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Mamdani Fuzzy Inference System (FIS) for Early Diagnosis of Diabetes Mellitus (DM) and Calorie Needs

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Abstract— Diabetes Mellitus (DM) is a frightening type of disease because DM causes complications for the sufferer if it is not treated quickly. From year to year DM in Indonesia has undergone a significant increase and ranked 6th in the world. In this study, a fuzzy logic system was created for the early diagnosis of DM and calorie needs using the Mamdani method. The trial was conducted in collaboration with Jombang Regional Hospital by comparing the results of the doctor's diagnosis with the fuzzy system created by taking 50 samples of inpatient's medical record data. The first result of this research is a DM diagnosis system with 6 input variables, 3 output variables and 155 rules with MAPE achieved 29.48%. The second is a system of need calorie with 2 input variables, 2 output variables and 9 rules with the results achieved BMI with MAPE of 10.57% and BMR of MAPE of 9.7%.

Keywords— FIS, Mamdani, Diabetes Mellitus, Calorie.

I. INTRODUCTION

Diabetes Mellitus (DM) comes from the Latin word, Diabetes meaning to drain and Mellitus meaning sweet. This disease arises due to metabolic disorders in the body so that blood sugar levels increase (hyperglycemia). Metabolic disorders occur if the pancreas cannot produce enough insulin as what the body needs [1], [2]. The hormone insulin has the function of maintaining blood sugar levels to remain balanced so that the metabolic processes of carbohydrates, fats, and proteins are converted into energy needed by the human body.

The development of DM in Indonesia from year to year has increased. According to the Atlas International Diabetes Federation (IDF) report in 2017 the DM epidemic in Indonesia was ranked sixth in the world after China, India, America, Brazil, and Mexico with DM at the age of 20-79 years of 10.3 million people. Furthermore, the Basic Health Research (Riskesdas) report in 2018 DM sufferers in Indonesia increased up to 8.5% when it is compared to 2013 which was 6.9%.

One of the ways to maintain the health of people with DM is by maintaining dietary habit through a healthy diet [3]. Dietary habit are managed by considering calorie need in a day [4]. The number of calories needed by the body affects the energy needed to do daily activities. Energy needs of each person is different because it is influenced by factors of age, gender, activity and body condition of a person.

DM cannot be cured completely. DM treatment is only used to control or manage blood sugar levels in the body to remain normal. Therefore, we need a method to control and provide early diagnostic information about DM. One of

them is by using Fuzzy Inference System (FIS). Fuzzy system is very suitable to be applied in helping to make decisions quickly and well because it is easily understood and practical.

Some researches that have been done by utilizing the fuzzy system are determining the risk level of DM with the Sugeno method with input variables consisting of fasting blood sugar, fasting plasma blood sugar, sleeping plasma sugar, 2 hour PP blood sugar, HbA1c levels, HDL levels, triglyceride levels and insulin levels [5], DM diagnosis using Mamdani and Sugeno methods [6], DM detection using fuzzy hierarchical models [7], using Mamdani method for DM disease detection with input variables consisting of age, weight, blood pressure [8], prediction and classification of DM using the adaptive neuro FIS application [9], using the Sugeno method in determining the type of DM with input variables consisting of age, insulin levels and body weight [10]. Based on the description above, the researchers had a purpose to apply Mamdani method to diagnose early DM and the calorie needs needed by sufferers of this disease. The results of the study are expected to be used as an information system in making decision in the early selection of DM disease.

II. DIABETES MELLITUS, MAMDANI FIS, AND CALORIE NEEDS

Some basic and supporting theories used in this study are:

A. Diabetes Mellitus (DM)

DM occurs due to metabolism disturbed because pancreas can't produce the hormone insulin effectively. The purpose of the pancreas to produce the hormone insulin to control blood sugar levels in the body remains balanced. There are two types of DM namely [11]:

1) Type I (Depending on Insulin)

It is characterized by failure to produce partial or total insulin by pancreatic beta cells. The cause of this factor is still unclear, but several viruses, autoimmune diseases, and genetic factors can be the causes. Children and adults can suffer DM of type 1. The treatment is by giving insulin injections to control blood sugar levels.

2) Type II (Not Depending on Insulin)

It is characterized by insulin resistance when the hormone insulin is produced in an ineffective amount. This DM is caused by strong genetic and obesity and usually experienced by adults. DM of type 2 is treated by diet and exercise and the use of diabetes medications.

B. Mamdani Fuzzy Inference System (FIS)

The Mamdani method was introduced by Ebrahim Mamdani in 1975, often called the max-min method [12]. To produce an output, four stages need to be passed namely:

1) Fuzzyfication

Formation of input and output variables in the form of craps so that it becomes a fuzzy set.

2) Function of Implications

The function used in this case is min (minimum).

3) Composition of Rules

What is done is the rule with the max (maximum) method. This method is obtained from the maximum value, then used to modify the fuzzy area and apply to the output with the OR (union) operator. The resulted output contains fuzzy set which is a reflection of the contribution of each proportion. The formulation is written as follows:

$$\mu_{sf}(x_i) = \max(\mu_{sf}(x_i), \mu_{kf}(x_i)) \quad (1)$$

with :

$\mu_{sf}(x_i)$ = fuzzy solution member values up to the i-th rule;

$\mu_{kf}(x_i)$ = fuzzy consequent member values up to the i rule;

4) Defuzzy

The defuzzyfication process input contains a set of fuzzy rule compositions while the output is a number in the origin area of the fuzzy membership. So if it is given a certain range of fuzzy set, the crisp value must be taken as output. The method used in this stage is the centroid method (composite moment). The centroid method is a crisp solution obtained from the central point (z^*) of the fuzzy region

$$z^* = \frac{\int_z z \mu(z) dz}{\int_z \mu(z) dz} \quad \text{for continuous variables or} \quad (2)$$

$$z^* = \frac{\sum_{j=1}^n z_j \mu(z_j)}{\sum_{j=1}^n \mu(z_j)} \quad \text{for discrete variables} \quad (3)$$

C. Calorie Needs

Calorie needs needed by people with DM are related to the food consumed every day. Foods that are consumed as what the body needs are balanced foods between nutrients, carbohydrates, proteins, fats, vitamins and minerals. Here are some types of diets and the number of calories for people with DM [13].

TABLE 1. DM DIET TYPE

| Diet Type | Energy (Kalori) | Carbohydrate (g) | Protein (g) | Fat (g) |
|-----------|-----------------|------------------|-------------|---------|
| I | 1100 | 172 | 43 | 30 |
| II | 1300 | 192 | 45 | 35 |
| III | 1500 | 235 | 51,5 | 36,5 |
| IV | 1700 | 275 | 55,5 | 36,5 |
| V | 1900 | 299 | 60 | 48 |
| VI | 2100 | 319 | 62 | 53 |
| VII | 2300 | 369 | 73 | 59 |
| VIII | 2500 | 396 | 80 | 62 |

Explanation:

1) Types of Diet I to III

It is given to people with fat DM and very fat (obese) DM.

2) Types of Diet IV to V

It is provided for people with DM without complications or normal weight.

3) Types of Diet VI to VIII

It is given to people with thin, very thin, and complicated diabetes.

The calculation of the number of calories needed for people with DM is also related to the Mass Body Index (BMI) which is calculated using the BMI formula:

$$BMI = \frac{Body_Mass(Kg)}{Height(m)} \times Height(m) \quad (4)$$

III. RESEARCH STAGES BY USING FUZZY MAMDANI METHOD

The stages of fuzzy research using the Mamdani method are described in the following flowchart as in Figure 3.1.

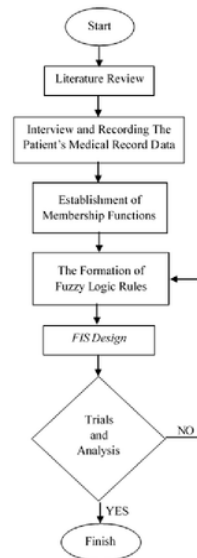


Figure 1. Research Stages

Based on Figure 1. The stages of research consist of:

- Literature review
The initial stage is to collect various information about DM disease from journal articles, books, internet and other various sources.
- Interviewing and Writing the Data of Patients' Medical Record
Direct interviews were conducted with doctors and nutritionists at a Jombang regional hospital to find out firsthand DM disease and continued to the data retrieval in the form of patients' medical record data related to DM variables.
- Establishment of Membership Functions
The formation of membership functions in the logic of the two fuzzy systems that will be made in this

study are: the first system consists of 7 inputs and 3 outputs. Input variables consist of: systole, diastole, glucose, total cholesterol, HDL levels, LDL levels, triglycerides. Output variables are normal, prediabetes, and diabetes. The detailed fuzzy process can be described as follows:

1) Blood Pressure

TABLE 1. BLOOD PRESSURE (mmHg)

| Range | | Fuzzy Zet |
|---------|----------|-----------------------|
| Systole | Diastole | |
| 100-120 | 20-80 | Normal |
| 115-145 | 75-95 | Prehypertension |
| 140-160 | 90-100 | Hypertension State I |
| 155-240 | 95-140 | Hypertension State II |

2) Glucose At a Time

TABLE 2. GLUCOSE AT A TIME (mg/dl)

| Range | Fuzzy Zet |
|---------|-----------|
| 100-200 | Normal |
| 200-300 | Diabetes |

3) Total Cholesterol

TABLE 3. CHOLESTEROL TOTAL (mg/dl)

| Range | Fuzzy Zet |
|---------|-------------|
| 100-200 | Normal |
| 190-250 | Rather High |
| 240-300 | High |

4) HDL Levels

TABLE 4. HDL LEVELS (mg/dl)

| Range | Fuzzy Zet |
|-------|-----------|
| 20-50 | Low |
| 45-65 | Normal |
| 60-80 | High |

5) LDL Levels

TABLE 5. LDL LEVELS (mg/dl)

| Range | Fuzzy Zet |
|---------|--------------------|
| 50-100 | Optimal |
| 90-135 | Near Optimal |
| 130-160 | High Boundary Line |
| 155-195 | High |
| 190-210 | Very High |

6) Triglycerides

TABLE 6. TRIGLYCERIDES (mg/dl)

| Range | Fuzzy Zet |
|---------|-------------|
| 50-150 | Normal |
| 145-205 | Rather High |
| 200-500 | High |
| 495-600 | Very High |

The second system is to determine the calories needed by people with DM. The membership function consists of 2 input variables namely body weight and height as well as output variables namely BMI and BMR. The detailed fuzzy process can be described as follows:

1) Body's Weight

TABLE 7. BODY MASS (kg)

| Range | Fuzzy Zet |
|-------|-----------|
| 25-40 | Thin |
| 38-60 | Normal |
| 58-80 | Fat |

2) Height

TABLE 8. HEIGHT (meter)

| Range | Fuzzy Zet |
|-----------|-----------|
| 1.20-1.45 | Short |
| 1.40-1.65 | Normal |
| 1.60-1.85 | High |

- Establishment of Fuzzy Logic Rules
Fuzzy logic rules are arranged based on a combination of fuzzy sets of each input variable.
- FIS Design
Making the application of function implications, composition of rules, and defusion is a step to interfere with fuzzy systems in a case sample.
- Trial and Analysis

The trial was conducted in collaboration with Jombang Regional Hospital by comparing the results of the doctor's diagnosis with the fuzzy system created by taking 50 samples of inpatient's medical record data. Analysis is made by using the Mean Absolute Percent Error (MAPE) method. The calculation of MAPE is as follows:

$$MAPE = \frac{\sum_{i=1}^n |Y_i - \bar{Y}_i|}{Y_i} \times 100 \quad (5)$$

With:

Y_i = actual data

\bar{Y}_i = predictive data

n = sum of data

IV. RESULT AND DISCUSSION

This research consists of 2 fuzzy systems, in which the first system diagnoses diabetes, prediabet, and normal and the second system determines the calories needed by using the Mamdani fuzzy method. The results of each system are as follows.

A. Diagnosis of Diabetes Mellitus (DM)

In the first system, the inputs used to build a fuzzy system for diagnosing diabetes mellitus are systole, diastole, glucose, total cholesterol, HDL, LDL and triglyceria. The fuzzyfication stage in this system forms the range and fuzzy sets of each input and output using a shoulder curve. The results of the membership function of the input variable at each set of fuzzy sets are as follows.

1) Blood Pressure

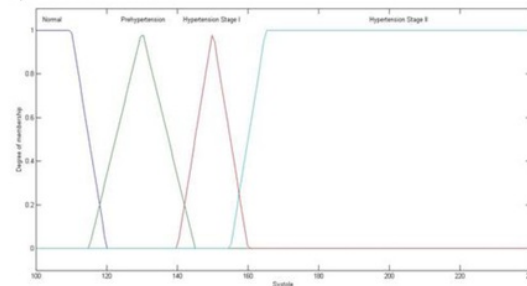


Figure 2. Membership of Systole

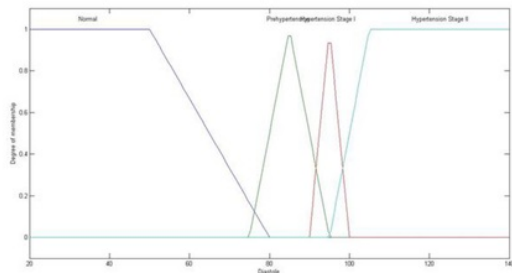


Figure 3. Membership of Diastole

2) Glucose At a Time

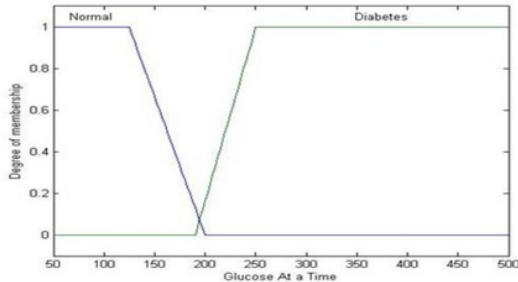


Figure 4. Timing Glucose Membership

3) Total Cholesterol

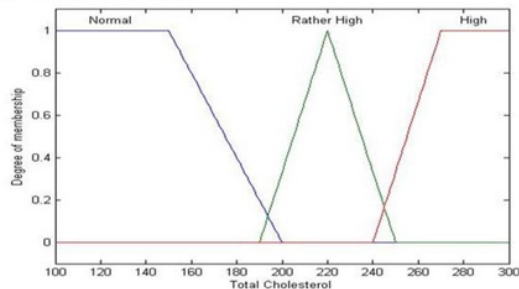


Figure 5. Total Cholesterol Membership

4) HDL Levels

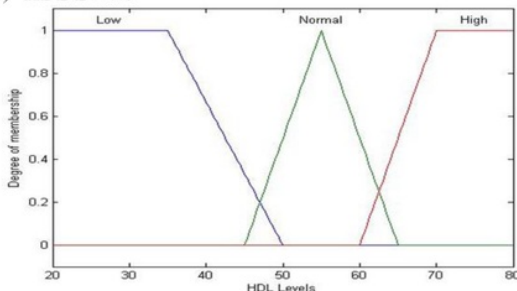


Figure 6. Membership of HDL Levels

5) LDL Levels

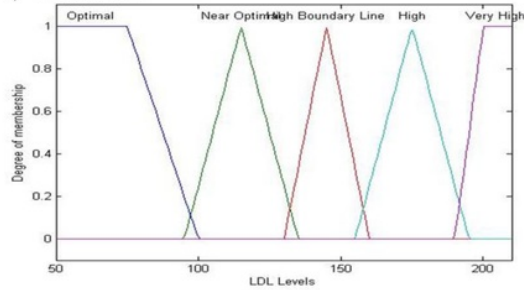


Figure 7. Membership of LDL Levels

6) Triglycerides

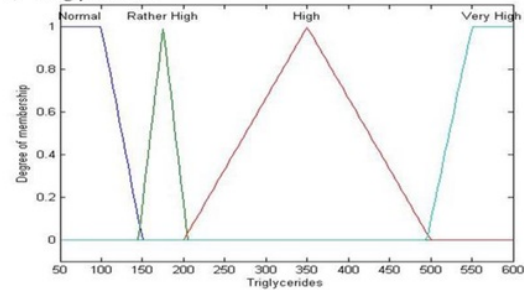


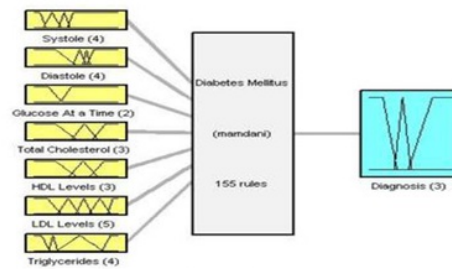
Figure 8. Triglyceride Membership

While the output in this system is divided into 3 fuzzy sets, namely normal, prediabetes and diabetes. Fuzzy sets of DM output formed as follows:

TABLE 9. OUTPUT DM

| Range | Fuzzy Zet |
|---------|-------------|
| 50-100 | Normal |
| 95-125 | Prediabetes |
| 120-200 | Diabetes |

The inference stage in this system is 155 rules. So that the diabetes mellitus system is formed with 7 inputs, 1 output and 155 rules as shown in Figure 9 below.



System Diabetes Mellitus: 7 inputs, 1 outputs, 155 rules

Figure 9. DM Diagnosis System

The results of the analysis of 50 data obtained from Jombang Regional Hospital with a fuzzy system using MAPE were 29.48%. For example i₄ blood pressure is 140/90 mmHg, glucose at 107 mg / dl, total cholesterol 203 mg / dl, HDL 44 mg / dl, LDL 140 mg / dl and triglyceria 94 mg / dl., then the rule formed is:

R27 If systole prehypertension and diastole prehypertension and glucose when normal and total cholesterol are

rather high and HDL is low and LDL is in high borderline and triglyceria is normal, then the diagnosis is normal

R27 If systole prehypertension and diastol prehypertension and glucose at time are normal and total cholesterol is rather high and HDL is low and LDL is in high boundary and triglyceria is normal, then the diagnosis is prediabetes.

Based on the results of the DM fuzzy diagnosis system obtained 85.5 which means normal, while according to data from Jombang Regional Hospital 98 whose meaning is that it is normal. The difference of results of the system from the data obtained is only 12.5 but both show normal diagnoses. The results of the DM diagnosis system based on fuzzy system can be seen in Figure 10.

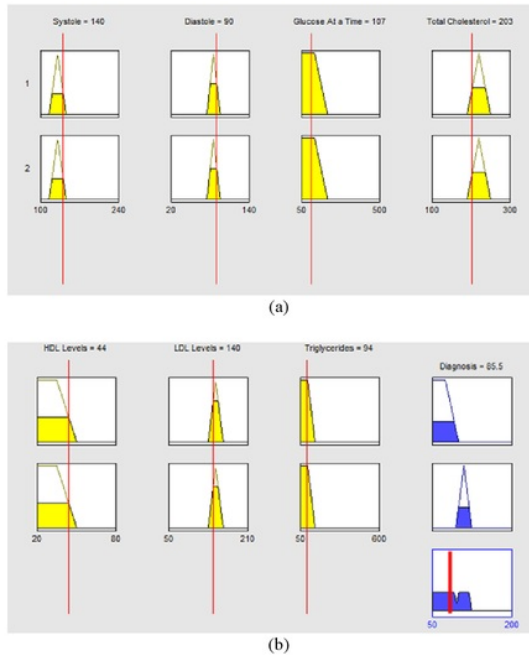


Figure 10. (a), (b) Results of DM Diagnosis by Using Fuzzy System

B. Calorie Needs

This second system is to determine the calories needed. This study used two outputs namely BMI and BMR, in the forms of inputs of weight and height. This kind of system is the same as the first system also using shoulder curves. It is with two inputs, two outputs and 9 fuzzy IMT and BMR system rules as shown in Figure 13 below. The results of the input variables of membership function at each fuzzy set are follows.

1) Weight

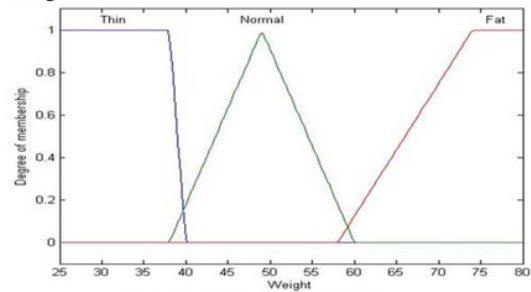


Figure 11. Membership of Weight

2) Height

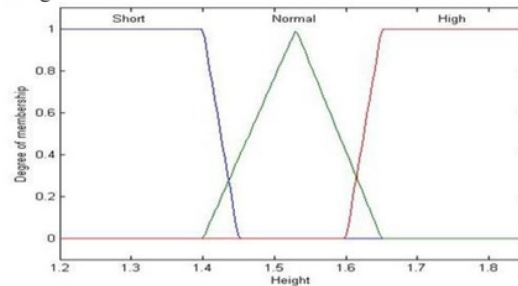
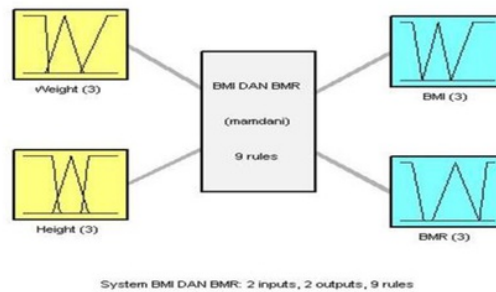


Figure 12. Membership of Height



System BMI DAN BMR: 2 inputs, 2 outputs, 9 rules

Figure 13. IMT and BMR system with 2 inputs, 2 outputs and 9 rules

For instance, if you weigh 53 kg and your height is 1.63 m., so the formed rule is

R5 If the weight and height are normal , BMI and BMR are normal

R8 If your weight is normal and you are tall, BMI and BMR are normal

Fuzzy sets of IMT output formed as follows:

TABLE 10. OUTPUT IMT

| Range | Fuzzy Zet |
|---------|-----------|
| 15-18,5 | Thin |
| 18,5-23 | Normal |
| 23-30 | Fat |

Fuzzy sets of BMR output formed as follows:

TABLE 11. OUTPUT BMR

| Range | Fuzzy Zet |
|-----------|-----------|
| 1300-1600 | Fat |
| 1700-2300 | Normal |
| 2300-2500 | Thin |

Based on the results of the fuzzy IMT and BMR system in Figure 12, the BMI of 20.8 kg / m² is normal so that the required BMR is 2000 calories. Whereas, according to the formula, IMT of 19.94 means normal and the required BMR is around 1700 to 2100 calories. The difference of the fuzzy system results from those of the system with the formula is only 0.86 and both of them show the normal BMI with the appropriate BMR.

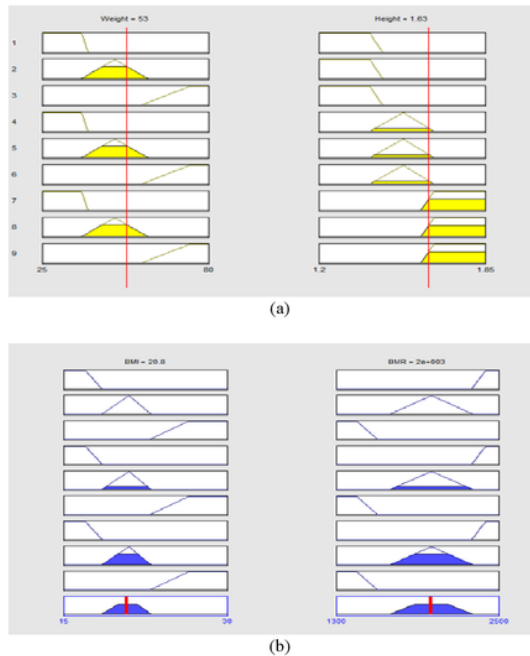


Figure 14. (a), (b) Results of IMT and BMR with fuzzy systems

Correlation between calorie requirements and DM according to the description of Table 1. Suppose the type of diet I to diet III is given to people with DM fat and very fat (obese) requires calories of 1100 to 1500 calories.

V. CONCLUSION

Based on the results and discussion of this study, it can be concluded that an application in the health field has been made, namely early diagnosis of DM using the Fuzzy Mamdani method and calorie needs. The DM diagnosis system consists of 6 input variables: blood pressure, glucose time, total cholesterol, HDL, LDL, triglycerides and 3 output variables: normal, prediabetes and diabetes by producing 155 rules with a MAPE of 29.48%. The calorie need system comprises of 2 input variables: body weight, and height and 2 output variables: BMI with MAPE of 10.57% and BMR of MAPE of 9.7% by producing 9 rules.

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