectations. Considering the evolution of this issue, it is expected that by 2025 18% of the male and 21% of the female world population will suffer from this disease [1].

Having roots in a desperate need of losing weight, a psychological issue developed among individuals, called Anorexia [15]. Individuals suffering from this condition do not eat, damaging their health condition until death.

Any lack of balance between body needs and calories intake leads to multiple issues and a proper alimentation is highly necessary.

1.2 Calories

Calories are units of measurement for energy. The human body consumes calories from food and beverages. No matter what weight goal an individual has, one important factor is the caloric intake. However, the amount of necessary calories is not straightforward to choose. Doinea explains in his paper [7] that simply dropping the amount of calories intake per day is not a solution for weight control. This drastic measure will only decrease the metabolic rate, which means that the body will need less calories and will be prone to create deposits and increase weight when returning to a normal calorie intake.

Also, it has been proven [1] that diets consisting in drastic reduction of calorie intake are highly inefficient. Even if on short term the results might look optimistic, the body will tend to go back to the initial weight immediately after ending the diet. The body will respond well for long term if calories are only reduced to the proper amount for the body. A diet should always take this fact into account and appropriate amount of calories must be initially determined.

1.3 Body mass index

The body mass index (BMI) is a measurement used to establish a ratio between weight and height of a person. Considering the established ranges for BMI value, this measurement is used to identify the appropriate weight for specific height of a person. BMI is calculated depending on the measurement unit, using the following formulas: [2]

$$bmi = \frac{width(kg)}{height^2(m^2)}$$

$$bmi = 703 \cdot \frac{width(lbs)}{height^2(in^2)}$$

According to the World Health Organization [2], the BMI range consists of: Very severely underweight, Severely underweight, Underweight, Normal, Overweight, and Obese of class I, II, III. A simplified representation of these categories is presented in [5] and can be observed in table 1.

Category	BMI range (km/m^2)
Underweight	< 18.5
Normal (healthy weight)	$18.5 - 25$
Overweight	$25 - 30$
Obese	> 30

Table 1: BMI range for adults

1.4 Determining necessary caloric intake

According to [5] and [1], for the same value of the BMI, the amount of body fat will be different for non-athletes and athletes. Athletes will have more muscular mass at the same height and weight than non-athletes. The first ones will need an increased amount of calories to preserve their muscular condition while the second ones will need less calories for not gaining weight. Same thing is happening as the age increases. Old people will have more body fat than middle-aged people.

Even if a specified range of the BMI can indicate an overweight condition and we would logically consider that the amount of calories should be reduced, there is an exception. Athletes can have a really high BMI under some circumstance because a really developed muscular mass. In this case, for supporting their condition, a high amount of calories will be necessary [5].

Age, activity level and BMI determined by weight and height are considered by many specialists [3] some of the most important factors that determine the caloric need.

1.5 Fuzzy inference systems

A fuzzy set represents a class of objects which are characterized by a value called degree of membership. The degree of membership is a value between 0 and 1 obtained by applying a membership function over the element [16].

A fuzzy inference system is determined by the following elements:

- The initial fuzzy sets used to shape the problems.

  E.g.: Consider the following sets: $I_{11}, I_{12}, I_{21}, I_{22}, O_1, O_2$.

- The rules used over the fuzzy sets.

  E.g.: If x is I_{11} and y is I_{12} then z is O_1.

  If x is I_{21} and y is I_{22} then z is O_2

- The inferencing system which is determined by:
  - The fuzzy composition, i.e. the ways in which the initial rules are combined for obtaining new ones. E.g. The Mamdani model (given fuzzy sets as inputs it generates fuzzy sets as output), the Takagi-Sugeno model (it generates crisp decisions given fuzzy sets as inputs).
  - The defuzzification method, i.e. transforming the fuzzy solution in a crisp solution.

Given two fuzzy sets as inputs the composition can return as output a fuzzy set or a crisp decision. In practice, crisp decisions will be required for fuzzy inputs. It is necessary to have a method to convert a fuzzy decision result into a crisp decision. This method is called defuzzification. The goal of defuzzification is to transform a fuzzy set in a single number.

The Fuzzy Inference System used in this paper will be described in the following chapters and implemented using Matlab in section 3.

2 Objectives

This paper aims to tackle the problem of calculating the healthy amount of calories for daily intake. To achieve this, the paper will present a fuzzy inference system providing the solution. Based on a set of inputs (i.e. age, activity and BMI) which influence the necessary calories intake, the system will predict the ideal amount of calories necessary during one day for a healthy life. Considering this goal, the following objectives are planned:

- Determine the MF for the input variables;

- Determine the MF for the output variable;

- Establish appropriate rules for computation (find proper correlation between variables);
- Identify the best structure of the FIS (types of MF, defuzzification method).

3 Fuzzy systems in Matlab

The calories calculator presented in this paper is designed using Matlab software, particularly Fuzzy logic toolbox from this software. This toolbox provides all necessary tools, i.e. functions, commands, graphical views, which are necessary to build a fuzzy system. The toolbox allows the user to design the rules in simple and clear ways.

A Mamdani Fuzzy Inference System (FIS) was created using a set of commands. All the commands used to implement the fuzzy inference system from this paper are listed in the table 2 and described below.

Nr.	Command
1	fis = newfis('name_of_fis','fis_type','and','or','implication','aggregation','defuzzification')
2	fis = addvar(fis, 'type_of_variable', 'name_of_variable', range) e.g.: fis = addvar(fis, 'input', 'bmi', [13 50])
3	fis = addmf(fis, 'type_of_variable', index_of_variable, 'name_of_mf', 'type_of_mf', parameters) e.g.: fis = addmf(fis, 'input', 1, 'underwright', 'trapmf', [13 13 17.5 18.5])
4	addrule(fis, rulelist)
5	showrule(fis)
6	plotmf(fis,'type_of_mf',index_of_mf)
7	subplot(m,n,p)
8	evalfis(input_data,fis)
9	gensurf(fis, inputs, output)

Table 2: Fuzzy logic toolbox commands

Commands description:

- Command 1 creates a new fuzzy inference system. It can have only the fis name specified and it will have the default type of a Mamdani-style FIS. Other parameters can be specified after the name, in the following order: FIS type, AND method (default is min), OR method (default is max), implication (default is min), aggregation (default is max) and defuzzification (default is centroid) methods. If not specified, all parameters will have the default value.
- Command 2 adds a variable to the fis system. It requires four arguments: the fuzzy inference system previously created, the type of the variable (i.e. input or output), the name of the variable and the range, which is a vector describing the interval of the variable (e.g. [a b]).
- Command 3 adds a membership function to an already created variable. It requires the following parameters: the fis, the type of variable (input or output), the index of the variable, the name and the type of the membership function (e.g. trapmf, trimf, etc.), a vector with parameters specific to the selected membership function (e.g. for trapmf four parameters are necessary such as [a b c d]).
- Command 4 adds a rule / a set of rules to the inference system. It requires two arguments, the fis and the list of rules. The rules of list has a specific format, i.e. list = [item1; item2; ...]. Each item has the following structure $item = [i_1, i_2, ..., i_m, o_1, ..., o_n, a, b]$ where:
  - m and n are the number of input and output variables;
  - the first m+n components are the index of the membership functions for the i^{th} input or o^{th} output variables, $i \in \{1, .., m\}$, $o \in \{1, ..., n\}$;
  - a is the weight for the rules;
  - b is the rule type (i.e for AND b = 1, while for OR b = 2);
- Command 5 prints the rules set for the system.
- Command 6 plots a graphic of the membership function for a specified variable. It takes three arguments as it follows: the fis variable, the type of the membership function (i.e. output or input) and the index of the membership function.

- Command 7 splits the graphical view in an m x n matrix and put the current plot in the p^{th} tile.
- Command 8 performs the calculations for the fuzzy inference. It will simulate the system for the input data and fis set as parameters. The input data is a n x m matrix where m is the number of input variables and n is the amount of samples. The command will return and n x t matrix where t is the number of output variables.
- Command 9 plots the 3D surface of the output variable using the input variables (e.g. input = [1 2]). It can also plot a 2D surface for observing how one input variable impacts the output (e.g. input = [1]).

The membership functions used are implemented in this toolbox and described in appendix A.

For a Mamdani FIS, matlab provides five options to defuzzify the output: centroid, bisector, middle / largest / smallest of maximum [12] which will be separately evaluated in the Results section.

4 Fuzzy system design

For this study, three input variables were selected, i.e. activity level, age and BMI. Because the BMI already extracts the important information regarding height and weight, it is preferred to use a single variable, the BMI and avoid unnecessarily usage of two variables. Gender, basal metabolic rate and other health particularities can influence the amount of daily necessary calories, but this paper will focus on the three variables mentioned as inputs.

The output variable will be represented by the level of calories intake per day necessary for a healthy condition.

Table 3 presents the membership functions for each variable.

Variable	BMI	Activity level	Age	Calories level
Type	Input	Input	Input	Output
Membership Functions	Underweight Normal Overweight Obese	Sedentary Light Moderate Active Very Active	Young Middle age Old	Very low Low Medium High Very High

Table 3: Membership functions

In the following sub-chapters it will be presented a short description of the variables and the correlation between each input variable separately, with the value of the output variable (i.e. the correlation between bmi, activity level and age with the calories level). Trapezoidal membership functions were initially chosen for each variable. Other membership functions will be discussed later in this paper for establishing the best one for the goal.

4.1 BMI

The BMI variable is the rapport between weight and height as described in section 1.3. The categories of the membership function used in this system are equivalent to the status of each category specified in the table 1.

Individuals with a small value of the BMI will not need to lose weight since they already have a small amount of body fat. They will need to increase the amount of calories to preserve their health, and increase their BMI to a healthy value. A high BMI might indicate a high amount of body fat. In this case, it means that the amount of calories could be dropped for getting rid of the fat tissue. Medium BMI means a balanced ratio between weight and height, it could mean that the calories intake should be preserved at a medium value according the body particularities.

The range for the BMI value will start from 13, which is a value of extreme anorexia [15]. The end of the rage will be the value of 50 which represents an extreme obesity. The trapezoidal membership function is presented in the table 4 and figure 1.

MF	a	b	c	d
Underweight	13	13	17.5	18.5
Normal	18	19	23	25
Overweight	24	26.5	28	30
Obese	28	35	50	50

Table 4: Trapezoidal MF - BMI

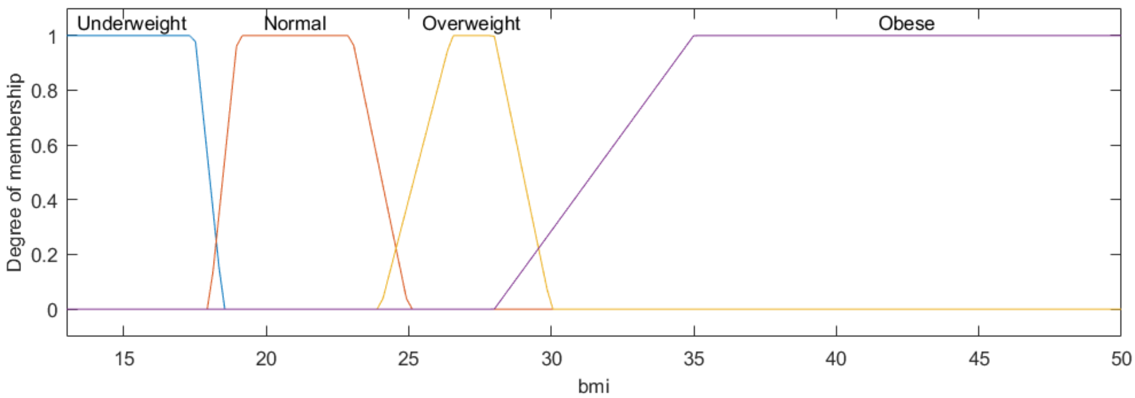

Figure 1: MF - BMI

4.2 Activity Level

The activity level variable indicates how active is an individual during an average week. The activity level will be set using five categories according to other available calorie calculators [9] [4] : sedentary, light (slightly active), moderate, active, very active.

Depending on the lifestyle, a person can perform physical activities multiple times during a week or not at all. A very active lifestyle refers to people who engage in different sportive activities, who have a job in this area such as athletes or simply enjoy having daily long runs and performs intense or very intense exercises 6-7 times/week. An active person performs exercises daily or an equivalent of intense exercises 4 time/week. A moderate activity level includes persons performing simple exercises 4-5 times/week, it will describe persons who either have a medium level of physical effort imposed by the job, either try to exercise a little every day. Regarding more sedentary lifestyles, a light (or lightly active person) performs simple exercises 1-3 times/week, while a completely sedentary person performs no exercises or up to once a week. This category includes persons who spend most of their day in the office, in their chair and do not exercise in their spare time.

Simple exercises refers to 15-30 minutes of physical activity which elevates the heart rate. It includes long walks (even home-work path), climbing stairs and anything else involving physical effort. Intense or very intense exercises refers to 45-120 minutes of physical effort or even more.

People with a very active lifestyle will require a bigger amount of calories than people with a sedentary lifestyle. The energy they consume during physical activities must be balanced by the caloric intake. The lower the level of activity is, the lower should be the caloric intake.

For the activity level, a range from 0 to 10 is used for correlating the number of times per week when a person engages in any physical activity. 0 represents a person with a sedentary level of activity, while 10 represents a very active person. The values for the membership function are represented in table 5 and figure 2.

MF	a	b	c	d
Sedentary	0	0	1	1.5
Light	1	2	2.5	3.2
Moderate	3	4	5	5.2
Active	5	6	7	7.2
Very Active	7.1	8	10	10

Table 5: Trapezoidal MF - Activity level

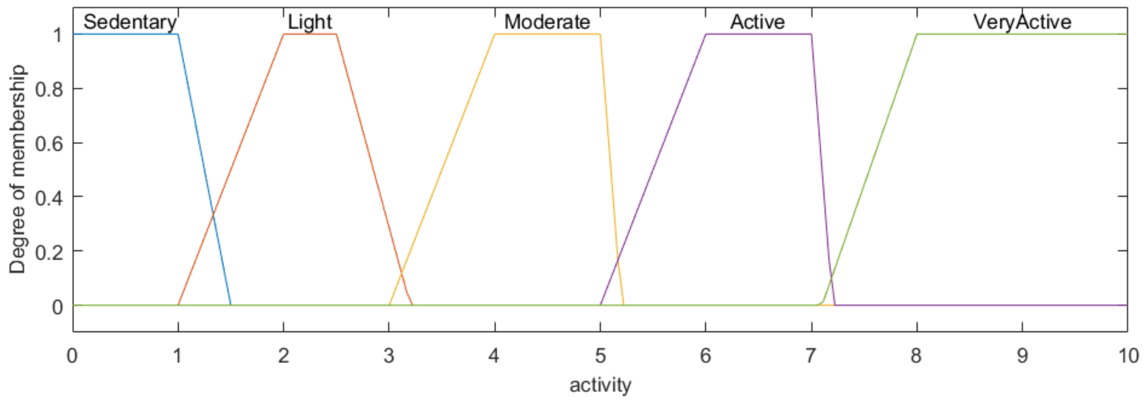

Figure 2: MF - Activity

4.3 Age

The age variable represents the actual age of the person. According to [14], early or young adulthood begins at the age of 20, this being considered the end of adolescence. Middle-aged persons are those having between 40 and 60 years, while old adulthood is any age above 60. The margins of these age intervals are also subject to physical development of the individual. According to these intervals, the values for the membership function are represented in table 6 and figure 3.

Young people consume more energy and need more calories than older people. For young people, the body needs more nutrients. Old people develop age related problems (e.g. kidney issues) which determines lower nutrients absorption and less calories to be necessary [11].

MF	a	b	c	d
Young adult	18	20	30	40
Middle-age	35	40	50	65
Old	60	85	120	120

Table 6: Trapezoidal MF - Age

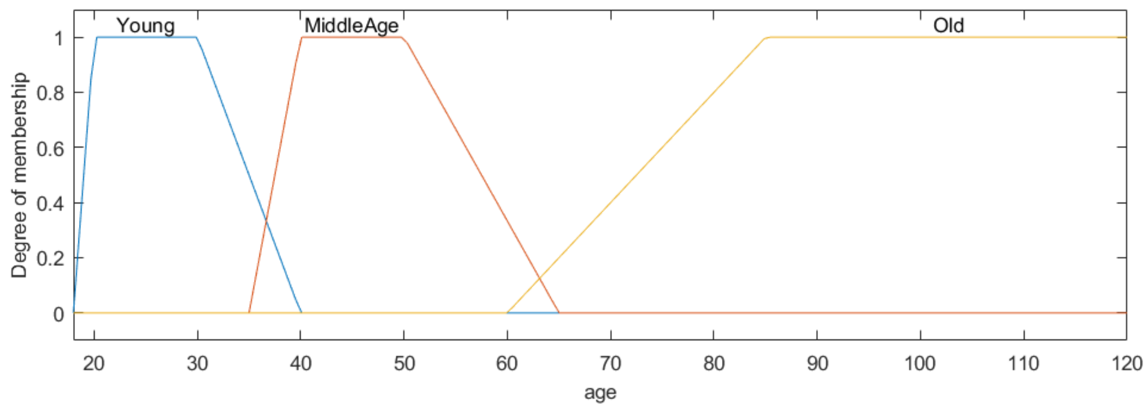

Figure 3: MF - Age

4.4 Calories Level

The calories level (or simply calories) output variable represents the amount of calories needed by an individual with respect to the particularities of the input variables. The rage for this variable will be from 1000 to 3000 calories.

According to the Institute of medicine [11] the average amount of calories necessary for a child starts from 1000. With age, the amount of calories increases, such as 1800-2200 for individuals aged 18 years. Between ages of 19 and 30 years, the average amount of calories is between 2000-2400. After the age of 31, the value decreases, 1800-2200 calories being necessary on average until the age of 50. After this age, because the sendarity increases and the energy required by the body is very low, the average amount of calories drops to a necessary amount of 1600-2000. In this regard, table 7 and figure 4 presents the values for the membership function.

MF	a	b	c	d
Very low	1000	1100	1300	1700
Low	1600	1850	1950	2000
Medium	1800	2050	2150	2200
High	2150	2300	2500	2700
Very High	2600	2750	3000	3000

Table 7: Trapezoidal MF - Calories

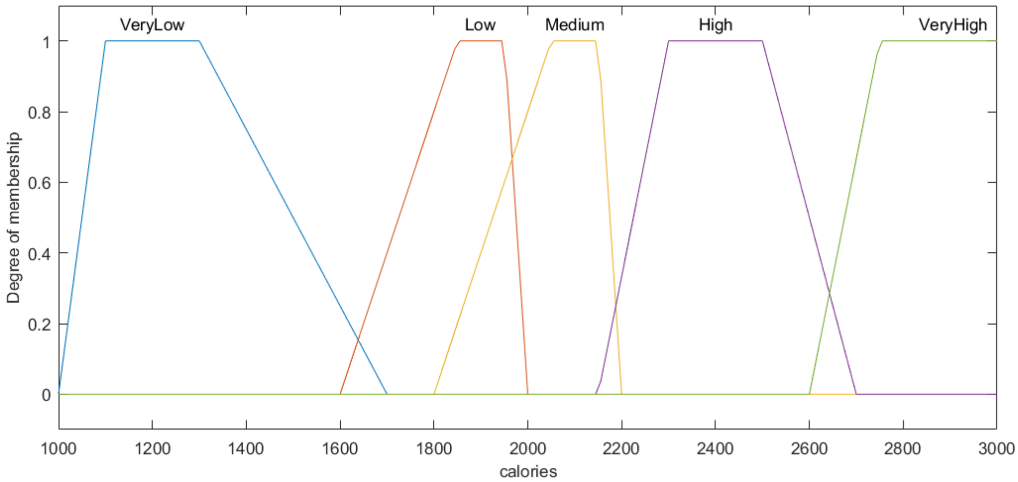

Figure 4: MF - Calories

5 Rules

According to section 1.4, a series of correlations between each two used variables were identified. Also, section 4 presents the connection between each input variable and the output variable. The rules were designed according to these correlations.

In this regard, section 4.4 presents the following correlations: young adults needs mainly a medium or high amount of calories, while middle aged people need a medium amount of calories and old people a low amount of calories.

The level of activity influences the amount of necessary calories as it follows:

- A sedentary lifestyle will determine a lower category of the calories level;
- A light and moderate level of activity should not change the calories level;
- An active level of activity could increase the calories level;
- A very active level of activity will increase the category of calories.

A normal BMI will not influence the standard value of the calories level identified using the age and activity level as parameters. However, all the other values of the BMI can change with one level the category of the calories amount as it follows:

- Underweight category can increase by one the category of the calories level for people with a very active or active lifestyle;
- Overweight category imposes a lower category of calories level for people having sedentary, light or medium level of activity but not for those having a active/very active level of activity, because the BMI value could be just determined by the muscular mass..
- Obesity indicates that the amount of calories must be dropped. For sedentary, light or medium level of activity it might be dropped with up to two levels.

6 Results

Initially the FIS was tested using the default Matlab configuration (i.e. Mamdani type, min for AND, max for OR, centroid defuzzification method, min for implication and max for aggregation) and trapezoidal membership functions for all the variables. The system was graphically analysed, then evaluated on a dataset of inputs. Results were compared for different membership function and defuzzification methods. The rules were adjusted according to results and the best structure for the system was chosen for the final version.

6.1 Surfaces

The surface plots were used to observe how each input variable influences the output results. Initially, a 2D surface was created specifying a single input variable.

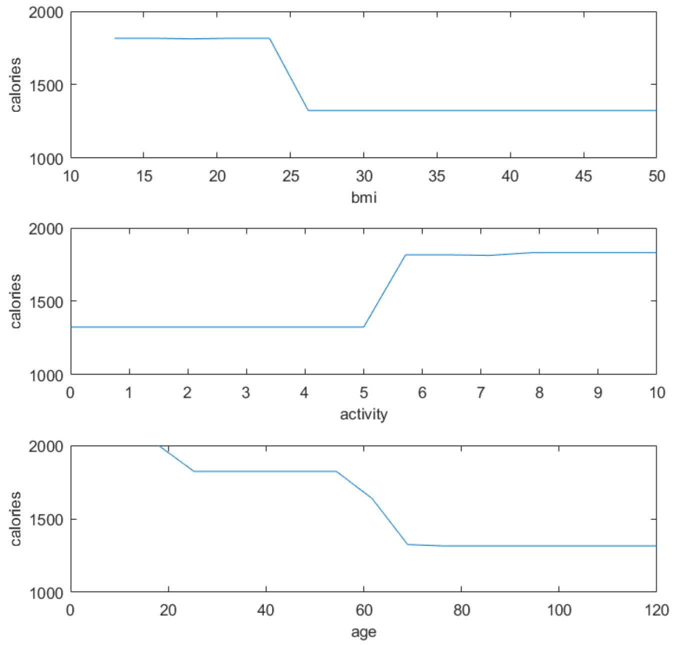

Figure 5: 2D Surfaces

According to the graphical view, it is noticeable that:

- The necessary calories intake drops once the BMI increases;
- The activity level generates an increased necessity of calories, but only when enough activity is performed for increasing muscular mass;
- The necessary amount of calories is high for young adults, drops slowly after 20 and has a relatively constant value for middle-aged persons. It drastically decreases for old persons after 65;

The observations regarding activity and age are valid according to previously identified connections. Nevertheless, according to these observations, we should pay attention to one aspect and rules need to be amended because a very low BMI does not necessarily expect the highest values for the necessary calories. In this regards, the amount of calories for an underweight person should not be necessarily higher than for a normal person; it only could be higher because they will burn calories faster.

As a next step, 3D plots were analysed to observe the impact of each to input variables to the output variable. According to figure 6 the following observations were made:

- Low levels of activity together with high bmi level will generate the flat surface for calories, meaning a low level of calories is necessary, while increased level of activity generates a high amount of calories to be necessary only for low or normal values of the bmi. This combination reaches the peak level when people have a very high level of activity and low bmi which means they are burning a lot of calories and have not had a proper intake of them so far.

- A low level of bmi and age generates a peak in the calories level, this being specific to young people with a good metabolism which indeed need more calories [11]. Increased levels of bmi and age lead to decreased levels of the necessary amount of calories.

- The flat surface is noticeable for highest ages with a sedentary lifestyle, meaning that these people do not need a high amount of calories. Young active people will need the biggest amount of calories. Old people with a very active lifestyle will still need more calories than those with a sedentary lifestyle but visibly lower than young people.

All the above observations respect the correlations mentioned in sections 1.4, 4.

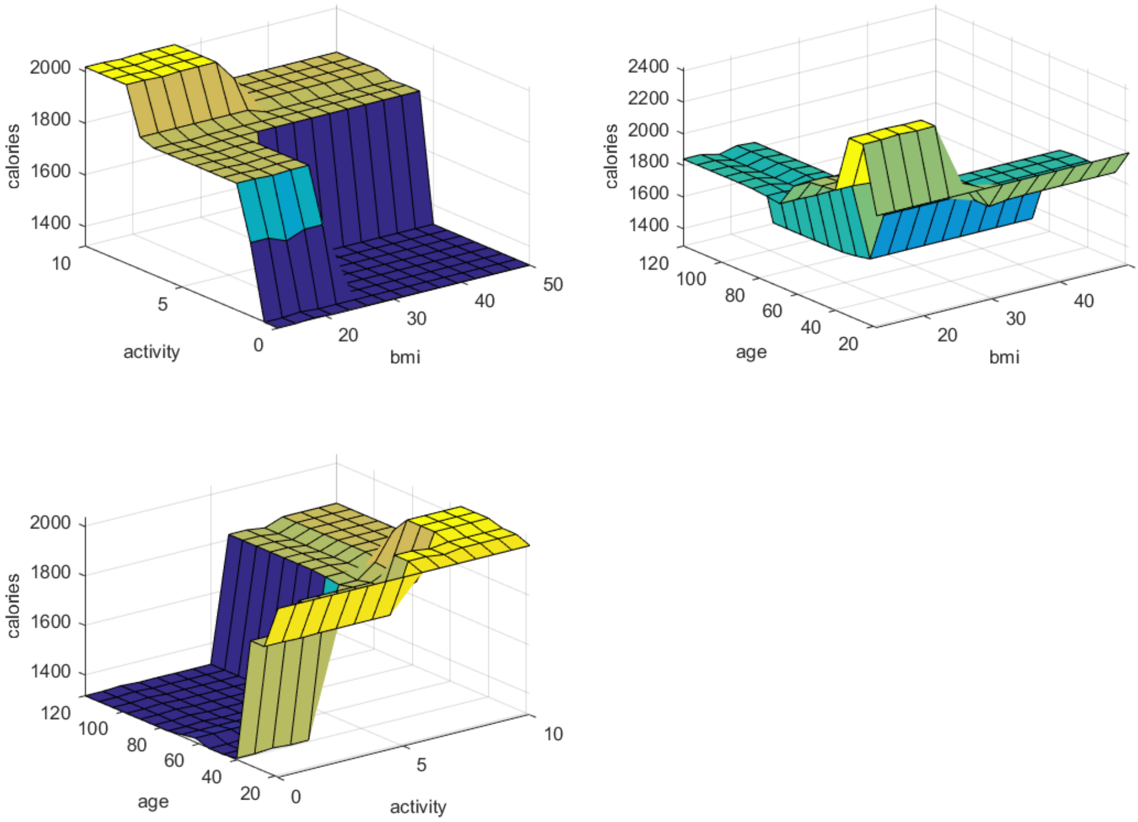

Figure 6: 3D Surfaces

Appendix C and D presents the surfaces obtained using two other membership functions: triangular MF and pi MF.

The 2D and 3D surfaces obtained using the other two membership functions respect all the observation made for those obtained with trapezoidal membership function. Nevertheless, some noticeable differences exists:

- The transitions for surfaces obtained with pi MF are smoother than those obtained for trapezoidal membership function.

- The 3D surfaces obtained using triangular MF produce more well defined edges. Also, the MF does not perform well for the edge values of the intervals of variables.

6.2 Evaluation

The expected output for each set of inputs was determined using available calories calculators [9] which are using the Mifflin-St Jeor equation. This equation has proven to be very accurate for estimating the calories needs along multiple studies [8] [13]. Since the equation used height and weight, the bmi value for the FIS in this paper was separately calculated. For consistency, it was assumed that all samples are male individuals when applying the equation.

Mifflin-St Jeor equation, provided three different values: the necessary calories to maintain, loss or extremely lose weight (i.e. "Maintain", "Loss" and "Extreme loss").

Since the aim of this paper is to calculate the necessary amount of calories for a healthy life, for each sample, a healthy goal was established according to the BMI value, as it follows:

- Underweight goal was set to "Gain weight";
- Normal weight goal was set to "Maintain" weight;
- Overweight goal was set to "Lose weight";
- Obese weight goal was set to "Extreme weight loss";

In this regards, the output obtained by the fuzzy inference system was compared to the output established using Mifflin-St Jeor equation consistent with the goal (e.g. if the goal was to "Lose weight", the value from Mifflin-St Jeor equation for weight "Loss" was compared, if the goal was to "Maintain" weight, then the value for weight maintaining was compared, if the goal was set to "Extreme weight loss" the value for "Extreme loss" was compared and if the goal was set to "Gain weight" then a value higher than the one for the maintaining goal was expected).

6.2.1 Different membership functions

The parameters for the membership functions were adjusted from the initial trapezoidal MF to fit for triangular and pi-shaped MF. The graphical representation of all MF is available in Appendix B and the parameters used for each MF in Appendix G.

The table in appendix E.1 shows the evaluation results for all three membership functions.

The results show consistency among all three membership functions. Identical or very similar output values were obtained (i.e only differences of negligible amounts). Nevertheless, Triangular membership function do not perform well for the interval edges. As an example, sample 21 which has the maximum activity level (10) should consume over 2596 calories according to Mifflin equation. The sample obtains an output of 2836 calories for trapezoidal membership function and 2840 for pi membership function, while the system with triangular membership functions ends up with 2000 calories. Due to the way they model the intervals, Pi-MF and Trap-MF have the most similar results.

6.2.2 Different defuzzification methods

Due to consistent results among different membership functions, four different defuzzification methods were applied to the initial structure of the fis. The results are available in appendix E.2.

Comparing the results, it was observed that SOM defuzzification method tends to generate lower outputs especially for overweight/obese individuals. The outputs obtained with this method gets far from the expected output, selecting the smallest values. The other three defuzzification methods obtained consistent and similar results.

6.2.3 Different And method

Different AND methods were tested for Centroid and SOM defuzzification methods and FIS with trapezoidal membership functions (all the rest of parameters were set to default matlab values, i.e. or with max, implication with min and aggregation with max). Using max for AND method has proven ineffective as it can be seen in appendix E.3.

6.3 Results analysis

Figure 7 presents a selection of samples which obtained great result. The following aspects can be observed according to the results:

- For underweight people, the amount of recommended calories by the FIS was with 200-300 calories more than the value recommended by the formula to maintain the weight. This is the proper amount of calories estimated by dietitians [6] to be necessary for healthily gaining weight. In this regard, it means that the FIS calculator was able to calculate a healthy goal of calories, for gaining weight.
- Sample 1 is an underweight young sedentary person. To maintain his weight, he should consume 1776 calories, according to Mifflin equation; the fuzzy system computed a necessary amount of 2000 calories for a healthy weight, which is with 224 more calories than to values for maintenance.

- Sample 5 is an overweight, moderately active, middle-aged person. To lose weight, Mifflin formula estimates a necessary amount of 1866 calories per day. The fuzzy system predicted 1839, which is equivalent, since a difference of 30 calories is negligible.

			Input Variables			Expected outputs - Mifflin-St. Jeor equation				FIS Outputs
Nr	Height	Width	BMI	Activity	Age	Maintain	Loss	Extreme loss	Healthy Goal	
1	180	44	13,6	0	18	1776	1421	1066	Gain weight	2000
5	160	70	27,3	4	40	2333	1866	1400	Lose weight	1839
10	190	110	30,5	7	30	3523	2819	2114	Extreme weight loss	2016
14	160	70	27,3	3	100	1657	1326	1000	Lose weight	1330
20	172	60	20,3	8	22	2983	2386	1790	Maintain	2839
21	165	48	17,6	10	30	2596	2077	1558	Gain weight	2836

Figure 7: Samples selection

Comparing the outputs with the expected ones, the following concerns were raised:

- Sample 2 has a higher output than expected. Calories level must be set to lower category for middle-aged people with sedentary lifestyle. Age value for this sample is boundary between old and middle aged category. Rules to be amended.
- Sample 8 has a lower output value than expected. Issue appears in context of a very active old person. Rule to be amended.
- Sample 18 have a little higher outputs than expected. It is a middle-aged to old persons with normal BMI. Calorie level should be lower for middle-aged persons with moderate activity level. Rule to be amended.
- Samples 9, 16 are very active persons and the calories value seems too low. Like for this sample. Their BMI is close to obesity which means that the output value should be in between the one for loss and extreme loss of the Mifflin-St Jeor equation, which is correct.
- Output calories for obese individual in sample 3 tends to be lower than expected. Even if in real life it could be a solution, rules will be amended to respect the healthy goal.

Figure 8 presents the set of samples which raised concerns and the results before/after rules updates. It can be observed that values were improved according to the healthy goal.

			Input Variables			Expected outputs				FIS Outputs - TrapMF	
Nr	Height	Width	BMI	Activity	Age	Maintain	Loss	Extreme loss	Healthy Goal	Before	After
2	150	60	26,7	1	60	1491	1193	1000	Lose weight	1815	1326
3	180	150	46,3	2	65	3169	2536	1902	Extreme weight loss	1335	1807
8	150	55	24,4	7	65	2014	1611	1208	Maintain	1807	1919
18	150	50	22,2	4	60	1771	1417	1063	Maintain	2015	1815

Figure 8: Concerning samples

The rules in appendix F.1 were amended according all observations in this section. New rules are visible in appendix F.2.

7 Conclusions

Existent calorie calculators based on formulas are very effective for calculating a specific value for the calories (calories necessary to maintain, to lose, or to drastically lose weight) but a fuzzy calculator widens the horizons of this approach. Calculating the healthy necessary amount of calories, a fuzzy calculator can estimate the proper amount of calories extracting a weight goal from the bmi and adjusting the calories according level of physical activity and individual's age.

Results obtained by the fuzzy calorie calculator approximate the values obtained using the equation, offering also a degree of freedom. A mathematical formula might be too crisp for this kind of problem.

Different defuzzification methods and membership function provided consistent results, which means that rules are stable in different contexts.

The observed issues were addressed updating the set of rules. Nevertheless, one issue was observed among the samples and that is: the fuzzy calculator tends to cut out too much the level of calories for obese individuals, more than allowed by the Mifflin equation. This is due to the crisp value. A healthy weight loss from obesity must be slow and the level of calories must be decreased in steps [11] but a crisp value will not be able to provide a slow descending level of calories, but only the goal amount.

The final version of the fuzzy inference system used the following structure:

- Trap-MF, since it performs better than Tri-MF and very similar to Pi-MF;
- Centroid defuzzification method, since it was the closest to the goal output. Bisector and Mom defuzzification methods could be also used, but not som method.
- For the AND operator min method was used, since max one proved inefficient.
- For aggregation and composition the default values were kept since other combinations did not provide proper results.

The paper describes the decisions taken in the design of the presented fuzzy calorie calculator. Fine tuning parameters, analysing rules and designing the full structure of a fuzzy systems implies multiple steps and a thorough analysis of the results after each step.

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Appendices

A Membership functions

MF	Full name	Syntax	Formula
pimf	Pi-shaped MF	pimf(x,[a b c d])	$f(x) = \begin{cases} 0 & x \leq a \\ 2(\frac{x-a}{b-a})^2 & a \leq x \leq \frac{a+b}{2} \\ 1-2(\frac{x-a}{b-a})^2 & \frac{a+b}{2} \leq x \leq b \\ 1 & b \leq x \leq c \\ 1-2(\frac{x-c}{d-c})^2 & c \leq x \leq \frac{c+d}{2} \\ 2(\frac{x-d}{d-c})^2 & \frac{c+d}{2} \leq x \leq d \\ 0 & d \leq x \end{cases}$
trapmf	Trapezoidal-shaped MF	trapmf(x,[a b c d])	$f(x) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a \leq x \leq b \\ 1 & b \leq x \leq c \\ \frac{d-x}{d-x} & c \leq x \leq d \\ 0 & d \leq x \end{cases}$
trimf	Triangular-shaped MF	trimf(x,[a b c])	$f(x) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a \leq x \leq b \\ \frac{c-x}{c-b} & b \leq x \leq c \\ 0 & c \leq x \end{cases}$

Table 8: Membership functions

B Membership functions graphs

B.1 Trapezoidal Membership Functions

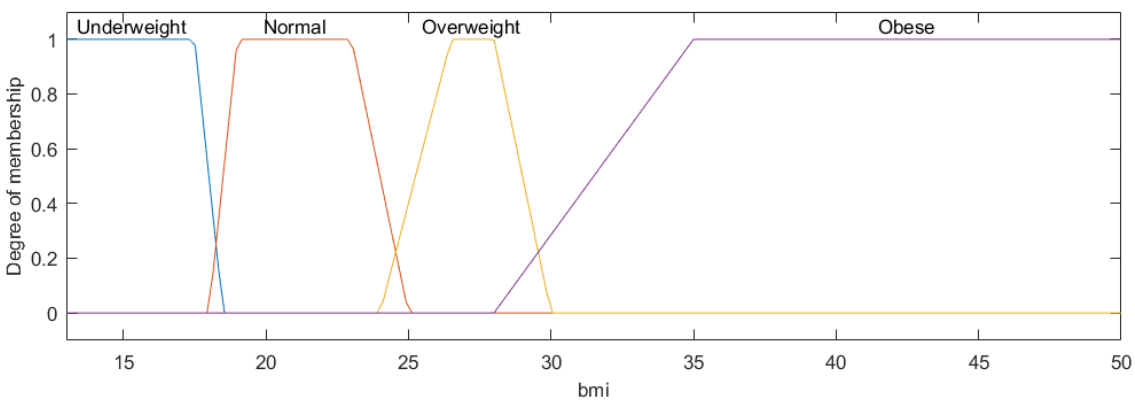

Figure 9: Input MF - BMI

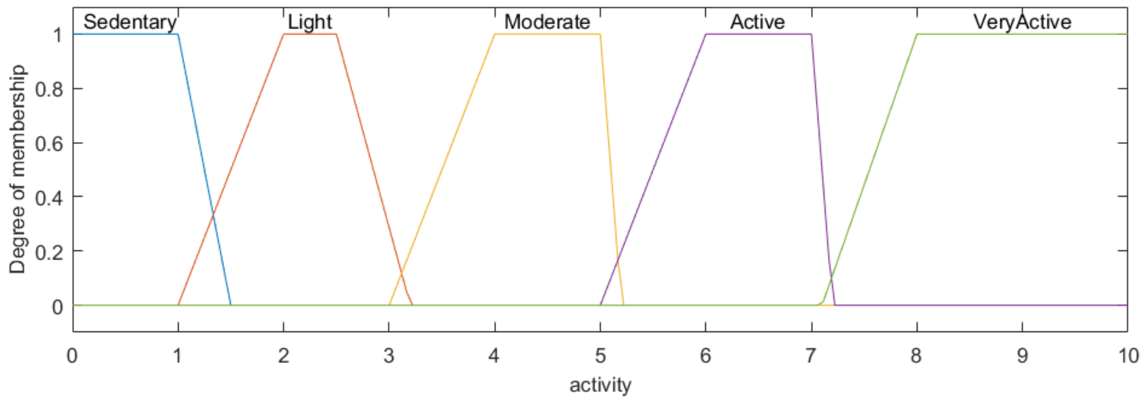

Figure 10: Input MF - Activity

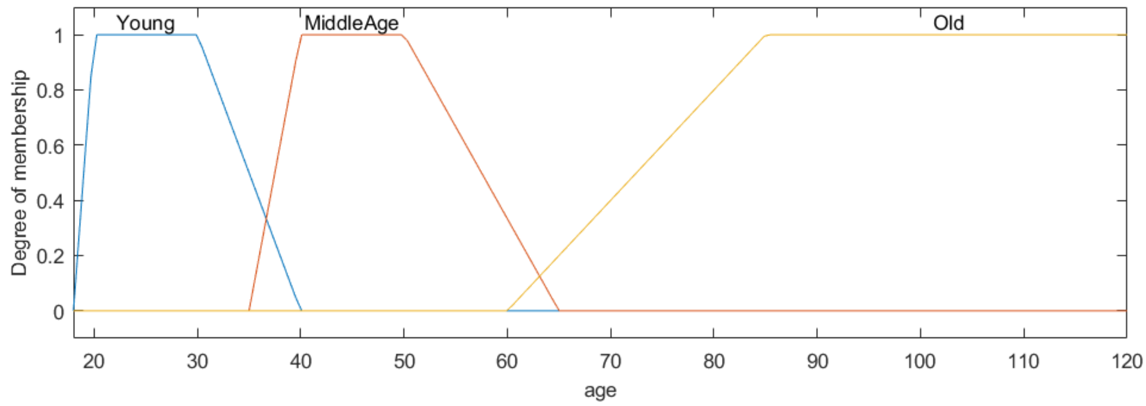

Figure 11: Input MF - Age

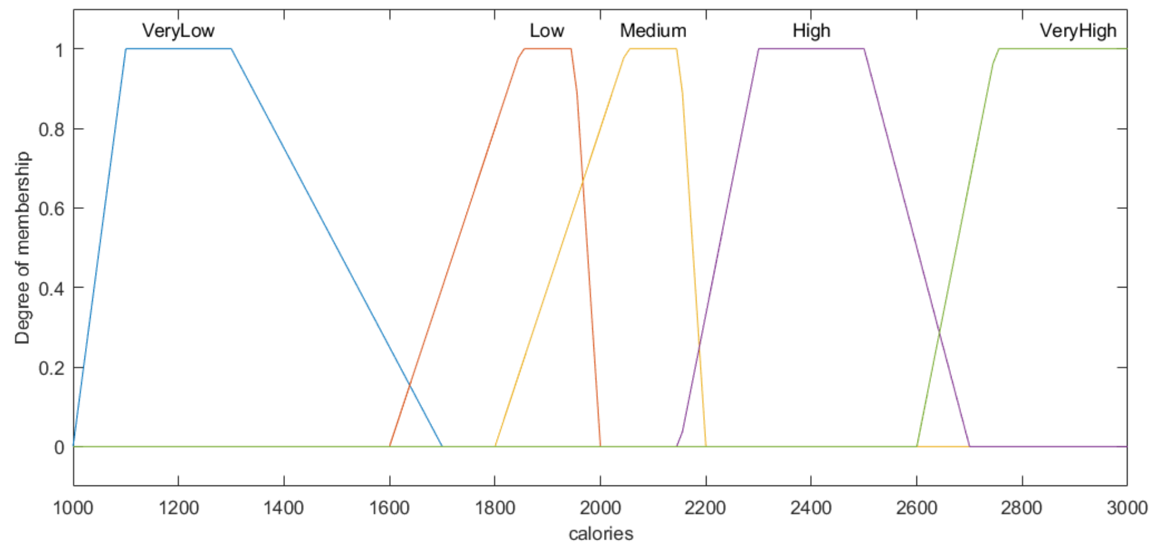

Figure 12: Output MF - Calories

B.2 Triangular Membership Functions

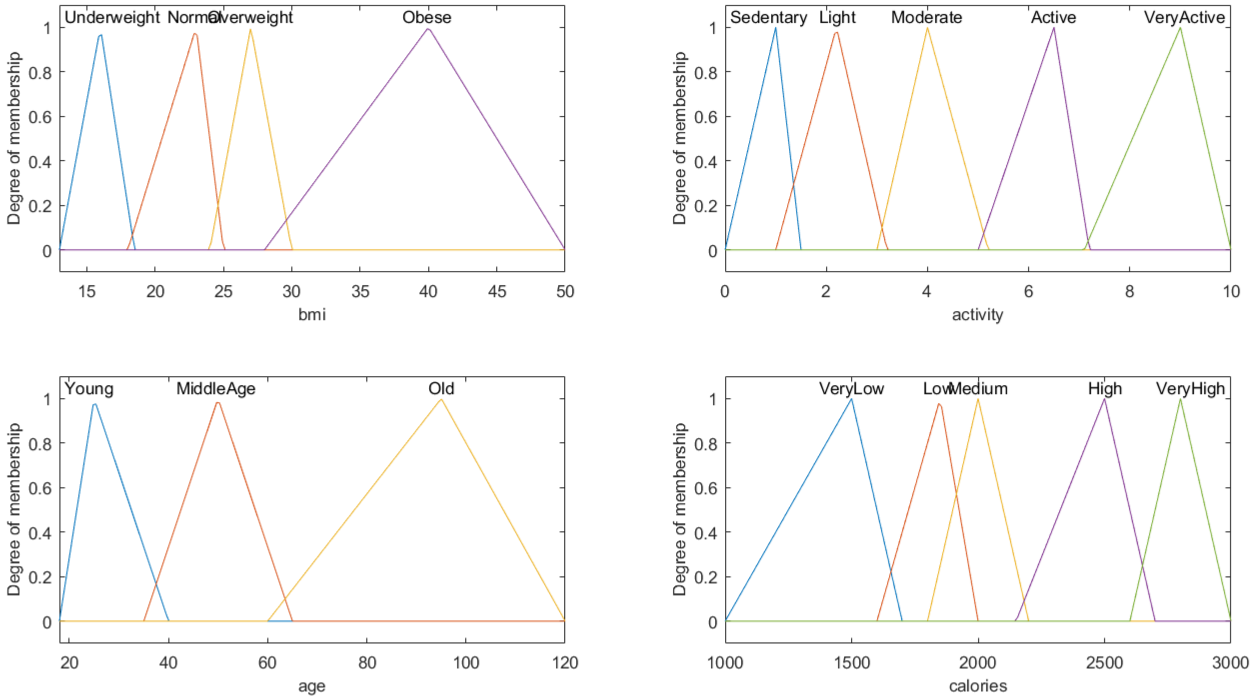

Figure 13: Triangular MF

B.3 Pi Membership Functions

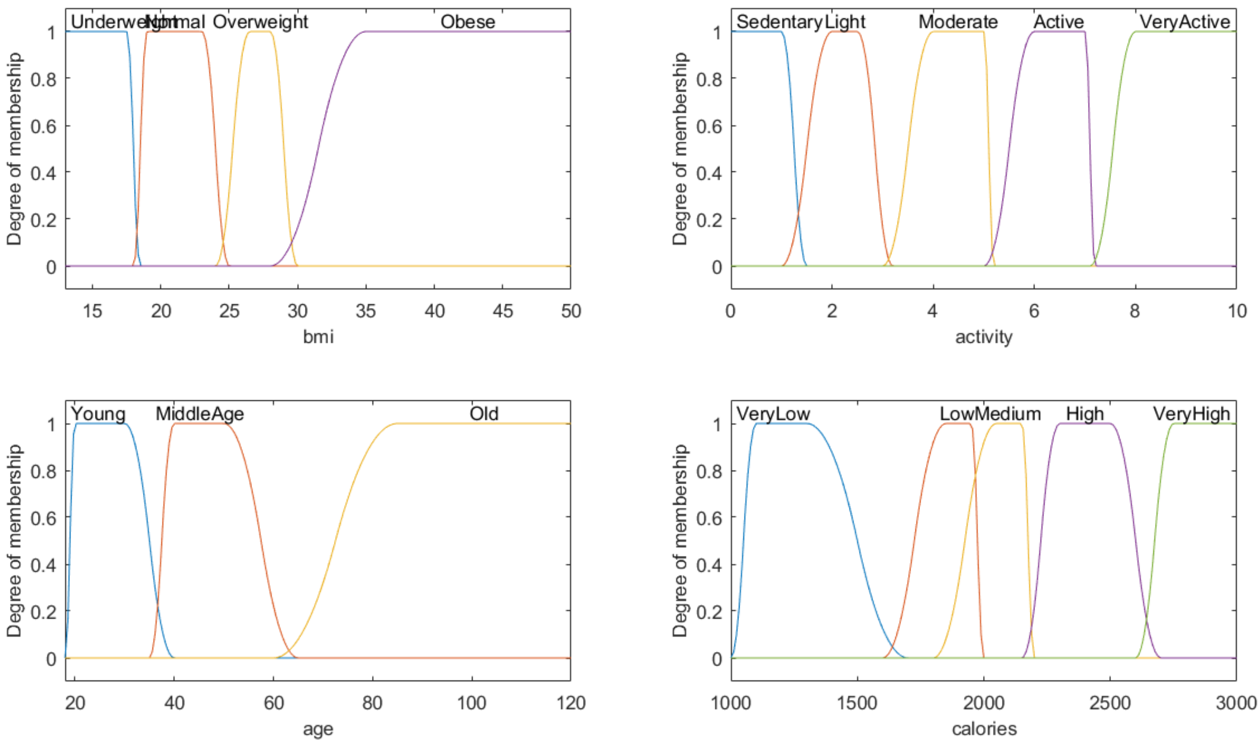

Figure 14: Pi MF

C 2D Surfaces

C.1 2D Surfaces for TrapMF

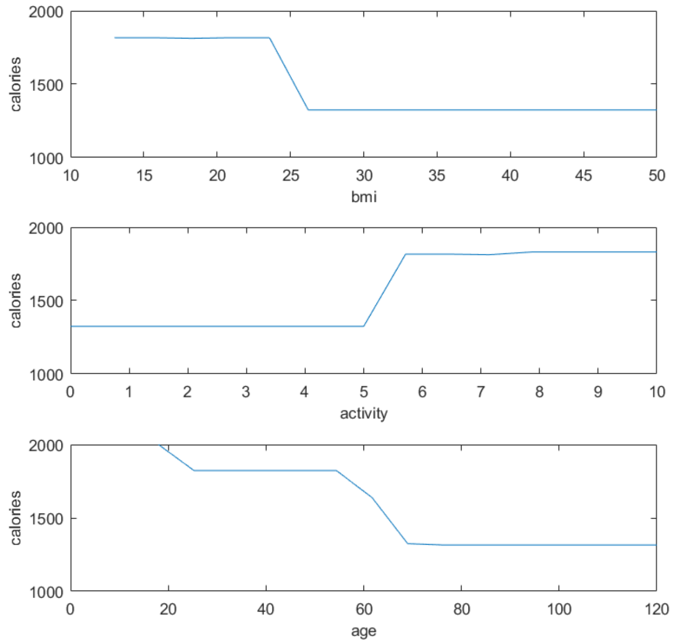

Figure 15: 2D Surfaces - TrapMF

C.2 2D Surfaces for TriMF

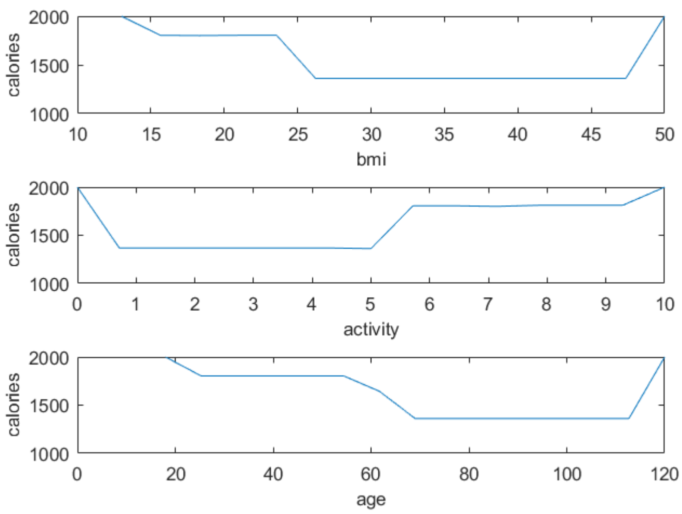

Figure 16: 2D Surfaces - TriMF

C.3 2D Surfaces for PiMF

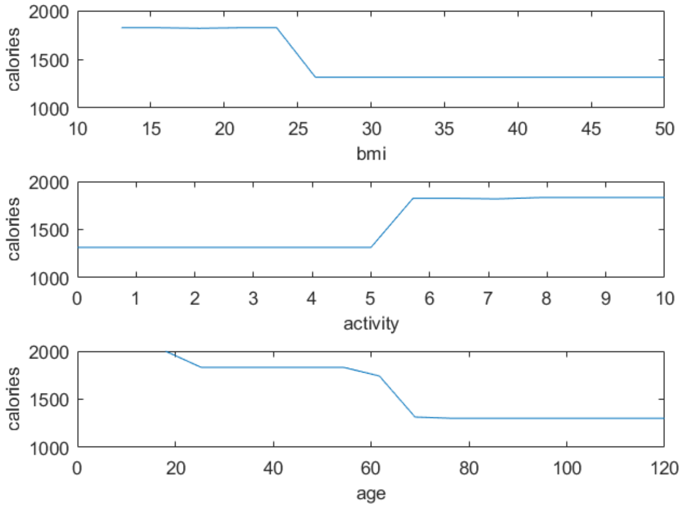

Figure 17: 2D Surfaces - PiMF

D 3D Surfaces

D.1 3D Surfaces for TrapMF

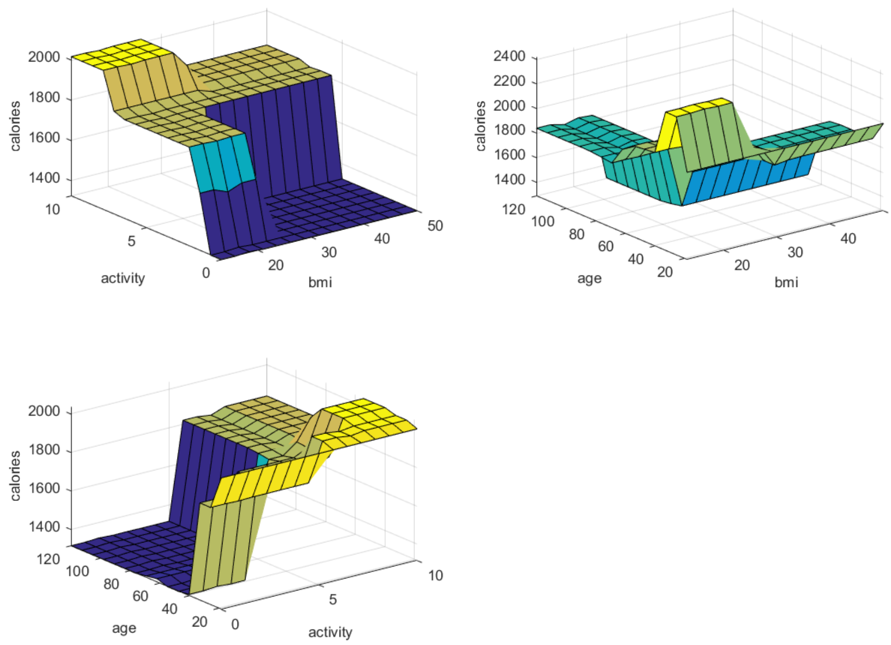

Figure 18: 3D Surfaces - TrapMF

D.2 3D Surfaces for TriMF

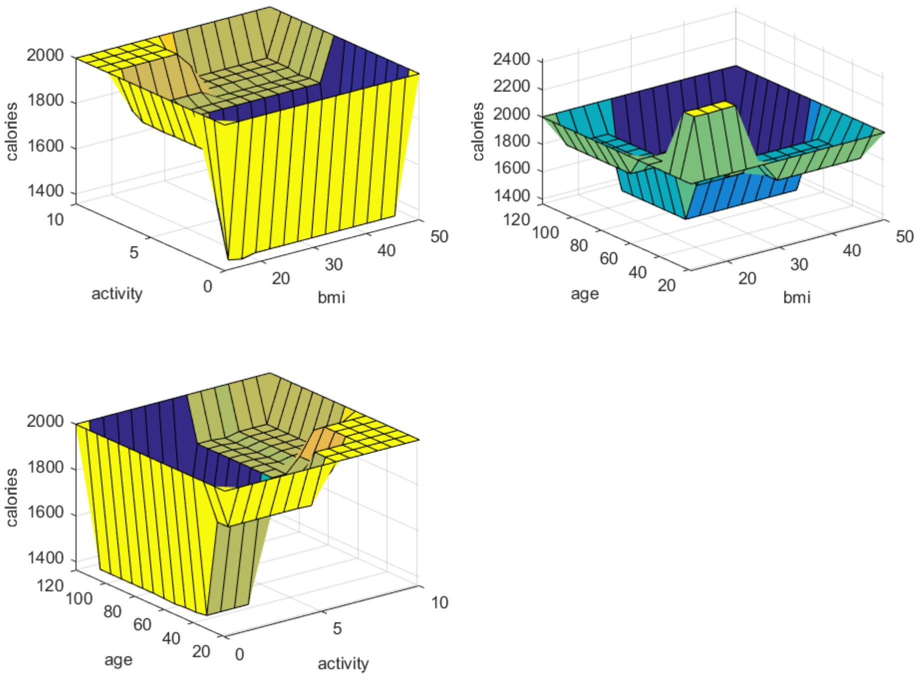

Figure 19: 3D Surfaces - TriMF

D.3 3D Surfaces for PiMF

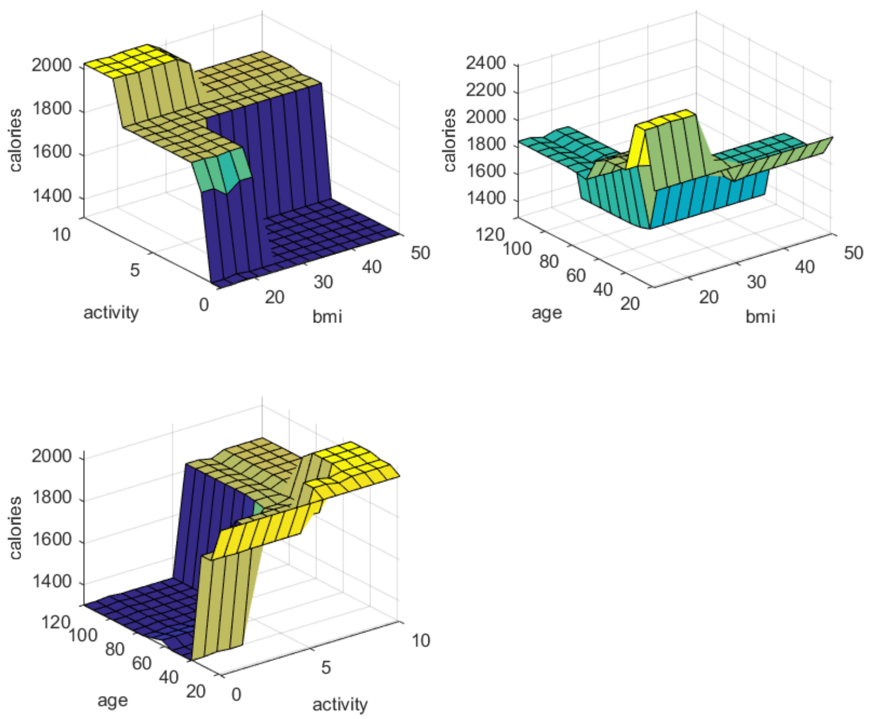

Figure 20: 3D Surfaces - PiMF

E FIS Evaluation

E.1 Different membership functions

			Input Variables			Expected outputs - Mifflin-St. Jeor equation				FIS Outputs		
Nr	Height	Width	BMI	Activity	Age	Maintain	Loss	Extreme loss	Healthy Goal	TrapMF	TriMF	PiMF
1	180	44	13,6	0	18	1776	1421	1066	Gain weight	2000	2000	2000
2	150	60	26,7	1	60	1491	1193	1000	Lose weight	1815	1807	1822
3	180	150	46,3	2	65	3169	2536	1902	Extreme weight loss	1335	1359	1329
4	160	45	17,6	3	35	1760	1408	1056	Gain weight	2012	2000	2018
5	160	70	27,3	4	40	2333	1866	1400	Lose weight	1839	1807	1844
6	170	55	19,0	4.5	45	2158	1727	1295	Maintain	2039	2000	2044
7	160	47	18,4	5	60	1821	1457	1093	Gain weight	2015	2000	2022
8	150	55	24,4	7	65	2014	1611	1208	Maintain	1807	1803	1811
9	190	105	29,1	8	22	4052	3241	2431	Lose weight	2612	2596	2738
10	190	110	30,5	7	30	3523	2819	2114	Extreme weight loss	2016	2000	2024
11	180	91	28,1	3	100	2218	1694	1271	Lose weight	1330	1364	1322
12	150	35	15,6	2	18	1653	1332	1000	Gain weight	2000	2000	2000
13	150	50	22,2	1	60	1371	1097	1000	Maintain	1326	1373	1317
14	160	70	27,3	3	100	1657	1326	1000	Lose weight	1330	1364	1322
15	190	110	30,5	3	35	2912	2329	1747	Extreme weight loss	1812	1804	1818
16	180	91	28,1	4	40	2530	2024	1518	Lose weight	1838	1807	1844
17	150	35	15,6	4.5	45	1655	1324	1000	Gain weight	2039	2000	2044
18	150	50	22,2	4	60	1771	1417	1063	Maintain	2015	2000	2022
19	145	35	16,6	7	65	1615	1293	1000	Gain weight	1807	1803	1811
20	172	60	20,3	8	22	2983	2386	1790	Maintain	2839	2800	2841
21	165	48	17,6	10	30	2596	2077	1558	Gain weight	2836	2000	2840

E.2 Different defuzzification methods

			Input Variables			Expected outputs - Mifflin-St. Jeor equation				Deffuzification methods			
Nr	Height	Width	BMI	Activity	Age	Maintain	Loss	Extreme loss	Healthy Goal	centroid	bisector	mom	som
1	180	44	13,6	0	18	1776	1421	1066	Gain weight	2000	2000	2000	2000
2	150	60	26,7	1	60	1491	1193	1000	Lose weight	1815	1820	1840	1700
3	180	150	46,3	2	65	3169	2536	1902	Extreme weight loss	1335	1340	1320	1020
4	160	45	17,6	3	35	1760	1408	1056	Gain weight	2012	2020	2030	1880
5	160	70	27,3	4	40	2333	1866	1400	Lose weight	1839	1840	1900	1860
6	170	55	19,0	4.5	45	2158	1727	1295	Maintain	2039	2040	2100	2060
7	160	47	18,4	5	60	1821	1457	1093	Gain weight	2015	2020	2040	1900
8	150	55	24,4	7	65	2014	1611	1208	Maintain	1807	1800	1820	1660
9	190	105	29,1	8	22	4052	3241	2431	Lose weight	2612	2760	2840	2680
10	190	110	30,5	7	30	3523	2819	2114	Extreme weight loss	2016	2020	2040	1900
11	180	91	28,1	3	100	2218	1694	1271	Lose weight	1330	1320	1310	1040
12	150	35	15,6	2	18	1653	1332	1000	Gain weight	2000	2000	2000	2000
13	150	50	22,2	1	60	1371	1097	1000	Maintain	1326	1320	1300	1040
14	160	70	27,3	3	100	1657	1326	1000	Lose weight	1330	1320	1310	1040
15	190	110	30,5	3	35	2912	2329	1747	Extreme weight loss	1812	1820	1830	1680
16	180	91	28,1	4	40	2530	2024	1518	Lose weight	1838	1840	1890	1840
17	150	35	15,6	4.5	45	1655	1324	1000	Gain weight	2039	2040	2100	2060
18	150	50	22,2	4	60	1771	1417	1063	Maintain	2015	2020	2040	1900
19	145	35	16,6	7	65	1615	1293	1000	Gain weight	1807	1800	1820	1660
20	172	60	20,3	8	22	2983	2386	1790	Maintain	2839	2840	2880	2760
21	165	48	17,6	10	30	2596	2077	1558	Gain weight	2836	2840	2870	2740

E.3 Different AND methods

										Different method for AND			
			Input Variables			Expected outputs - Mifflin-St. Jeor equation				centroid		som	
Nr	Height	Width	BMI	Activity	Age	Maintain	Loss	Extreme loss	Healthy Goal	min	max	min	max
1	180	44	13,6	0	18	1776	1421	1066	Gain weight	2000	2053	2000	1100
2	150	60	26,7	1	60	1491	1193	1000	Lose weight	1815	2053	1700	1100
3	180	150	46,3	2	65	3169	2536	1902	Extreme weight loss	1335	1608	1020	1100
4	160	45	17,6	3	35	1760	1408	1056	Gain weight	2012	2047	1880	1100
5	160	70	27,3	4	40	2333	1866	1400	Lose weight	1839	2053	1860	1100
6	170	55	19,0	4.5	45	2158	1727	1295	Maintain	2039	2053	2060	1100
7	160	47	18,4	4.1	60	1821	1457	1093	Gain weight	2015	1947	1900	1100
8	150	55	24,4	7	65	2014	1611	1208	Maintain	1807	2085	1660	1860
9	190	105	29,1	8	22	4052	3241	2431	Lose weight	2612	2162	2680	1860
10	190	110	30,5	7	30	3523	2819	2114	Extreme weight loss	2016	2193	1900	1860
11	180	91	28,1	3	100	2218	1694	1271	Lose weight	1330	2044	1040	1100
12	150	35	15,6	2	18	1653	1332	1000	Gain weight	2000	2053	2000	1100
13	150	50	22,2	1	60	1371	1097	1000	Maintain	1326	2053	1040	1100
14	160	70	27,3	3	100	1657	1326	1000	Lose weight	1330	2053	1040	1100
15	190	110	30,5	3	35	2912	2329	1747	Extreme weight loss	1812	2075	1680	1780
16	180	91	28,1	4	40	2530	2024	1518	Lose weight	1838	2046	1840	1100
17	150	35	15,6	4.5	45	1655	1324	1000	Gain weight	2039	2053	2060	1100
18	150	50	22,2	3.1	60	1771	1417	1063	Maintain	2015	2053	1900	1100
19	145	35	16,6	7	65	1615	1293	1000	Gain weight	1807	2053	1660	1100
20	172	60	20,3	8	22	2983	2386	1790	Maintain	2839	2053	2760	1100
21	165	48	17,6	10	30	2596	2077	1558	Gain weight	2836	2066	2740	1860

F FIS Rules

F.1 Initial rules

1. If (bmi is Underweight) and (activity is Sedentary) and (age is Young) then (calories is Medium)
2. If (bmi is Underweight) and (activity is Light) and (age is Young) then (calories is Medium)
3. If (bmi is Underweight) and (activity is Moderate) and (age is Young) then (calories is High)
4. If (bmi is Underweight) and (activity is Active) and (age is Young) then (calories is High)
5. If (bmi is Underweight) and (activity is VeryActive) and (age is Young) then (calories is VeryHigh)
6. If (bmi is Normal) and (activity is Sedentary) and (age is Young) then (calories is Low)
7. If (bmi is Normal) and (activity is Light) and (age is Young) then (calories is Medium)
8. If (bmi is Normal) and (activity is Moderate) and (age is Young) then (calories is High)
9. If (bmi is Normal) and (activity is Active) and (age is Young) then (calories is High)
10. If (bmi is Normal) and (activity is VeryActive) and (age is Young) then (calories is VeryHigh)
11. If (bmi is Overweight) and (activity is Sedentary) and (age is Young) then (calories is Low)
12. If (bmi is Overweight) and (activity is Light) and (age is Young) then (calories is Medium)
13. If (bmi is Overweight) and (activity is Moderate) and (age is Young) then (calories is Medium)
14. If (bmi is Overweight) and (activity is Active) and (age is Young) then (calories is High)
15. If (bmi is Overweight) and (activity is VeryActive) and (age is Young) then (calories is VeryHigh)
16. If (bmi is Obese) and (activity is Sedentary) and (age is Young) then (calories is Low)
17. If (bmi is Obese) and (activity is Light) and (age is Young) then (calories is Low)
18. If (bmi is Obese) and (activity is Moderate) and (age is Young) then (calories is Low)
19. If (bmi is Obese) and (activity is Active) and (age is Young) then (calories is Medium)
20. If (bmi is Obese) and (activity is VeryActive) and (age is Young) then (calories is Medium)
21. If (bmi is Underweight) and (activity is Sedentary) and (age is MiddleAge) then (calories is Low)
22. If (bmi is Underweight) and (activity is Light) and (age is MiddleAge) then (calories is Medium)
23. If (bmi is Underweight) and (activity is Moderate) and (age is MiddleAge) then (calories is Medium)
24. If (bmi is Underweight) and (activity is Active) and (age is MiddleAge) then (calories is Medium)
25. If (bmi is Underweight) and (activity is VeryActive) and (age is MiddleAge) then (calories is High)
26. If (bmi is Normal) and (activity is Sedentary) and (age is MiddleAge) then (calories is VeryLow)
27. If (bmi is Normal) and (activity is Light) and (age is MiddleAge) then (calories is Low)
28. If (bmi is Normal) and (activity is Moderate) and (age is MiddleAge) then (calories is Medium)
29. If (bmi is Normal) and (activity is Active) and (age is MiddleAge) then (calories is Medium)
30. If (bmi is Normal) and (activity is VeryActive) and (age is MiddleAge) then (calories is High)
31. If (bmi is Overweight) and (activity is Sedentary) and (age is MiddleAge) then (calories is Low)
32. If (bmi is Overweight) and (activity is Light) and (age is MiddleAge) then (calories is Low)
33. If (bmi is Overweight) and (activity is Moderate) and (age is MiddleAge) then (calories is Low)
34. If (bmi is Overweight) and (activity is Active) and (age is MiddleAge) then (calories is Medium)
35. If (bmi is Overweight) and (activity is VeryActive) and (age is MiddleAge) then (calories is High)
36. If (bmi is Obese) and (activity is Sedentary) and (age is MiddleAge) then (calories is VeryLow)
37. If (bmi is Obese) and (activity is Light) and (age is MiddleAge) then (calories is VeryLow)
38. If (bmi is Obese) and (activity is Moderate) and (age is MiddleAge) then (calories is Low)
39. If (bmi is Obese) and (activity is Active) and (age is MiddleAge) then (calories is Low)
40. If (bmi is Obese) and (activity is VeryActive) and (age is MiddleAge) then (calories is Medium)
41. If (bmi is Underweight) and (activity is Sedentary) and (age is Old) then (calories is VeryLow)
42. If (bmi is Underweight) and (activity is Light) and (age is Old) then (calories is Low)
43. If (bmi is Underweight) and (activity is Moderate) and (age is Old) then (calories is Low)
44. If (bmi is Underweight) and (activity is Active) and (age is Old) then (calories is Low)
45. If (bmi is Underweight) and (activity is VeryActive) and (age is Old) then (calories is Medium)
46. If (bmi is Normal) and (activity is Sedentary) and (age is Old) then (calories is VeryLow)
47. If (bmi is Normal) and (activity is Light) and (age is Old) then (calories is Low)
48. If (bmi is Normal) and (activity is Moderate) and (age is Old) then (calories is Low)
49. If (bmi is Normal) and (activity is Active) and (age is Old) then (calories is Low)
50. If (bmi is Normal) and (activity is VeryActive) and (age is Old) then (calories is Medium)
51. If (bmi is Overweight) and (activity is Sedentary) and (age is Old) then (calories is VeryLow)
52. If (bmi is Overweight) and (activity is Light) and (age is Old) then (calories is VeryLow)
53. If (bmi is Overweight) and (activity is Moderate) and (age is Old) then (calories is VeryLow)
54. If (bmi is Overweight) and (activity is Active) and (age is Old) then (calories is Low)
55. If (bmi is Overweight) and (activity is VeryActive) and (age is Old) then (calories is Medium)
56. If (bmi is Obese) and (activity is Sedentary) and (age is Old) then (calories is VeryLow)
57. If (bmi is Obese) and (activity is Light) and (age is Old) then (calories is VeryLow)

58. If (bmi is Obese) and (activity is Moderate) and (age is Old) then (calories is VeryLow)
59. If (bmi is Obese) and (activity is Active) and (age is Old) then (calories is Low)
60. If (bmi is Obese) and (activity is VeryActive) and (age is Old) then (calories is Low)

F.2 Final rules

1. If (bmi is Underweight) and (activity is Sedentary) and (age is Young) then (calories is Medium)
2. If (bmi is Underweight) and (activity is Light) and (age is Young) then (calories is Medium)
3. If (bmi is Underweight) and (activity is Moderate) and (age is Young) then (calories is High)
4. If (bmi is Underweight) and (activity is Active) and (age is Young) then (calories is High)
5. If (bmi is Underweight) and (activity is VeryActive) and (age is Young) then (calories is VeryHigh)
6. If (bmi is Normal) and (activity is Sedentary) and (age is Young) then (calories is Low)
7. If (bmi is Normal) and (activity is Light) and (age is Young) then (calories is Medium)
8. If (bmi is Normal) and (activity is Moderate) and (age is Young) then (calories is High)
9. If (bmi is Normal) and (activity is Active) and (age is Young) then (calories is High)
10. If (bmi is Normal) and (activity is VeryActive) and (age is Young) then (calories is VeryHigh)
11. If (bmi is Overweight) and (activity is Sedentary) and (age is Young) then (calories is Low)
12. If (bmi is Overweight) and (activity is Light) and (age is Young) then (calories is Medium)
13. If (bmi is Overweight) and (activity is Moderate) and (age is Young) then (calories is Medium)
14. If (bmi is Overweight) and (activity is Active) and (age is Young) then (calories is High)
15. If (bmi is Overweight) and (activity is VeryActive) and (age is Young) then (calories is VeryHigh)
16. If (bmi is Obese) and (activity is Sedentary) and (age is Young) then (calories is Low)
17. If (bmi is Obese) and (activity is Light) and (age is Young) then (calories is Low)
18. If (bmi is Obese) and (activity is Moderate) and (age is Young) then (calories is Low)
19. If (bmi is Obese) and (activity is Active) and (age is Young) then (calories is Medium)
20. If (bmi is Obese) and (activity is VeryActive) and (age is Young) then (calories is Medium)
21. If (bmi is Underweight) and (activity is Sedentary) and (age is MiddleAge) then (calories is Low)
22. If (bmi is Underweight) and (activity is Light) and (age is MiddleAge) then (calories is Medium)
23. If (bmi is Underweight) and (activity is Moderate) and (age is MiddleAge) then (calories is Medium)
24. If (bmi is Underweight) and (activity is Active) and (age is MiddleAge) then (calories is Medium)
25. If (bmi is Underweight) and (activity is VeryActive) and (age is MiddleAge) then (calories is High)
26. If (bmi is Normal) and (activity is Sedentary) and (age is MiddleAge) then (calories is VeryLow)
27. If (bmi is Normal) and (activity is Light) and (age is MiddleAge) then (calories is Low)
28. If (bmi is Normal) and (activity is Moderate) and (age is MiddleAge) then (calories is Low)
29. If (bmi is Normal) and (activity is Active) and (age is MiddleAge) then (calories is Medium)
30. If (bmi is Normal) and (activity is VeryActive) and (age is MiddleAge) then (calories is High)
31. If (bmi is Overweight) and (activity is Sedentary) and (age is MiddleAge) then (calories is VeryLow)
32. If (bmi is Overweight) and (activity is Light) and (age is MiddleAge) then (calories is VeryLow)
33. If (bmi is Overweight) and (activity is Moderate) and (age is MiddleAge) then (calories is Low)
34. If (bmi is Overweight) and (activity is Active) and (age is MiddleAge) then (calories is Medium)
35. If (bmi is Overweight) and (activity is VeryActive) and (age is MiddleAge) then (calories is High)
36. If (bmi is Obese) and (activity is Sedentary) and (age is MiddleAge) then (calories is VeryLow)
37. If (bmi is Obese) and (activity is Light) and (age is MiddleAge) then (calories is VeryLow)
38. If (bmi is Obese) and (activity is Moderate) and (age is MiddleAge) then (calories is Low)
39. If (bmi is Obese) and (activity is Active) and (age is MiddleAge) then (calories is Low)
40. If (bmi is Obese) and (activity is VeryActive) and (age is MiddleAge) then (calories is Medium)
41. If (bmi is Underweight) and (activity is Sedentary) and (age is Old) then (calories is VeryLow)
42. If (bmi is Underweight) and (activity is Light) and (age is Old) then (calories is Low)
43. If (bmi is Underweight) and (activity is Moderate) and (age is Old) then (calories is Low)
44. If (bmi is Underweight) and (activity is Active) and (age is Old) then (calories is Low)
45. If (bmi is Underweight) and (activity is VeryActive) and (age is Old) then (calories is Medium)
46. If (bmi is Normal) and (activity is Sedentary) and (age is Old) then (calories is VeryLow)
47. If (bmi is Normal) and (activity is Light) and (age is Old) then (calories is Low)
48. If (bmi is Normal) and (activity is Moderate) and (age is Old) then (calories is Low)
49. If (bmi is Normal) and (activity is Active) and (age is Old) then (calories is Medium)
50. If (bmi is Normal) and (activity is VeryActive) and (age is Old) then (calories is Medium)
51. If (bmi is Overweight) and (activity is Sedentary) and (age is Old) then (calories is VeryLow)
52. If (bmi is Overweight) and (activity is Light) and (age is Old) then (calories is VeryLow)
53. If (bmi is Overweight) and (activity is Moderate) and (age is Old) then (calories is VeryLow)
54. If (bmi is Overweight) and (activity is Active) and (age is Old) then (calories is Low)

55. If (bmi is Overweight) and (activity is VeryActive) and (age is Old) then (calories is Medium)
56. If (bmi is Obese) and (activity is Sedentary) and (age is Old) then (calories is VeryLow)
57. If (bmi is Obese) and (activity is Light) and (age is Old) then (calories is Low)
58. If (bmi is Obese) and (activity is Moderate) and (age is Old) then (calories is Low)
59. If (bmi is Obese) and (activity is Active) and (age is Old) then (calories is Low)
60. If (bmi is Obese) and (activity is VeryActive) and (age is Old) then (calories is Low)

G Matlab Code

G.1 TrapMF

```
%Add membership functions for bmi variable
calories_fis = addmf(calories_fis, 'input', 1, 'Underweight', 'trapmf', [13 13
    17.5 18.5]);
calories_fis = addmf(calories_fis, 'input', 1, 'Normal', 'trapmf', [18 19 23
    25]);
calories_fis = addmf(calories_fis, 'input', 1, 'Overweight', 'trapmf', [24 26.5
    28 30]);
calories_fis = addmf(calories_fis, 'input', 1, 'Obese', 'trapmf', [28 35 50 50])
    ;

%Add membership functions for activity variable
calories_fis = addmf(calories_fis, 'input', 2, 'Sedentary', 'trapmf', [0 0 1
    1.5]);
calories_fis = addmf(calories_fis, 'input', 2, 'Light', 'trapmf', [1 2 2.5 3.2])
    ;
calories_fis = addmf(calories_fis, 'input', 2, 'Moderate', 'trapmf', [3 4 5
    5.2]);
calories_fis = addmf(calories_fis, 'input', 2, 'Active', 'trapmf', [5 6 7 7.2]);
calories_fis = addmf(calories_fis, 'input', 2, 'VeryActive', 'trapmf', [7.1 8 10
     10]);

%Add membership functions for age
calories_fis = addmf(calories_fis, 'input', 3, 'Young', 'trapmf', [18 20 30 40])
    ;
calories_fis = addmf(calories_fis, 'input', 3, 'MiddleAge', 'trapmf', [35 40 50
    65]);
calories_fis = addmf(calories_fis, 'input', 3, 'Old', 'trapmf', [60 85 120 120])
    ;

%Add membership functions for output variable
calories_fis = addmf(calories_fis, 'output', 1, 'VeryLow', 'trapmf', [1000 1100
    1300 1700]);
calories_fis = addmf(calories_fis, 'output', 1, 'Low', 'trapmf', [1600 1850 1950
     2000]);
calories_fis = addmf(calories_fis, 'output', 1, 'Medium', 'trapmf', [1800 2050
    2150 2200]);
calories_fis = addmf(calories_fis, 'output', 1, 'High', 'trapmf', [2150 2300
    2500 2700]);
calories_fis = addmf(calories_fis, 'output', 1, 'VeryHigh', 'trapmf', [2600 2750
     3000 3000]);
```

G.2 TriMF

```
%Add membership functions for bmi variable
calories_fis = addmf(calories_fis, 'input', 1, 'Underweight', 'trimf', [13 16
    18.5]);
calories_fis = addmf(calories_fis, 'input', 1, 'Normal', 'trimf', [18 23 25]);
```

```
calories_fis = addmf(calories_fis , 'input', 1, 'Overweight', 'trimf', [24 27
    30]);
calories_fis = addmf(calories_fis , 'input', 1, 'Obese', 'trimf', [28 40 50]);

%Add membership functions for activity variable
calories_fis = addmf(calories_fis , 'input', 2, 'Sedentary', 'trimf', [0 1 1.5]);
calories_fis = addmf(calories_fis , 'input', 2, 'Light', 'trimf', [1 2.2 3.2]);
calories_fis = addmf(calories_fis , 'input', 2, 'Moderate', 'trimf', [3 4 5.2]);
calories_fis = addmf(calories_fis , 'input', 2, 'Active', 'trimf', [5 6.5 7.2]);
calories_fis = addmf(calories_fis , 'input', 2, 'VeryActive', 'trimf', [7.1 9
    10]);

%Add membership functions for age
calories_fis = addmf(calories_fis , 'input', 3, 'Young', 'trimf', [18 25 40]);
calories_fis = addmf(calories_fis , 'input', 3, 'MiddleAge', 'trimf', [35 50 65])
    ;
calories_fis = addmf(calories_fis , 'input', 3, 'Old', 'trimf', [60 95 120]);

%Add membership functions for output variable
calories_fis = addmf(calories_fis , 'output', 1, 'VeryLow', 'trimf', [1000 1500
    1700]);
calories_fis = addmf(calories_fis , 'output', 1, 'Low', 'trimf', [1600 1850
    2000]);
calories_fis = addmf(calories_fis , 'output', 1, 'Medium', 'trimf', [1800 2000
    2200]);
calories_fis = addmf(calories_fis , 'output', 1, 'High', 'trimf', [2150 2500
    2700]);
calories_fis = addmf(calories_fis , 'output', 1, 'VeryHigh', 'trimf', [2600 2800
    3000]);
```

G.3 PiMF

```
%Add membership functions for bmi variable
calories_fis = addmf(calories_fis , 'input', 1, 'Underweight', 'pimf', [13 13
    17.5 18.5]);
calories_fis = addmf(calories_fis , 'input', 1, 'Normal', 'pimf', [18 19 23 25]);
calories_fis = addmf(calories_fis , 'input', 1, 'Overweight', 'pimf', [24 26.5 28
     30]);
calories_fis = addmf(calories_fis , 'input', 1, 'Obese', 'pimf', [28 35 50 50]);

%Add membership functions for activity variable
calories_fis = addmf(calories_fis , 'input', 2, 'Sedentary', 'pimf', [0 0 1 1.5])
    ;
calories_fis = addmf(calories_fis , 'input', 2, 'Light', 'pimf', [1 2 2.5 3.2]);
calories_fis = addmf(calories_fis , 'input', 2, 'Moderate', 'pimf', [3 4 5 5.2]);
calories_fis = addmf(calories_fis , 'input', 2, 'Active', 'pimf', [5 6 7 7.2]);
calories_fis = addmf(calories_fis , 'input', 2, 'VeryActive', 'pimf', [7.1 8 10
    10]);

%Add membership functions for age
calories_fis = addmf(calories_fis , 'input', 3, 'Young', 'pimf', [18 20 30 40]);
calories_fis = addmf(calories_fis , 'input', 3, 'MiddleAge', 'pimf', [35 40 50
    65]);
calories_fis = addmf(calories_fis , 'input', 3, 'Old', 'pimf', [60 85 120 120]);

%Add membership functions for output variable
calories_fis = addmf(calories_fis , 'output', 1, 'VeryLow', 'pimf', [1000 1100
    1300 1700]);
calories_fis = addmf(calories_fis , 'output', 1, 'Low', 'pimf', [1600 1850 1950
    2000]);
calories_fis = addmf(calories_fis , 'output', 1, 'Medium', 'pimf', [1800 2050
```

```
2150 2200]);
calories_fis = addmf(calories_fis, 'output', 1, 'High', 'pimf', [2150 2300 2500 2700]);
calories_fis = addmf(calories_fis, 'output', 1, 'VeryHigh', 'pimf', [2600 2750 3000 3000]);
```

G.4 Final implementation

```
%Create a FIS
calories_fis = newfis('caloriescalculator','mamdani','min','max','min','max','centroid');

%Add input variables
calories_fis = addvar(calories_fis, 'input', 'bmi', [13 50]);
calories_fis = addvar(calories_fis, 'input', 'activity', [0 10]);
calories_fis = addvar(calories_fis, 'input', 'age', [18 120]);

%Add output variable
calories_fis = addvar(calories_fis, 'output', 'calories', [1000 3000]);

%Add membership functions for bmi variable
calories_fis = addmf(calories_fis, 'input', 1, 'Underweight', 'trapmf', [13 13 17.5 18.5]);
calories_fis = addmf(calories_fis, 'input', 1, 'Normal', 'trapmf', [18 19 23 25]);
calories_fis = addmf(calories_fis, 'input', 1, 'Overweight', 'trapmf', [24 26.5 28 30]);
calories_fis = addmf(calories_fis, 'input', 1, 'Obese', 'trapmf', [28 35 50 50]);

%Add membership functions for activity variable
calories_fis = addmf(calories_fis, 'input', 2, 'Sedentary', 'trapmf', [0 0 1 1.5]);
calories_fis = addmf(calories_fis, 'input', 2, 'Light', 'trapmf', [1 2 2.5 3.2]);
calories_fis = addmf(calories_fis, 'input', 2, 'Moderate', 'trapmf', [3 4 5 5.2]);
calories_fis = addmf(calories_fis, 'input', 2, 'Active', 'trapmf', [5 6 7 7.2]);
calories_fis = addmf(calories_fis, 'input', 2, 'VeryActive', 'trapmf', [7.1 8 10 10]);

%Add membership functions for age
calories_fis = addmf(calories_fis, 'input', 3, 'Young', 'trapmf', [18 20 30 40]);
calories_fis = addmf(calories_fis, 'input', 3, 'MiddleAge', 'trapmf', [35 40 50 65]);
calories_fis = addmf(calories_fis, 'input', 3, 'Old', 'trapmf', [60 85 120 120]);

%Add membership functions for output variable
calories_fis = addmf(calories_fis, 'output', 1, 'VeryLow', 'trapmf', [1000 1100 1300 1700]);
calories_fis = addmf(calories_fis, 'output', 1, 'Low', 'trapmf', [1600 1850 1950 2000]);
calories_fis = addmf(calories_fis, 'output', 1, 'Medium', 'trapmf', [1800 2050 2150 2200]);
calories_fis = addmf(calories_fis, 'output', 1, 'High', 'trapmf', [2150 2300 2500 2700]);
calories_fis = addmf(calories_fis, 'output', 1, 'VeryHigh', 'trapmf', [2600 2750 3000 3000]);

```

```
rulelist = [ ...
1 1 1 3 1 1; 1 2 1 3 1 1; 1 3 1 4 1 1; 1 4 1 4 1 1; 1 5 1 5 1 1;...
2 1 1 2 1 1; 2 2 1 3 1 1; 2 3 1 4 1 1; 2 4 1 4 1 1; 2 5 1 5 1 1;...
3 1 1 2 1 1; 3 2 1 3 1 1; 3 3 1 3 1 1; 3 4 1 4 1 1; 3 5 1 5 1 1;...
4 1 1 2 1 1; 4 2 1 2 1 1; 4 3 1 2 1 1; 4 4 1 3 1 1; 4 5 1 3 1 1;...

1 1 2 2 1 1; 1 2 2 3 1 1; 1 3 2 3 1 1; 1 4 2 3 1 1; 1 5 2 4 1 1;...
2 1 2 1 1 1; 2 2 2 2 1 1; 2 3 2 2 1 1; 2 4 2 3 1 1; 2 5 2 4 1 1;...
3 1 2 1 1 1; 3 2 2 1 1 1; 3 3 2 2 1 1; 3 4 2 3 1 1; 3 5 2 4 1 1;...
4 1 2 1 1 1; 4 2 2 1 1 1; 4 3 2 2 1 1; 4 4 2 2 1 1; 4 5 2 3 2 1;...

1 1 3 1 1 1; 1 2 3 2 1 1; 1 3 3 2 1 1; 1 4 3 2 1 1; 1 5 3 3 1 1;...
2 1 3 1 1 1; 2 2 3 2 1 1; 2 3 3 2 1 1; 2 4 3 3 1 1; 2 5 3 3 1 1;...
3 1 3 1 1 1; 3 2 3 1 1 1; 3 3 3 1 1 1; 3 4 3 2 1 1; 3 5 3 3 1 1;...
4 1 3 1 1 1; 4 2 3 2 1 1; 4 3 3 2 1 1; 4 4 3 2 1 1; 4 5 3 2 2 1];

calories_fis = addrule(calories_fis, rulelist);
showrule(calories_fis)

%Plot the membership functions
subplot(2,2,1); plotmf(calories_fis,'input', 1)
subplot(2,2,2); plotmf(calories_fis,'input', 2)
subplot(2,2,3); plotmf(calories_fis,'input', 3)
subplot(2,2,4); plotmf(calories_fis,'output', 1)

%Plot the 2D sufaces
subplot(3,1,1);
gensurf(calories_fis,[1],1)
subplot(3,1,2);
gensurf(calories_fis,[2],1)
subplot(3,1,3);
gensurf(calories_fis,[3],1)

%Plot the 3D surfaces
subplot(2,2,1);
gensurf(calories_fis,[1 2],1)
subplot(2,2,2);
gensurf(calories_fis,[1 3],1)
subplot(2,2,3);
gensurf(calories_fis,[2 3],1)

%Evaluate the FIS
input_data = [...
13.6 0 18;...
26.7 1 60;...
46.3 2 65;...
17.6 3 35;...
27.3 4 40;...
19 4.5 45;...
18.4 5 60;...
24.4 7 65;...
29.1 8 22;...
30.5 7 30;...
28.1 3 100;...
15.6 2 18;...
22.2 1 60;...
27.3 3 100
30.5 3 35;...
28.1 4 40;...
15.6 4.5 45;...
22.2 4 60;...
```

```
16.6 7 65;...
20.3 8 22;...
17.6 10 30;...
];

y = evalfis(input_data, calories_fis);
```