University of Nottingham

G54 FUZ/ COMP4033 Coursework (2021/2022)

Designing and Tuning a Fuzzy Inference System

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1. Introduction

This is an imaginary fuzzy inference system to assist doctor in making decision on whether a patient should be transferred to a hospital for further emergency investigations. Body temperature and the severity of a headache are two consequential parameters of inputs that directly modify the outcome of the fuzzy inference system. The outcome is generated based on the pre-defined rules calculated by the system designer.

2. Hypothesis

It was hypothesized that the urgency level would be affected by different ranges of body temperature, and by high severity of a headache. It was anticipated that the urgency level would increase as the severity of a headache increased. Similarly, the urgency level would rise when the body temperature reaches two extreme ends of either the high or low body temperature range.

3. Related Work

3.1 The Range of Body Temperature

Normal body temperature varies for everyone and changes slightly during the day based on a person's activity and the time of day. It is usually between 36°C and 37.5. The National Health Service (NHS) has suggested that a high temperature, or fever, is usually considered to be 38°C or above. And, normally a fever should not go higher than 42°C. However, an extremely low temperature, known as hypothermia, is also a medical emergency. The Cleveland Clinic has suggested that hypothermia conditions occur when the body's temperature range drops below 35°C.

3.2 Linguistic Variable Definition

Based on the given information and research from the NHS and Cleveland Clinic, the linguistic variables were defined. Generally, there are two input linguistic variables and one output linguistic variable, followed by their membership functions in different types of models.

Severity of headache are composed of three different terms- '*mild*', '*moderate*', '*severe*' over its universe of discourse.

$$U = [0, 10]$$
$$T(\text{Headache}) = \text{mild} + \text{moderate} + \text{severe}$$

Temperature range are composed of five different terms- '*very low*', '*low*', '*normal*', '*high*', '*very high*' over its universe of discourse.

$$U = [30, 42]^* \text{ and } U = [31, 42]^{**}$$
$$T(\text{Temperature}) = \text{very low} + \text{low} + \text{normal} + \text{high} + \text{very high}$$

Urgency level are consisted of three different terms- '*negligible*', '*medium*', '*emergent*' over its universe of discourse.

$$U = [0, 100]$$
$$T(\text{Urgency}) = \text{negligible} + \text{medium} + \text{emergent}$$

4. Models

We had conducted a preliminary work with fuzzy inputs, outputs, and universal sets which were defined beforehand. Different membership functions and fuzzy rule matrices were built and tested in the following models.

4.1 Model One

Using the predefined universe of discourse and term-set, three different membership functions were applied to these linguistic variables. A Gaussian membership function was applied to the parameters of the severity of headache; a trapezoidal membership function was applied to the parameters of body temperature; and a triangular membership function was applied to the urgency level.

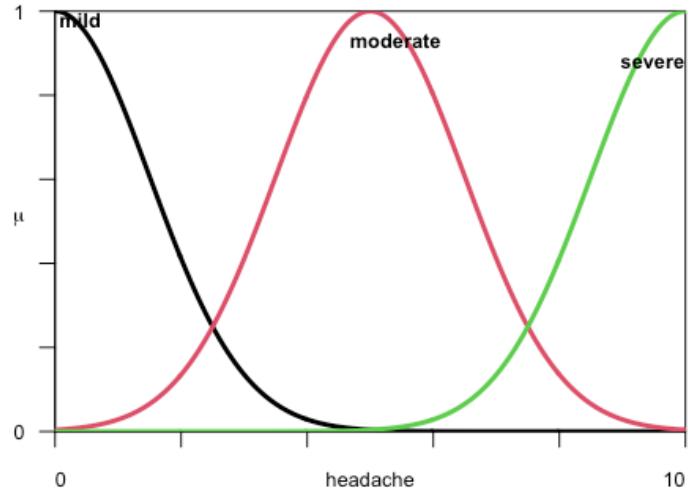

Figure 4.1 Plot of membership function of severity of a headache.

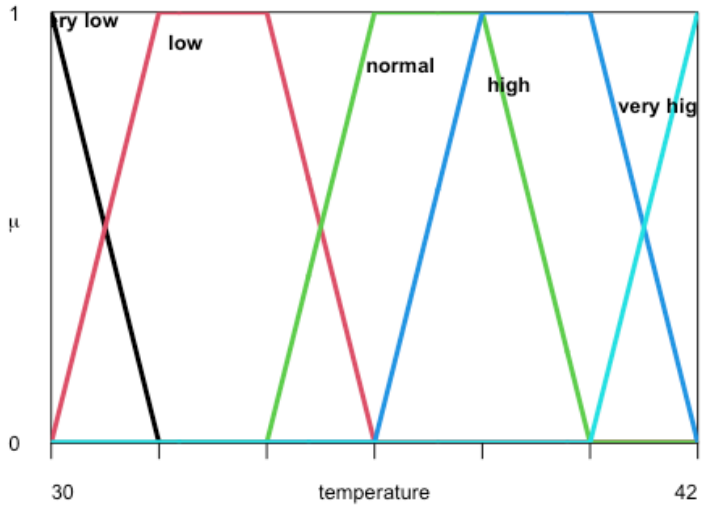

Figure 4.2 Plot of membership function of body temperature.

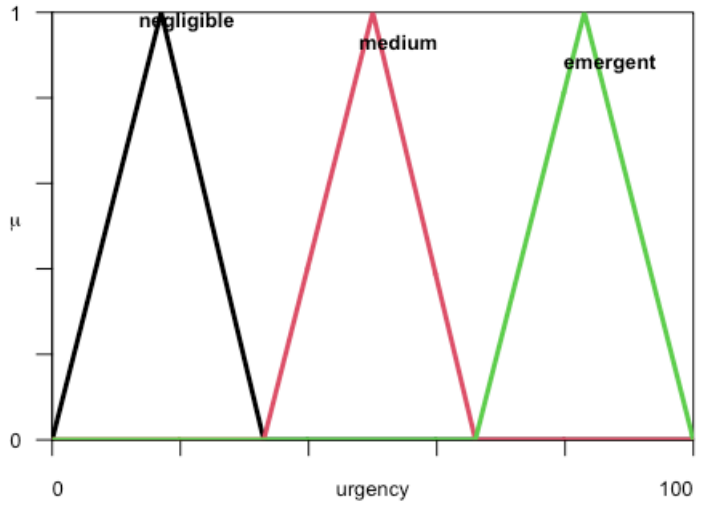

Figure 4.3 Plot of membership function of urgency level.

A rule set was created to fit in this fuzzy inference model. The decision of urgency should be made based on the rule set.

Rule No.	Headache	Temperature	Urgency	Weighting	AND/OR
1	Mild	Low	Negligible	1	AND
2	Mild	Very High	Urgent	1	AND
3	Moderate	Normal	Negligible	1	AND
4	Moderate	Very High	Urgent	1	AND
5	Moderate	Very Low	Urgent	1	AND
6	Severe	Very Low	Urgent	1	AND
7	Severe	Normal	Medium	1	AND
8	Severe	Very High	Urgent	1	AND

Figure 4.4 Table of rule set.

The final 3D plot was generated as follows, however, the direction of the plot was not easy to view. In the next models, the axes of body temperature and severity of headache were switched in order to be read more clearly.

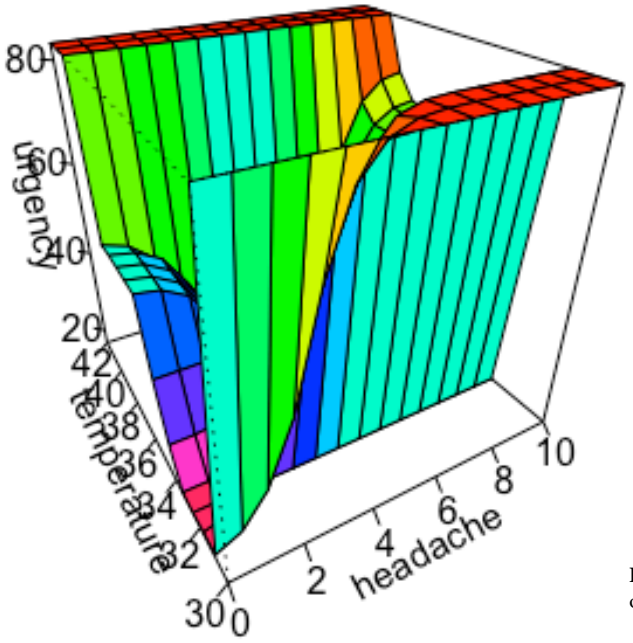

Figure 4.5 3D plot of model one.

4.2 Model Two

In model two, the presentation of membership functions of body temperature was changed significantly as we knew that the '*normal*' range should be wider. Therefore, the trapezoidal membership function was only applied to the term '*normal*' range. The rest of the term were presented in triangular membership functions. Gaussian membership functions were applied to both severity of headache and urgency term-sets.

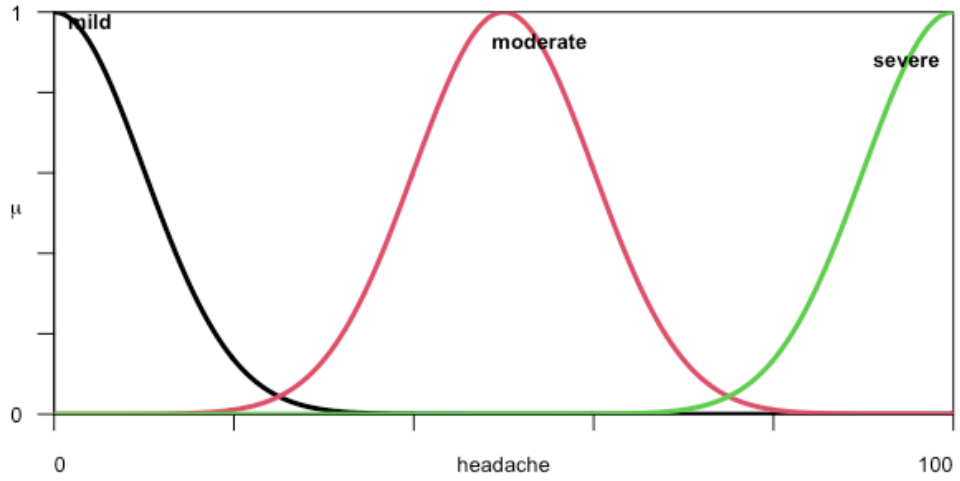

Figure 4.6 Plot of membership function of severity of a headache.

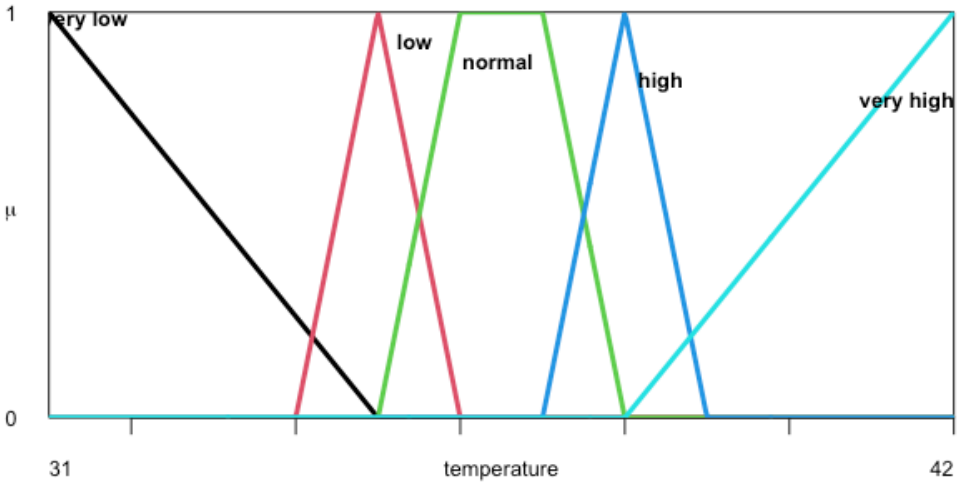

Figure 4.7 Plot of membership function of body temperature.

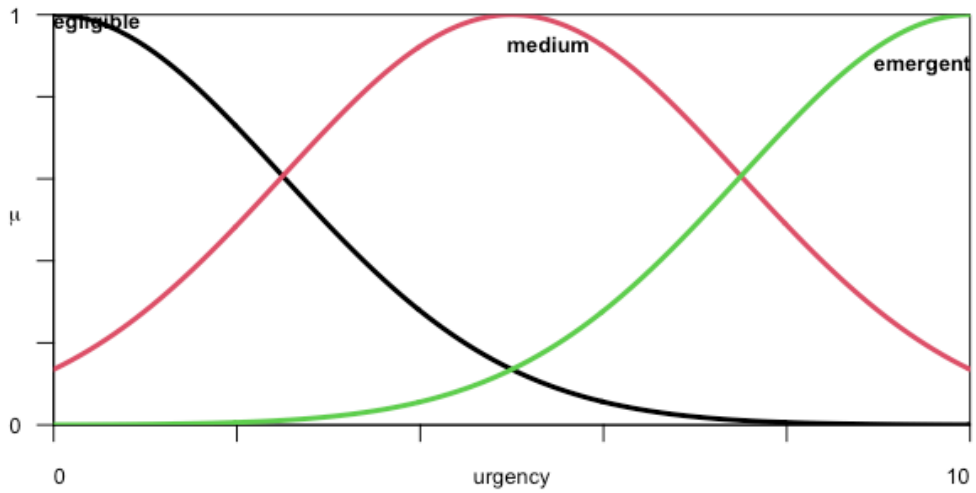

Figure 4.8 Plot of membership function of urgency level.

Another set of fuzzy inference system rule was introduced to fit the model. As the slope between '*low*' and '*very low'*; and '*high*' and '*very high*' should be more smooth and sharper than the previous model.

Rule No.	Headache	Temperature	Urgency	Weighting	AND/OR
1	Mild	Normal	Urgent	1	OR
2	Moderate	Low	Medium	1	AND
3	Severe	Very High	Urgent	1	OR
4	Moderate	High	Medium	1	AND
5	Moderate	Normal	Negligible	1	AND

Figure 4.9 Table of rule set.

The final 3D plot indicates that model two does have a more smooth layout when the urgency level is high.

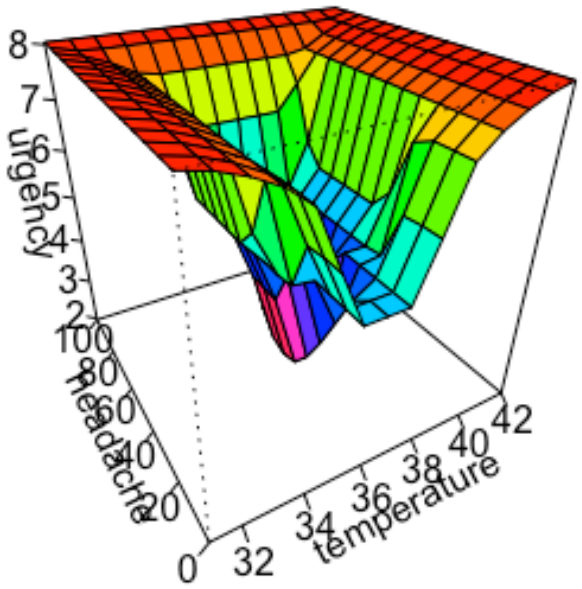

Figure 4.10 3D plot of model two.

5. Final Fuzzy Model and its Performance

In this model, the goal is to maximize the area of '*negligible*' and '*medium*' in the urgency term-set. Three triangular membership functions were used in both the input and output term-sets. Moreover, each of the two inputs has its own membership functions with one shared control parameter (cp= 50). The exact same rule set from model two was adopted in this model, and it generated a 3D plot that matched the hypothesis.

This model is composed of two input membership functions, Severity of Headache and Body Temperature, and one output membership function, Urgency Level. The linguistic variables and their mathematical triangular membership functions are listed below:

5.1 Linguistic Variable and Membership Function

Severity of Headache:

$$U = [0, 10]$$
$$T(\text{Headache}) = \text{mild} + \text{moderate} + \text{severe}$$
$$\mu(\text{mild}) = max(min(x/0, (50-x)/50), 0)$$
$$\mu(\text{moderate}) = max(min((x/50), (100-x)/50), 0)$$
$$\mu(\text{severe}) = max(min((x-50)/50, (100-x)/0), 0)$$

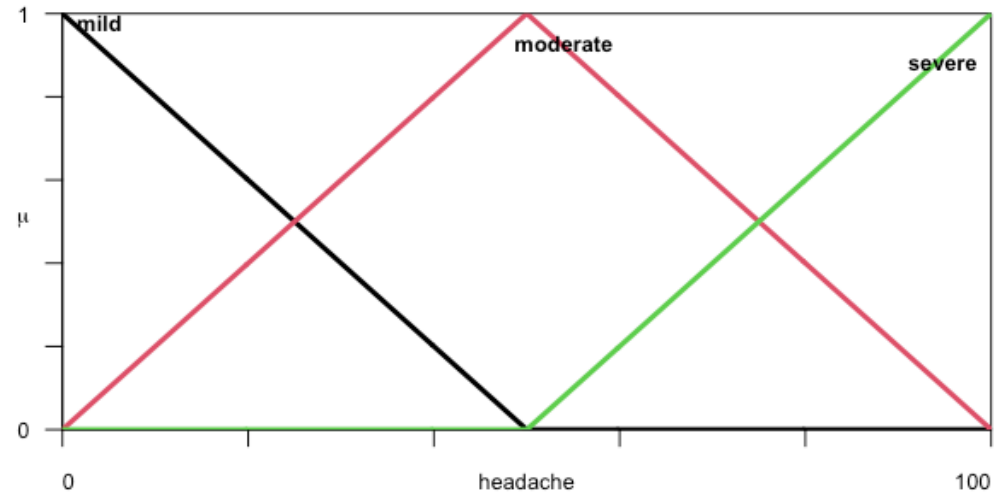

Figure 5.1 Plot of membership function of severity of a headache.

Body Temperature:

$$U = [31, 42]$$
$$T(\text{Temperature}) = \text{very low} + \text{low} + \text{normal} + \text{high} + \text{very high}$$
$$\mu(\text{very low}) = max(min((x-31)/0, (34-x)/3), 0)$$
$$\mu(\text{low}) = max(min((x-31)/3, (37-x)/3), 0)$$
$$\mu(\text{normal}) = max(min((x-33)/3, (39-x)/3), 0)$$
$$\mu(\text{high}) = max(min((x-35)/3, (41-x)/3), 0)$$
$$\mu(\text{very high}) = max(min((x-38)/3, (41-x)/0), 0)$$

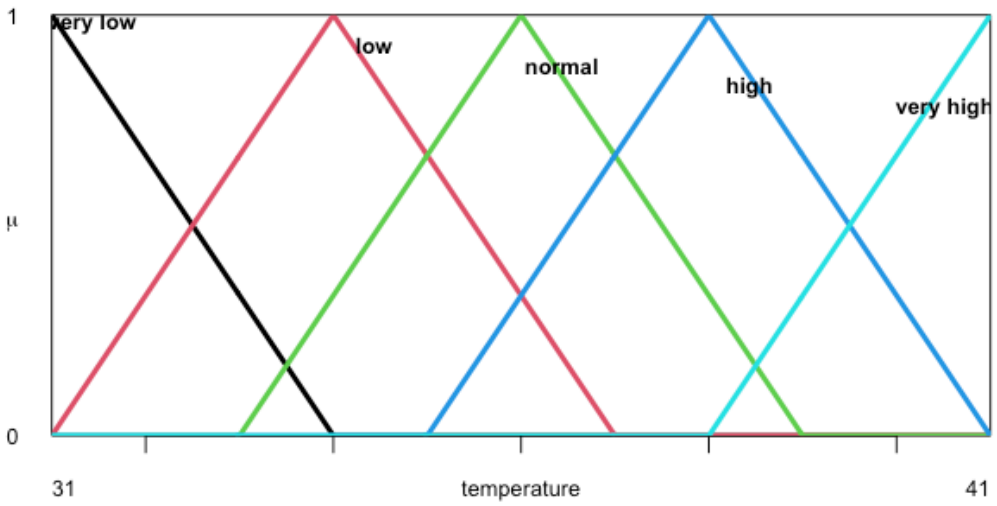

Figure 5.2 Plot of membership function of body temperature.

Urgency:

$$U = [0, 10]$$
$$T(\text{Urgency}) = \text{negligible} + \text{medium} + \text{emergent}$$
$$\mu(\text{negligible}) = max(min((x-0)/0, (5-x)/5), 0)$$
$$\mu(\text{medium}) = max(min((x-0)/5, (10-x)/5), 0)$$
$$\mu(\text{urgent}) = max(min((x-5)/5, (10-x)/0), 0)$$

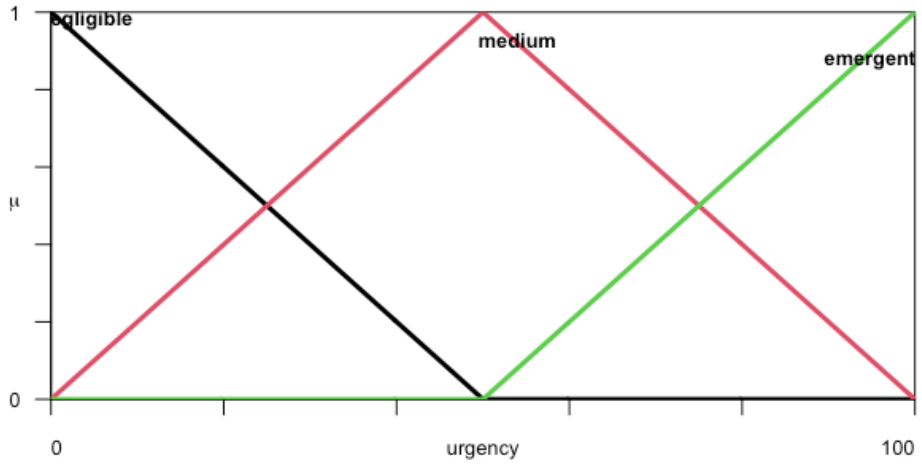

Figure 5.3 Plot of membership function of urgent level.

5.2 Fuzzy Rules

A fuzzy rule was developed to store the If-Then statement to inform doctors about the decision made by this fuzzy inference system. In my designing concept, I aimed to increase the urgency level when temperature reaches extreme ends or when severity of headache rises. Moreover, the need for emergent investigation in the emergency room should also be minimized if the urgency level of a patient is in the range between '*Negligible*' and '*Medium*'. The rule is presented in the following chart:

Rule No.	Headache	Temperature	Urgency	Weighting	AND/OR
1	Mild	Normal	Urgent	1	OR
2	Moderate	Low	Medium	1	AND
3	Severe	Very High	Urgent	1	OR
4	Moderate	High	Medium	1	AND
5	Moderate	Normal	Negligible	1	AND

Figure 5.4 Table of rule set.

5.3 Results

The outcome shows that the fuzzy inference system illustrates that the urgency level is high when the body temperature is too high or too low and when the severity of a headache is high regardless of the body temperature. On the other hand, the urgency level does not change drastically as the body temperature stays in the normal range and the severity of a headache remains low.

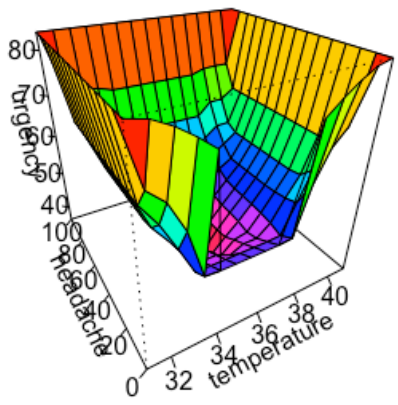

Figure 5.5 3D plot of the final model

5.4 Defuzzification

Making adjustment on the R script and interpreting the result through GUI, the results of different defuzzification methods are listed in the followings:

Center of Gravity: 83.67
Largest of Maxima: 100
Smallest of Maxima: 100
Mean of Maxima: 100
Bisector: 85.71

5.5 Performance

The final fuzzy model met the anticipation I had before starting to construct the models. Therefore, further verification of its accuracy and reliability is needed to assure its performance. This model was tested by the defuzzifier in the 'FuzzyR' package. To evaluate the accuracy of the model and to discover the limit of this model, a RMSE model was used. The RMSE result turned out to be approximately 15.72, which is far lower than the two models introduced earlier.

Temperature	Headache	Target Urgency	Actual Urgency	Error	Error^2
31	0	100	83.67	16.33	266.6689
31	100	100	83.67	16.33	266.6689
42	0	100	83.67	16.33	266.6689
42	100	100	83.67	16.33	266.6689
36	5	50	37	13	169
				Sum	1235.6756
				Mean Squared Error	247.13512
				RMSE	15.72

Figure 5.6 Table of the RMSE calculation.

5.6 Limitation

Although the RMSE result is low, a better fuzzy inference system can be developed based on the current model. Without thorough knowledge in medical field; there is a possibility that this system was built up without an experienced insight of human thinking. In order to develop a more advanced fuzzy inference system, we may need to test a larger amount of parameters for input membership functions and consult for experts in medical fields to develop a more accurate output membership functions.