

The Design of Fuzzy-Based Weaning Protocol in LabVIEW Environment

[Hasan Guler]

Abstract—The main purpose of this study is to design universally accepted approach to weaning patients from ventilator. Fuzzy logic controller was used for achieving this aim. The reason for the use of fuzzy controller is that it represents expert notions employed in decision making. The developed all protocols were designed on LabVIEW software. The inputs of the developed system were PH, partial carbondioxide percent (PaCO_2), saturation of oxygen (SpO_2), the rate of $\text{PaO}_2/\text{FiO}_2$, saturation of oxygen (SaO_2), hemoglobin (Hb) and positive end expiratory pressure (PEEP). 20 clinical scenarios were generated by using Monte-Carlo simulations and Gaussian distribution method to test performance of the developed protocol. The generated scenarios were applied to the developed protocol. Clinician was asked to evaluate the each scenario to determine weaning probability. Student t-test for $p < 0.05$ was used to show statistical difference between the developed protocol and clinician's evaluation. According to results, there is no statistical difference for % 97.8 probability between them.

Keywords—Weaning, fuzzy system, student t-test, Gaussion Distribution

I. Introduction

Weaning patients from mechanical ventilator is important process. It was reported that twenty percentages of the ventilated patients fail their first attempt at weaning [1-3]. Hence, the patients spend more time in intensive care units (ICU) to wean from MV. Prolonged MV may cause some complications such as infection, pneumonia, barotraumas [4-6]. However, if the clinicians cannot predict the right time to start weaning, the patients may need the reintubation and so, this failure may increase the percentage of morbidity and mortality [7-9]. Many researchers have attempted to reduce the duration of MV and have declared reducing the weaning times by their defined protocols rather than usual intensive care protocols [10-12].

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In literature, many studies about weaning from ventilator have been done according to the three weaning predictor such as rapid shallow breathing index (RSBI), pressure time index (PTI) and Jabour' weaning index (JWI) [13-15]. Owing to its ease of calculation, RSBI is widely used in ICU.

According to one minute spontaneous breathing of patient, RSBI calculates the ratio of frequency to tidal volume. If this value is below the threshold of 100 (breaths/min)/L, RSBI predicts weaning success with a sensitivity of up to 97 % [16]. However, prolonged MV decreases sensitivity of RSBI and the state of disease influences the specificity of that [17-19]. The other predictors used in weaning process require more detailed respiratory parameters and so they cannot be preferred by staff of ICU. Thus, there is no broadly accepted protocol to weaning patients from mechanical ventilator.

In this study, it was attempted to constitute a new LabVIEW-fuzzy based weaning protocol. The aim of the study is to eliminate disadvantages of the predictors used in literature. The weaning system was designed in LabVIEW. The reason of preferring the LabVIEW program is its graphic based structure and the ease provided to user in constituting interface. In addition, fuzzy logic controller can be easily created by using Fuzzy Logic Toolkit on LabVIEW software. Seven vital parameters were used to determine weaning probability. Three of them such as PH, PaCO_2 and SpO_2 were used to determine acid-base balance and the other parameters such as $\text{PaO}_2/\text{FiO}_2$, SaO_2 , Hb and PEEP were used to determine adequate oxygenation. Acid-base balance and adequate oxygenation determined the percentage of weaning probability. First of all, 20 clinical scenarios for seven parameters were generated by using Monte-Carlo simulations and Gaussian distribution. The generated scenarios were applied to the developed protocol. In addition, clinician evaluated the each scenario, independently. Finally, student t-test was used to show statistical difference between the developed protocol and clinician's evaluation. According to the obtained results, there is no statistical difference for % 97.8 probability between them.

II. Material and Methods

Clinicians working in ICUs try to manage successful weaning process so as to decrease the percentage of morbidity and mortality. Thus, they spend much more time for each patient who need no ventilation support. Many researchers have studied about weaning process to decrease clinician's workload in ICUs. The schematic outline of the developed protocol is given in Figure 1. PH, PaCO_2 and SpO_2 were used to determine acid-base balance and $\text{PaO}_2/\text{FiO}_2$, PEEP, SaO_2 and Hb were used to determine adequate oxygenation. These two systems were also used to determine final percentage of weaning probability.

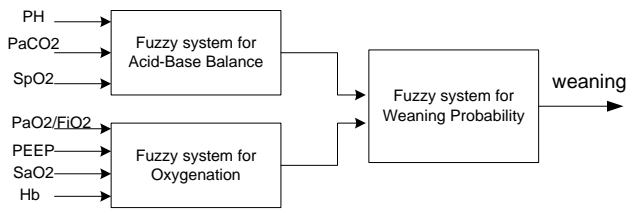


Figure 1. The schematic outline of the developed algorithm

A. Fuzzy System for Acid-Base Balance

Fuzzy system for acid-base balance has three input such as PH, PaCO₂ and SpO₂. The membership functions of fuzzy inputs and output are given Figure 2, 3, 4 and 5.

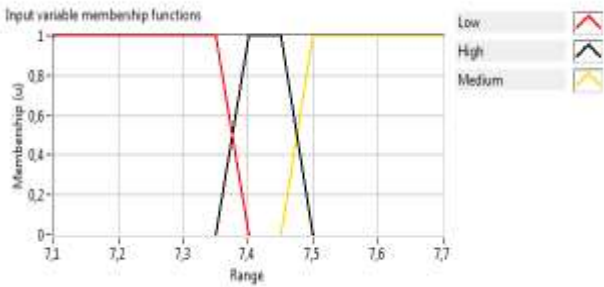


Figure 2. PH membership functions

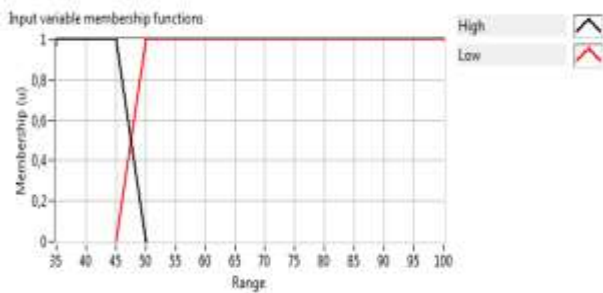


Figure 3. PaCO₂ membership functions

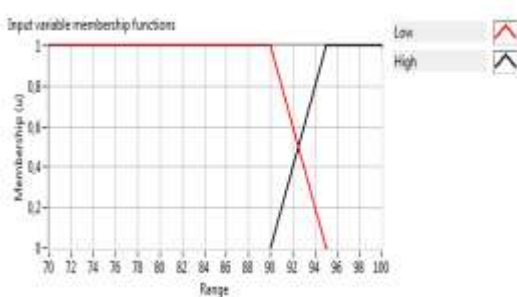


Figure 4. SpO₂ membership functions

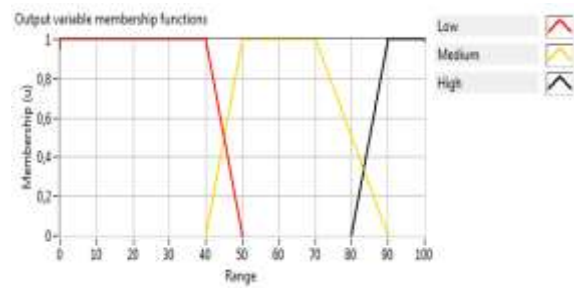


Figure 5. Acid-base balance membership functions

The rule table of the acid-base balance is given in Table 1.

TABLE I. RULE TABLE FOR ACID-BASE BALANCE

PH	PaCO ₂	SpO ₂	Acid-Base Balance
Low	Low	Low	Low
Low	Low	High	Low
Low	High	Low	Low
Low	High	High	High
Medium	Low	Low	Low
Medium	Low	High	Medium
Medium	High	Low	Medium
Medium	High	High	High
High	Low	Low	Medium
High	Low	High	High
High	High	Low	High
High	High	High	High

The all rule table was constituted with clinician's opinion.

B. Fuzzy system for Adequate Oxygenation

Fuzzy system for adequate oxygenation has four input such as PaO₂/FiO₂, PEEP, SaO₂ and Hb. The membership functions of fuzzy inputs and output are given Figure 6, 7, 8 and 9.

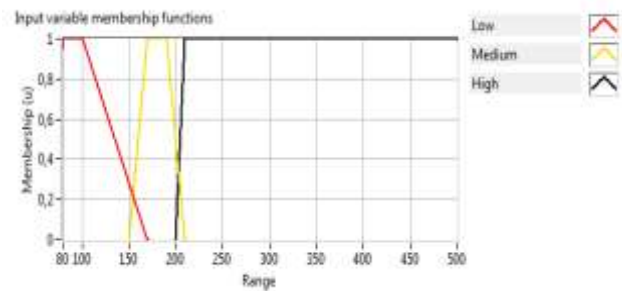


Figure 6. PaO₂/FiO₂ membership functions

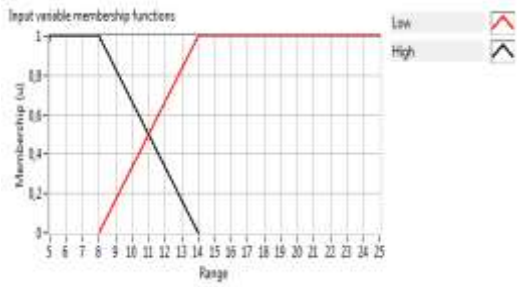


Figure 7. PEEP membership functions

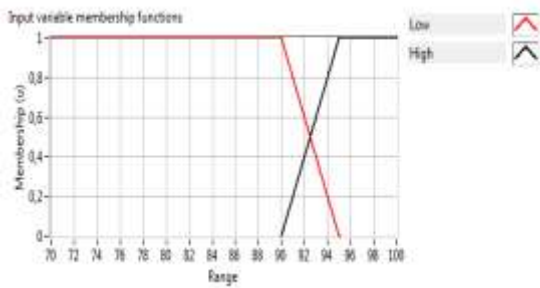


Figure 8. SaO₂ membership functions

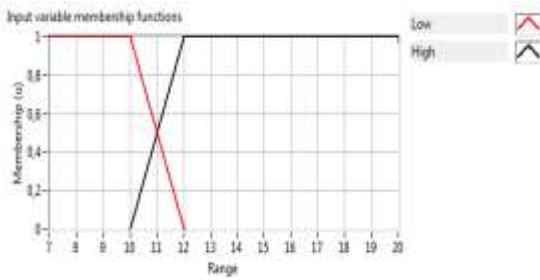


Figure 9. Hb membership functions

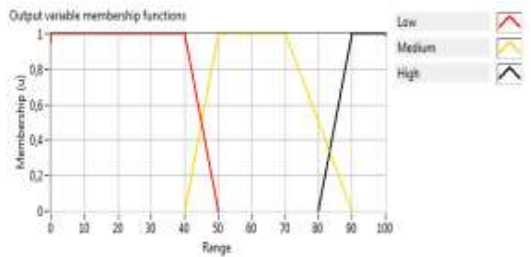


Figure 10. Adequate membership function

The rule table of the acid-base balance is given in Table 2. In this paper, Monte-Carlo simulation and Gaussian distribution method were used to generate random clinical scenarios. Gaussian distribution equation used in this algorithm is given in equation 1, 2 and 3.

$$f(x; \mu; \sigma^2) = \frac{1}{\sigma\sqrt{2\pi}} * e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (1)$$

$$z = \frac{x - \mu}{\sigma} \quad (2)$$

$$x = z\sigma + \mu \quad (3)$$

Where x is new data, z is standard normal distribution, μ is the mean value, σ^2 is the variance random value and σ is random value.

TABLE II. RULE TABLE FOR ADEQUATE OXYGENATION

PaO ₂ /FiO ₂	PEEP	SaO ₂	Hb	Adequate Oxygenation
Low	Low	Low	Low	Low
Low	Low	Low	High	Low
Low	Low	High	Low	Low
Low	Low	High	High	Medium
Low	High	Low	Low	Low
Low	High	Low	High	Medium
Low	High	High	Low	Medium
Low	High	High	High	High
Medium	Low	Low	Low	Low
Medium	Low	Low	High	Low
Medium	Low	High	Low	Medium
Medium	Low	High	High	High
Medium	High	Low	Low	Medium
Medium	High	Low	High	High
Medium	High	High	Low	High
Medium	High	High	High	High
High	Low	Low	Low	Low
High	Low	Low	High	High
High	Low	High	Low	Medium
High	Low	High	High	High
High	High	Low	Low	Medium
High	High	Low	High	High
High	High	High	Low	High
High	High	High	High	High

The developed algorithm in LabVIEW is shown in Figure 11.

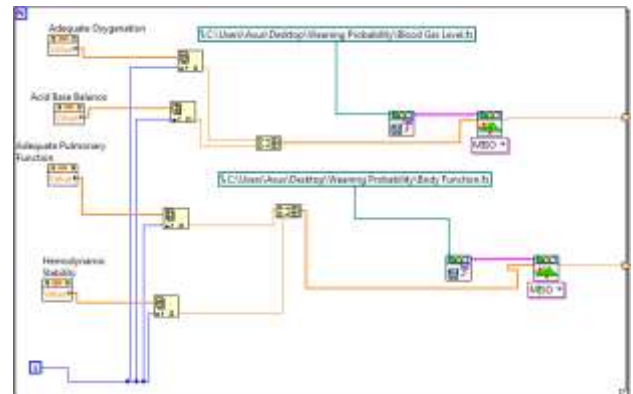


Figure 11. The block diagram of the developed weaning protocol

The output membership function of fuzzy system for weaning probability is given in Figure 12.

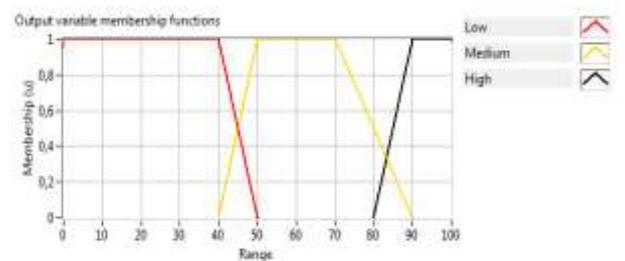


Figure 12. Weaning probability membership function

The final rule table of fuzzy system for weaning probability is shown in Table 3.

TABLE III. RULE TABLE FOR WEANING PROBABILITY

Acid-Base Balance	Adequate Oxygenation	Percentage of Weaning Probability
Low	Low	Low
Medium	Low	Low
High	Low	Medium
Low	Medium	Low
Medium	Medium	Medium
High	Medium	High
Low	High	Medium
Medium	High	High
High	High	High

III. Results

The developed protocol gives the percentage of weaning probability according to the generated scenarios. In addition, clinician evaluated the each scenario and he gave the percentage of weaning probability. The results obtained from the protocol and clinician's evaluation applied to student t-test for $p < 0.05$. The obtained results are given in Table 4.

TABLE IV. THE OBTAINED RESULTS FROM THE DEVELOPED PROTOCOL AND CLINICIAN'S EVALUATION

Patient Data (P.D.)	The Percentage of Weaning Probability(%)	The Percentage of Clinician's Evaluation(%)
1st P.D.	78.355257	80
2nd P.D.	91.709245	95
3rd P.D.	97.858109	95
4th P.D.	64.698356	60
5th P.D.	92.244709	90
6th P.D.	54.745297	50
7th P.D.	83.528863	90
8th P.D.	93.425975	90
9th P.D.	18.753698	10
10th P.D.	49.523691	50
11th P.D.	22.125896	25
12th P.D.	32.458791	40
13th P.D.	76.257859	75
14th P.D.	62.853257	60
15th P.D.	65.525965	70
16th P.D.	62.753258	60
17th P.D.	84.659874	90
18th P.D.	52.326985	50
19th P.D.	44.236547	40
20th P.D.	65.459632	65

The Student's t-test was used to determine statistical difference because it assesses whether the means of three groups are statistically different from each other. This test is appropriate whenever a person wants to compare the means of two or more groups [20-23]. Equations 4, 5 and 6 were used to calculate the statistical difference.

$$\bar{X} = \frac{\sum x}{n} \quad (1)$$

$$S^2 = \frac{\sum (x - \bar{x})^2}{n-1} \quad (2)$$

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{S_1^2}{n_1-1} + \frac{S_2^2}{n_2-1}}} \quad (3)$$

Where \bar{x} is the arithmetic mean, S^2 is variance, t is the test formula, x is the investigated group and n is the number of data points in group. According to the results from the t-test, there is no statistical difference for 97.8% probability between the percentage of developed algorithm results and clinician evaluation.

IV. Discussion

Weaning patients from mechanical ventilator is important issue. If clinician does not estimate right time for weaning, prolonged ventilation support may cause infection, pneumonia, barotraumas and etc. Thus, many biomedical researchers have tried to create weaning protocol to estimate right weaning time. In literature, there are three basic weaning predictors such as RSBI, PTI and JWI. However, these predictors ignore some patient data so they cannot be universally accepted by clinicians.

In this paper, it was tried to eliminate disadvantages of the predictors used in literature. Seven vital parameters which are easy collected in ICU were used to determine weaning probability. Since the system has seven parameters to estimate weaning probability, some parameters were grouped. Otherwise, the fuzzy system would have 288 rules. However, after grouping, the all systems have 45 rules. PH, PaCO₂ and SpO₂ were used to determine acid-base balance while PaO₂/FiO₂, PEEP, SaO₂ and Hb were used to determine adequate oxygenation. Finally, these two systems were used to determine weaning probability. 20 clinical scenarios were generated to test the developed protocol. In addition, clinician evaluated the each scenario and he gave the percentage for it. Each scenario represented a patient in this study. The obtained results from the protocol and clinician's evaluation applied to student t-test for $p < 0.05$ to show statistical difference. The results obtained from t-test, there is no statistical difference for %97.8 probability between the developed protocol and clinician's evaluation.

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