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Original Article

A Novel Wound Assessment System Using Fuzzy Logic

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***Abstract** - Wounds are simply injuries that cause the skin and body tissues to break down. Cuts, punctures, scratches, and scrapes are all examples of wounds. Numerous parameters can be used when evaluating a wound, such as wounds depth and size, the colour of the wound, its odour, the amount of tissue present, etc. Each of these parameters can be used on its own or in combination with others. The appearance of the wound is an essential factor in determining the healing time. For this paper, fuzzy logic is used to calculate the values of variables, which does not require precise input and instead estimates the values of variables and incorporates a number of different input parameters.*

Keywords — *Fuzzy logic, Membership functions, Wound Assessment, MATLAB.*

I. INTRODUCTION

Medical research has progressed to the point that wound assessment has become a required and demanding task. Since it necessitates a considerable deal of observation, evaluation, and strong judgment, comprehensive and accurate wound assessment has become increasingly crucial. The primary goals of wound assessment are to obtain an accurate diagnosis and deliver the most effective treatment possible. Wound status can be identified by using physical aspects of the wound, such as its size and colour, odour, and its depth, among other things. Already, specific instruments for wound assessment are available, such as wound charts and the TIME technique, which are both regularly utilized in the field[1-3]. It is vital to conduct wound assessments to determine appropriate treatment recommendations for the wound being treated. Determining whether or not to clean the wound, selecting a dressing, and dealing with discomfort are all examples of decisions that need to be taken in this situation. When it comes to healing a wound properly, numerous stages must be completed. These stages include inflammation, haemostasis (clotting), proliferation (cell division), and epithelialization (skin formation)[4-6].

Fuzzy logic is becoming increasingly popular in various industries, particularly the defence and electronics industries. The fuzzy logic notion produces the output based on the assumptions made about the input data set. When it comes to determining the severity of the wound, fuzzy logic is employed[5-10]. This particular case uses the four input parameters that have been previously discussed. Using the example of body temperature, ambient temperature, humidity, and oxygenation as an input parameter, and wound evaluation as an output parameter. Specifically, the purpose of this study article is to determine how a wound responds to variations in temperature or meteorological conditions[10-15].

II. MATERIALS AND METHODS

When it comes to detecting and responding to changes in tissue, wound monitoring systems rely on a fuzzy logic framework. The wound monitoring is done using body temperature, humidity, and oxygen levels parameters and can be performed using a fuzzy inference system built-in in MATLAB. Membership functions are used to fuzzify both the input and output signals simultaneously[15-20]. In particular, the current research work uses a triangular membership function to accomplish its conclusions and findings. Input factors include body temperature, air temperature, humidity, and oxygen levels. It creates an output parameter, a score based on how well the wound is healing. The wound assessment is categorized into three normal, improved, and alert levels. The most frequently encountered category is "normal" [20-25]. The fuzzy rule base is used to provide information about the current state of the output variables. When it comes to providing information about the present state of the output variables, the fuzzy rule base comes in handy. Fuzzy logic to construct the monitoring system's decision-making inference system, illustrated in Figure 1.

A. Categorisation of Input and Output Parameters

During the wound assessment process, the physical appearance of the wound is taken into consideration. Calculating the input parameters is done using triangular membership functions. It is straightforward to put into action. To do so, it is necessary to employ frequently observed parameters, such as temperature, oxygen, and humidity.

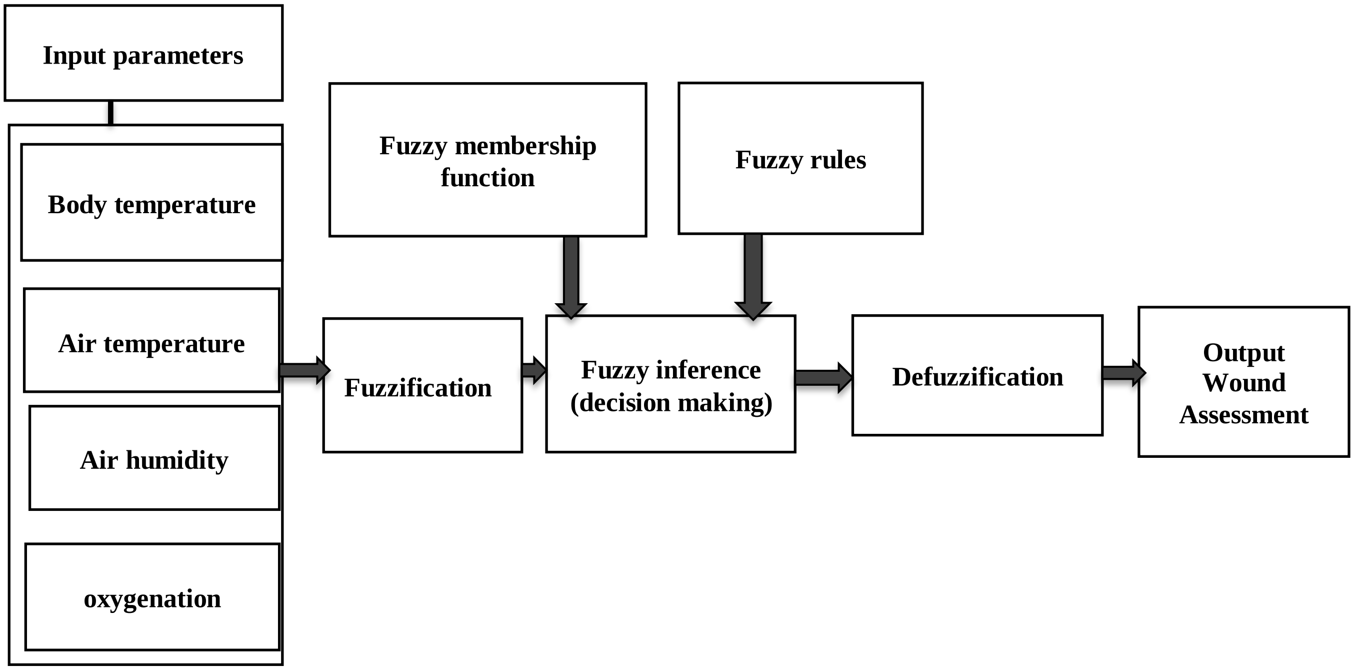

Fig 1. Fuzzy inference system

a) Measuring body temperature

When the human body's temperature fluctuates, it is called "thermoregulation." Temperature values for measuring body temperature are listed in Table 1. When assessing a wound, body temperature is considered an essential factor. The membership function is depicted in Figure 2. The following equations show that the triangular membership function represents the body temperature ranges.

Table 1. Body temperature

Standard range	Body temperature in Celcius
Low	<33°C
Normal	34-38°C
High	38-43°C
Very high	<44°C

$$\text{Body Temperature}_{\text{low}}(x) = \begin{cases} 0, & x \le 0 \\ \frac{37-x}{37}, & 0 < x \le 37 \\ 0, & x \ge 37 \end{cases}$$

$$\text{Body Temperature}_{\text{normal}}(x) = \begin{cases} 0, & x \le 34 \\ \frac{x-34}{3}, & 34 < x \le 37 \\ \frac{41-x}{4}, & 37 < x \le 41 \\ 0, & x \ge 41 \end{cases}$$

$$\text{Body Temperature}_{\text{high}}(x) = \begin{cases} 0, & x \le 37 \\ \frac{x-37}{3}, & 37 < x \le 40 \\ \frac{43-x}{3}, & 40 < x \le 43 \\ 0, & x \ge 43 \end{cases}$$

$$\text{Body Temperature}_{\text{high}}(x) = \begin{cases} 0, & x \le 39 \\ \frac{x-39}{31}, & 39 < x \le 70 \\ 1, & x \ge 70 \end{cases}$$

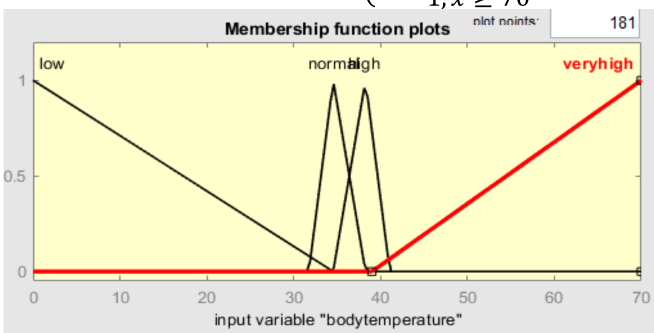

Fig. 2 Body temperature membership function

b) Air temperature

Changes in the temperature of the surrounding environment can affect the body's temperature regulation. As a result of a high air temperature, skin damage can occur. The surrounding air temperature is also vital for determining the severity of a wound. The standard range of surrounding air's temperature is shown in table 2. The triangular membership function graphical representation is depicted in Figure 3.

Table 2. Air temperature ranges

Standard range	Temperature range
Low	10°C-17°C
Normal	18°C-22°C
High	23°C-30°C

$$\text{Air Temperature}_{\text{low}}(x) = \begin{cases} 0, & x \le 0 \\ \frac{x}{9}, & 0 < x \le 10 \\ \frac{20-x}{10}, & 9 < x \le 20 \\ 0, & x \ge 20 \end{cases}$$

$$\text{Air Temperature}_{\text{normal}}(x) = \begin{cases} 0, & x \le 15 \\ \frac{x-20}{5}, & 15 < x \le 20 \\ \frac{25-x}{5}, & 20 < x \le 25 \\ 0, & x \ge 25 \end{cases}$$

$$\text{Air Temperature}_{\text{high}}(x) = \begin{cases} 0, & x \le 20 \\ \frac{x-30}{10}, & 20 < x \le 30 \\ \frac{40-x}{10}, & 30 < x \le 40 \\ 0, & x \ge 40 \end{cases}$$

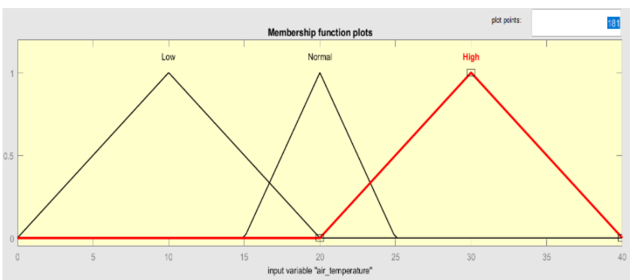

Fig. 3 Air temperature membership function

c) Air humidity

During the daytime hours, humidity ranges from 0 to 20 per cent. Ordinary environments have relative humidity levels ranging from 20 to 60 per cent. The relative humidity is extremely high, ranging from 60 per cent to 100 per cent in some areas. Conversely, low humidity in the air causes the skin to become dry. Table 3 shows the relative humidity ranges, and figure 4 depicts the triangular membership function for relative humidity in the air.

Table 3. Air humidity

Standard range	Air Humidity range
Low	0-25%
Normal	26-65%
High	66-100%

$$\text{Humidity}_{\text{low}}(x) = \begin{cases} 0, & x \le 0 \\ \frac{x}{22}, & 0 < x \le 22 \\ 0, & x \ge 22 \end{cases}$$

$$\text{Humidity}_{\text{normal}}(x) = \begin{cases} 0, & x \le 18 \\ \frac{x-18}{22}, & 18 < x \le 40 \\ \frac{63-x}{23}, & 40 < x \le 63 \\ 0, & x \ge 63 \end{cases}$$

$$\text{Humidity}_{\text{high}}(x) = \begin{cases} 0, & x \le 58 \\ \frac{x-58}{42}, & 58 < x \le 100 \\ 1, & x \ge 100 \end{cases}$$

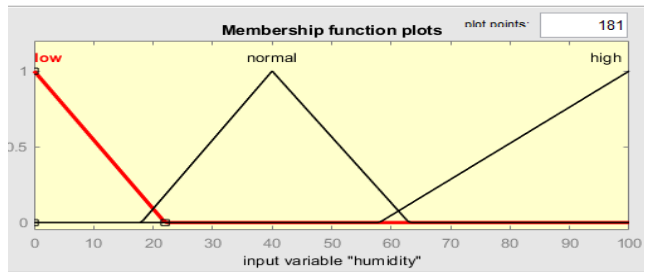

Fig. 4 Humidity membership function

d) Measuring oxygenation

The amount of oxygen present in the blood is referred to as "oxygenation." When conducting wound evaluation, the most crucial factor to consider is oxygen. When measuring the oxygenation blood level in a patient, the standard oxidation range provided in table 4 is referred to as a guideline. The oxygenation range is represented by triangular membership function is represented as shown in Figure 5,

Table 4. Standard oxygenation

Standard range	Oxygen range
Low	0-94%
Normal	95-99%
High	100-140%

$$\text{Oxygenation}_{\text{low}(x)} = \begin{cases} 0, & x \le 96 \\ \frac{x}{48}, & 96 < x \le 120 \\ \frac{95-x}{47}, & 48 < x < 95 \\ 0, & x \ge 95 \end{cases}$$

$$\text{Oxygenation}_{\text{normal}(x)} = \begin{cases} 0, & x \le 93 \\ \frac{x-93}{3}, & 93 < x \le 96 \\ \frac{100-x}{5}, & 97 < x < 102 \\ 0, & x \ge 102 \end{cases}$$

$$\text{Oxygenation}_{\text{high}(x)} = \begin{cases} 0, & x \le 96 \\ \frac{x-96}{24}, & 96 < x \le 120 \\ 1, & x \ge 120 \end{cases}$$

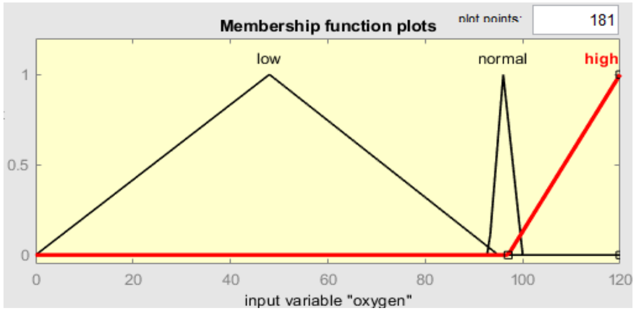

Fig. 5 Oxygen MF

e) Output Decision

The output of the wound monitoring system provides information on the present status of the injury. Wound Assessment Status output is shown in fig. 6. It has three ranges -1,0,1, which define Alert, Normal, Better respectively. In this particular instance, a variety of distinct input parameters are used. The characteristics used as input include body temperature, atmospheric temperature, humidity, and oxygen. When the input parameters are changing, how the wound reacts to the changes can be observed. The accompanying graphic makes it possible to see what the fuzzy logic designer and monitoring system will look like in advance. Fuzzy logic rules are combined in MATLAB FIS. When it comes to reaching our conclusions in the current study work, the fuzzy inference system is used. A realistic expectation for this system is to have four input parameters and one output parameter, with the latter being optional. Table 5 offers sample data for the parameters of the input and output. The data in the table reflects input and output parameters, and the output actions can be observed by adjusting the input parameters in the manner given in Fig. 9.

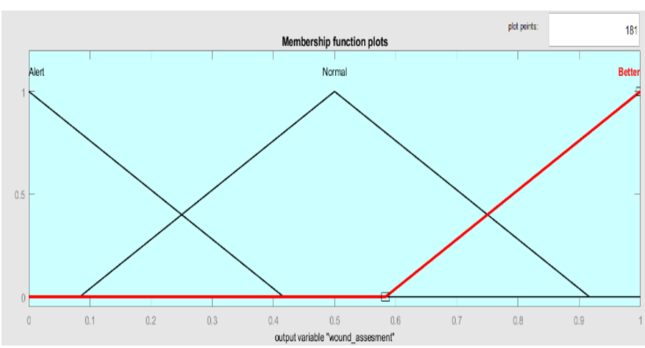

Fig. 6 Wound Assessment Status

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III. RESULTS AND DISCUSSION

Fig. 8 displays a simulation of the wound assessment system using a FIS to estimate the severity of the wound. The variation in parameters such as Standard body temperature, ambient temperature, relative humidity, and oxygenation will vary the wound status to normal, better, and alarming. The input test data is applied to this research's proposed wound assessment system. According to the established rules, the wound assessment system is gathered at various points in time. The output is seen and approximated to evaluate whether or not they are equal on an intended basis at each point in time. Figures 7 and 8, respectively, the fuzzy rule and the rule window viewer are depicted. Figures 9-13 show the surface plots for wound assessment based on various input data. According to the body temperature vs humidity surface plot displayed in figure 9, wound assessment will be more accurate when the body temperature maintains normal. According to the surface plot of temperature against oxygen concentration shown in Figure 10, wound assessment will be more accurate when the air temperature is high than when the air temperature is low. Figure 11 illustrates a surface plot of humidity versus body temperature, demonstrating that only assessment will be alert when the humidity is low. Figure 11: Surface plot of humidity versus body temperature Figure 12 displays a surface plot of oxygen concentration vs body temperature, which indicates that when the oxygen concentration is high, the assessment is considered to be normal. Body temperature vs ambient air temperature is depicted in Fig. 13, which demonstrates that the assessment will be normal when the body temperature is normal, as seen in the graph. A Comparative analysis of Wound monitoring using various input parameters is shown in Fig. 14, and it shows that Fuzzy is superior in performance compared to similar techniques.

A. RMSE Calculation

The combined input dataset is compared with the synthetic dataset in which fuzzy rules are formed to get the output as an automatic decision. The root-mean-square error (RMSE) is calculated using the least-squares method.

$$RMSE= \sqrt{\frac{1}{m}\sum_{j=1}^{m}[\{predicted\ value(j) - Actual\ value(j)\}^2]}$$

The RMSE value for various membership functions is shown in table 6, and the triangular MF has generated a low RMSE value.

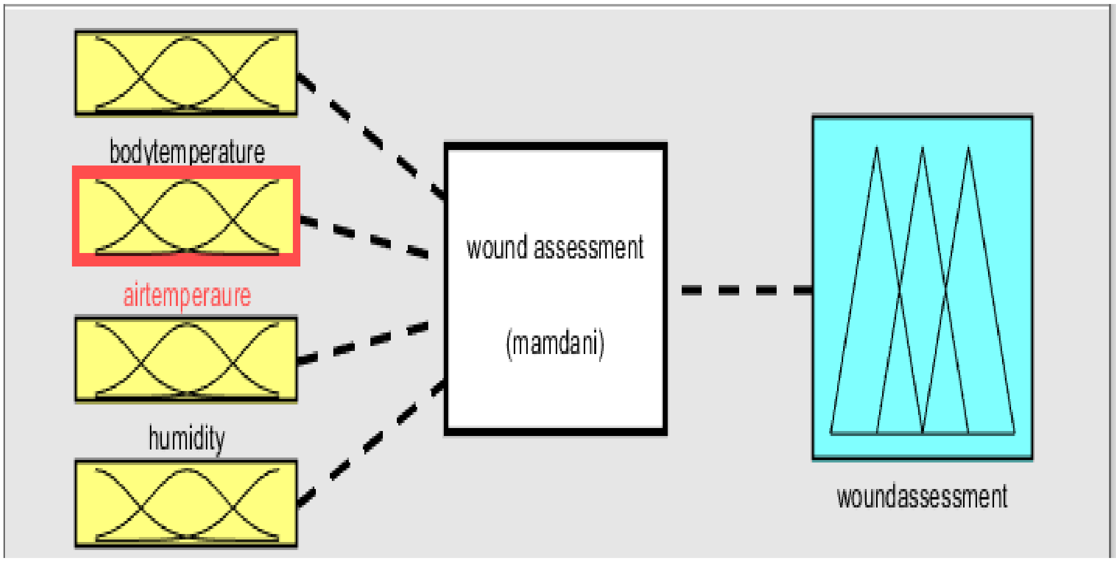

Fig. 7 Wound monitoring system using fuzzy logic

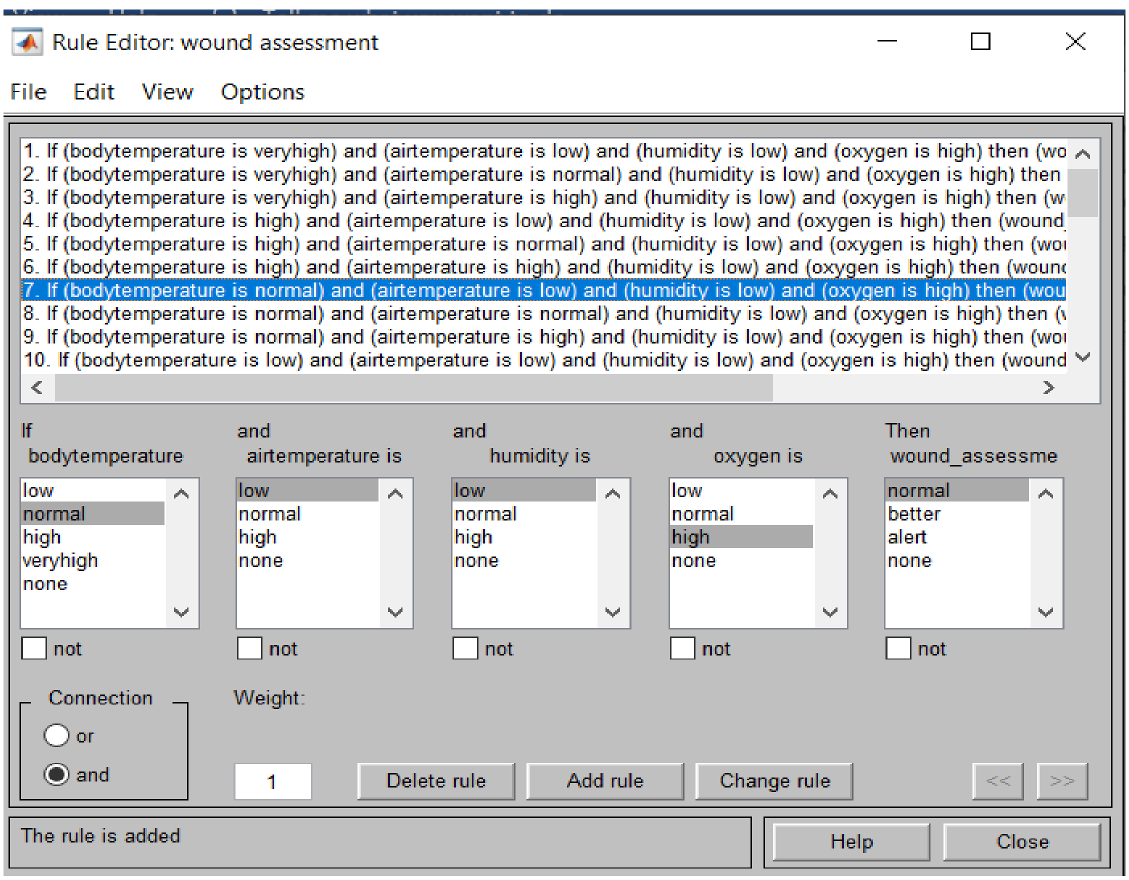

Fig. 8 Verbal fuzzy rules

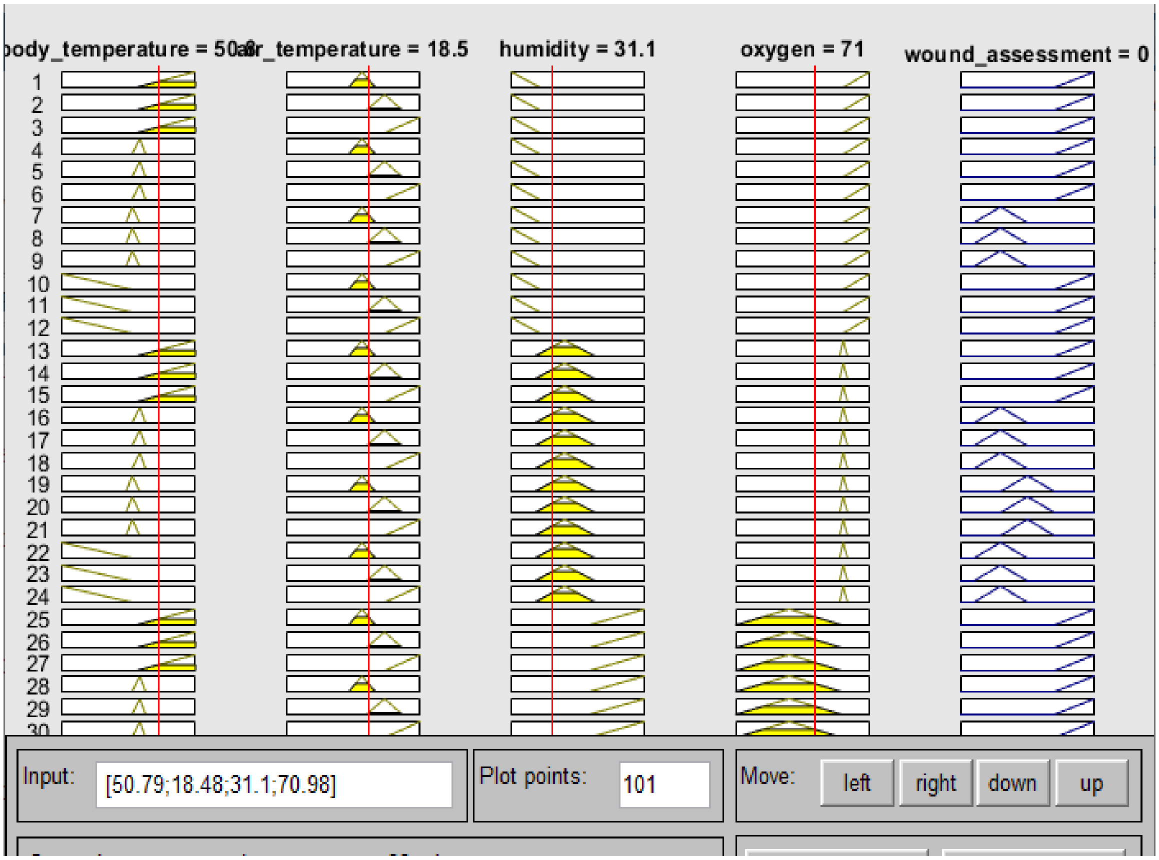

Fig. 9 fuzzy rule window viewer

Table 5. Few inputs output actions

STANDARD TEMPERATURE	HUMIDITY	Body Temperature	OXYGEN	Wound Asessment
30	32	47.3	99.1	1
3	65	44.2	83.7	1
23	78	49.9	83.7	1
44	88	46	61.2	1
0	70	40.9	56.9	1
28	92	39.3	77.1	1
34	75	38.3	69.1	1
15	89	28.9	90.9	1
25	66	25.2	91.7	0
35	93	34.9	73.2	0
11	36	36.3	98.2	-1
26	56	36.1	97.1	-1
34	35	35.8	98.1	-1
4	2	37.3	104.3	0

IV. CONCLUSION

When observing the wound assessment, it is necessary to consider the I/P parameters humidity, body temperature, air temperature, and oxygen discussed in the current research work. Depending on how the input parameters change, the output outcomes will vary as normal, better, alert. When making decisions, the system relied on fuzzy logic. Fuzziness is applied to the input and output. The triangle membership function yielded a low RMSE value and was applied to the input and output along with fuzzy rules. The triangle membership function is simple, can be adjusted as needed, and is used to fuzzify and defuzzify the inputs and outputs simultaneously. Approximately 97 per cent accuracy is achieved with the proposed model.

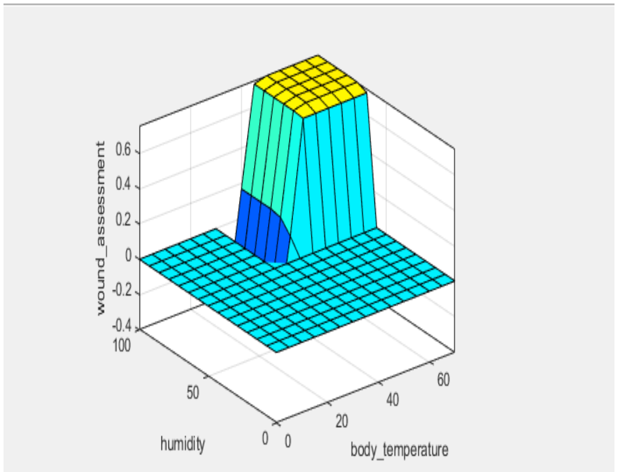

Fig. 10 Body temperature vs humidity surface plot

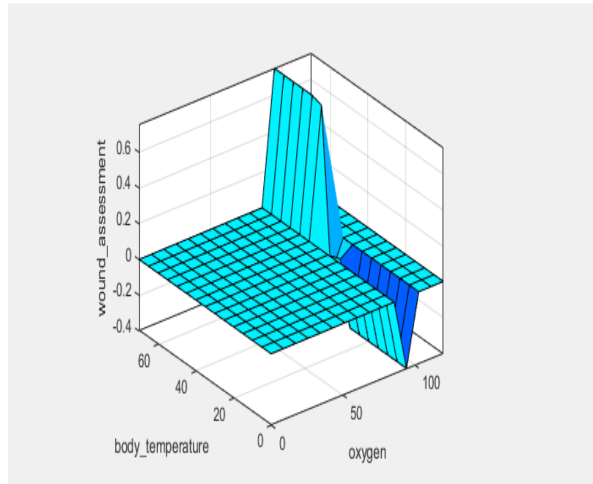

Fig. 13 Oxygen vs body temperature surface plot

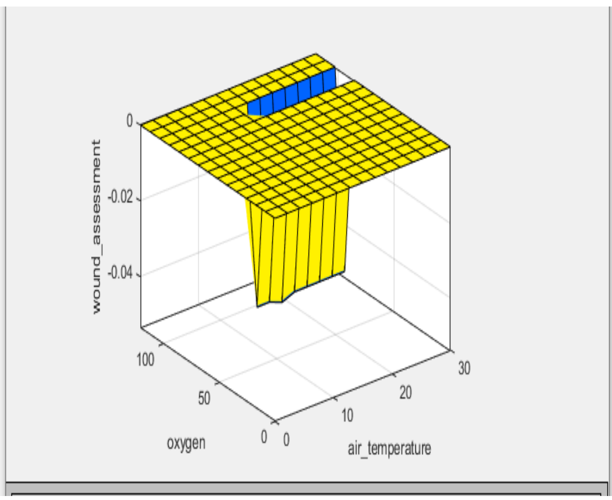

Fig. 11 Air temperature vs oxygen surface plot

Table 6. RMSE Calculation

Membership function used	RMSE
Bell	0.1123
Trapezoidal	0.0987
Gaussian	0.0855
Triangular	0.0789

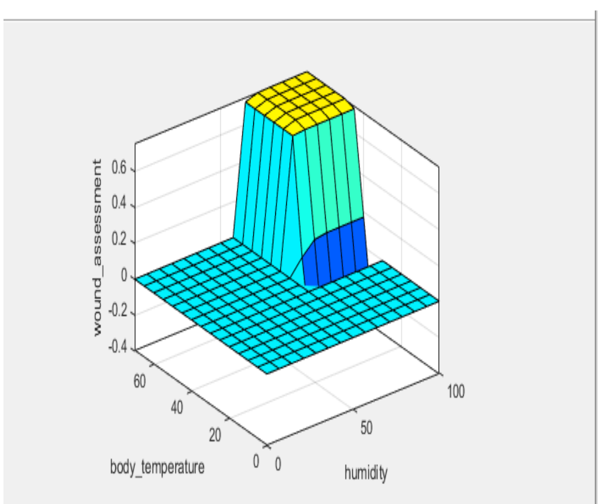

Fig. 12 Humidity vs body temperature surface plot

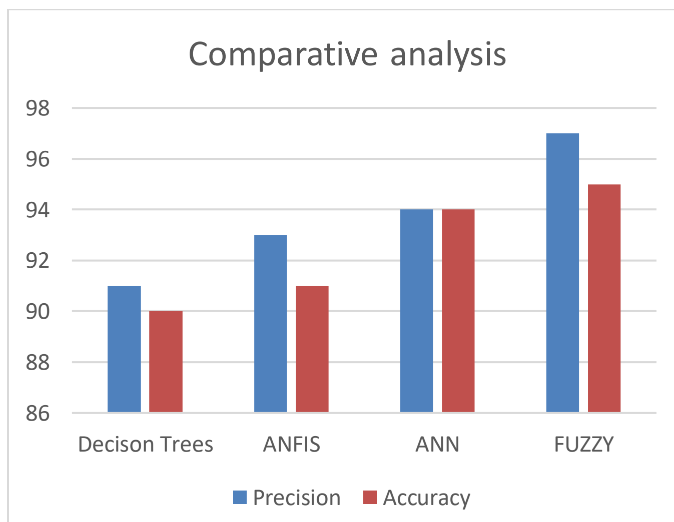

Fig. 14 Comparative Analysis

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