ISSN 2231-346X (Print)
JUSPS-A Vol. 35(4), 34-45 (2023). Periodicity-Monthly
Section A
(Online) ISSN 2319-8044

JOURNAL OF ULTRA SCIENTIST OF PHYSICAL SCIENCES
An International Open Free Access Peer Reviewed Research Journal of Physical Sciences
website:- www.ultrascientist.org
Estd. 1989

Implementation of Fuzzy Logic in Managing Common Anesthesia

HEMLATA SAHAY[1], and SHUBHNESH KUMAR GOYAL[2]

[1,2]Department of Mathematics, Dharam Samaj College, Aligarh (Aligarh), (India)
Dr. Bhimrao Ambedkar University, Agra (India)
Corresponding Author Email:- hemlata.sahay233@gmail.com
http://dx.doi.org/10.22147/jusps-A/350401

Acceptance Date 09th April, 2023, Online Publication Date 27th April, 2023

Abstract

Using fuzzy sets for reasoning is what we mean when we talk about fuzzy logic. Contradictory natures are prevalent phenomena in the medical field. Guidelines are used by anesthesiologists when taking care of patients. After gauging the patient's vitals, he may make adjustments to the flow of medication and fluids, or even the ventilator settings. Knowledge about the real world is typically sketchy, inaccurate, and inconsistent. Due to the inherent representation of subjective human conceptions used in much medical decision making, fuzzy logic seems well-suited for use in anaesthesia.

We have developed a fuzzy expert system using fuzzy methodology for the aim of fluid management during general anaesthesia. The desired intravenous fluid rate (IFR) is the defuzzified value that is output by the fuzzy expert system. Fuzzy inputs serve as antecedent parts of rules for a fuzzy expert system, and some examples of such inputs are mean arterial pressure (HUO), hourly urine output (HUO), and central venous pressure (CVP).

It would only cost a little sum to have a human operator sometimes enter MAP, HUO, and CVP values into a personal computer for this purpose. The study's overarching goal was to devise a method for approximating IFR by making use of a linguistic description of MAP and HUO. Fuzzy sets, including decreasing, constant, and growing MAP and HUO rates of change, would assist to illustrate the trend in a patient's fluid state. To regulate fluid levels more precisely would be possible. Expert guidance in addition to the calculated use of fuzzy methods are essential for achievement of the desired outcome. Patients must be in generally good health before this mode may be used on them, and they must be undergoing minimally invasive surgery. Moderate to severe blood loss after surgery need more complex modalities involving more factors.

Keywords : *FIS, MAP, HUO, CVP, IFR*

This is an open access article under the CC BY-NC-SA license (https://creativecommons.org/licenses/by-nc-sa/4.0)

1. Introduction

Many fields have benefited from the incorporation of AITs, including healthcare, where they have been used for things like disease diagnosis and treatment, patient tracking and risk assessment. Artificial intelligence technologies (AITs) permit the development of systems that enable the construction of intelligent models for forecasting both the therapeutic response of patients and the danger of illness in the future. Several academics have developed AITs including fuzzy logic, artificial neural networks, genetic algorithms, artificial immune systems, and others to help deal with the extremely high levels of complexity and uncertainty present in these areas. Most areas of medicine have investigated the AIT's competency capacities. Anesthesiology is the medical specialty concerned with the use of anaesthetic drugs to render a patient unconscious before, during, and after surgery. Muscle relaxation, unconsciousness (or depth of anaesthesia), and pain relief are all components of contemporary balanced general anaesthesia (blocking response to pain). The anesthesiologist controls the first two in the operating room, while the third is related to recovery. Many investigations towards the use of AI for anaesthesia regulation and control have been conducted during the past two decades.

Tsutsui and Arita[11] developed a closed-loop blood pressure control system for use with fuzzy logic while the subject was under the influence of enflurane. Bates and Young[2] provided an explanation of the operation of fuzzy logic by demonstrating its application in a condensed version of a model for the fluid resuscitation of intensive care unit patients. IFR was computed by Rahim *et al*.[8] using a linguistic description of MAP and HUO. Fuzzy sets of HUO and HUO rate of change values, such as falling, stable, and increasing, were used to represent the direction of a patient's fluid status change. Using the anaesthetic medication isoflurane, Tomar and Dubey[10] conceived and constructed a fuzzy logic controller to regulate the patient's mean arterial pressure (HUO) while under anaesthesia. In their study on automatic anaesthetic regulation, Liu *et al*.[5] compared type-1 and type-2 SOFLCs employing expert initialised and pretrained extracted rule-bases. The anesthesiologist's predictions were compared to those derived from fuzzy logic by Samira and Hanane[9]. In 2018, Mendez et al. developed and implemented a new fuzzy logic method to automate medicine administration to patients receiving general anaesthesia. The anaesthetic dosage received by patients during surgery is now regulated and monitored thanks to the efforts of Kumar *et al*.[4]. They created the fuzzy logic controller to accomplish this goal. Using machine learning, Miyaguchi *et al*.[7] tackled the issue of anticipating anesthesiologists' judgements during surgery. By treating the decision to increase the rate of continuous remifentanil administration as a supervised binary classification issue, they were able to design a problem that required them to make decisions at each time point. An artificial intelligence (AI) enabled internet of things system was presented by Farivar *et al*.[3] to track and modify anaesthetic levels remotely using IP networks. To better understand the current state of artificial intelligence (AI) in paediatric anaesthesia and to pinpoint the obstacles that prevent its widespread adoption, Antel *et al*.[1] conducted a comprehensive literature review.

2. Basic terminology of fuzzy inference system:

2.1 Crisp Set: A crisp set is one that is characterized by a characteristic function that gives each element in the universe a value of 0 or 1, distinguishing between members and non-members of the

crisp set in question. Crisp sets are typically called "classical" or "ordinary" sets when discussing them in the context of fuzzy sets theory.

2.2 Fuzzy Set: A fuzzy set is a grouping of things whose inclusion can be qualified on a scale. The objects in such a set are classified on a membership scale from 0 to 1 by a membership (characteristic) function.

2.3 Fuzzy Numbers: Fuzzy numbers are a more generalized form of real numbers; instead of referring to a single value, they refer to a connected set of values, where each value is assigned a weight between zero and one. The membership function is the name given to this relative importance. Several ambiguous numerical values are out there. But, only trapezoidal fuzzy numbers will do for our purposes.

2.4 Trapezoidal fuzzy number: Let's make the assumption that there is a fuzzy trapezoidal number $T\ (a, b, c, d)$. $\mu_T(x)$ is the membership function of T, and it is defined as

$$\mu_T(x) = \begin{Bmatrix} \dfrac{x-a}{b-a} & a \le x \le b \\ 1 & b \le x \le c \\ \dfrac{c-x}{d-c} & c \le x \le d \end{Bmatrix}$$

3. Medical terminology :

- **General Anesthesia:** The goal of administering general anaesthesia is to induce a deep sleep state in the patient. Anesthetics are drugs that numb pain and make surgery or other medical operations more tolerable for patients. In most cases, both intravenous drugs and breathed anaesthetic gas are used to induce a deep sleep during general anaesthesia.
- **Mean arterial pressure (MAP):** The average pressure of the blood vessels during systole and diastole of a single cardiac cycle is known as mean arterial pressure (HUO). There are many factors that affect HUO, including cardiac output and systemic vascular resistance.

  $MAP = DP + \frac{1}{3}(SP - DP) = DP + \frac{1}{3}PP$

  Where DP = Diastolic blood pressure, SP =Systolic blood pressure and
  PP =Pulse pressure
  MAP values between 70 and 100 mmHg are considered normal.

- **Hourly urine output (HUO):** In a healthy person, the rate of urine production should be between 50 and 150 ml/h.
- **Central venous pressure (CVP):** As a proxy for preload and right atrial pressure, central venous pressure (CVP) is a measure of pressure in the vena cava. While evaluating a patient's hemodynamic condition, central venous pressure is frequently measured. This is especially true in the critical care unit. CVP is typically measured in a range from 3 to 8 mmHg.

4. The Meaning of Input and Output variables :

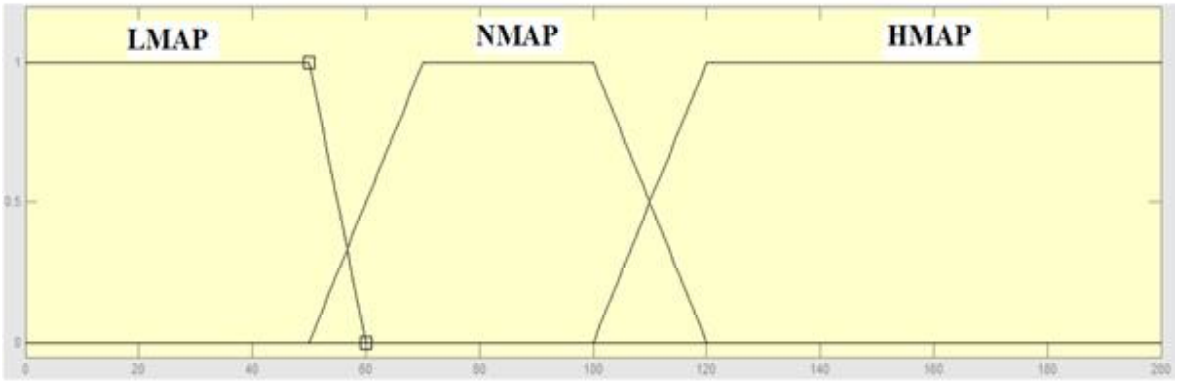
Table -1: Input and output variables

Input variables						Output variable	
MAP		HUO		CVP		IFR	
LMAP	LOW MAP	LHUO	LOW HUO	LCVP	LOW CVP	LIFR	LOW IFR
NMAP	NORMAL MAP	NHUO	NORMAL HUO	NCVP	NORMAL CVP	MAIFR	MAINTAIN IFR
HMAP	HIGH MAP	HHUO	HIGH HUO	HCVP	HIGH CVP	MOIFR	MODERATE IFR
						HIFR VHIFR	HIGH IFR VERY HIGH IFR

5. Membership plot function of input variables :

The input and output variables' range of possible values are established before the fuzzy control's finer processing details are carried out. These are the membership functions that convert precise values into fuzzy ones for use in calculations. Input and output variables, as well as their corresponding membership functions, are depicted in figures 2–4.

Figure 1:Membership plot function for input variable '1'



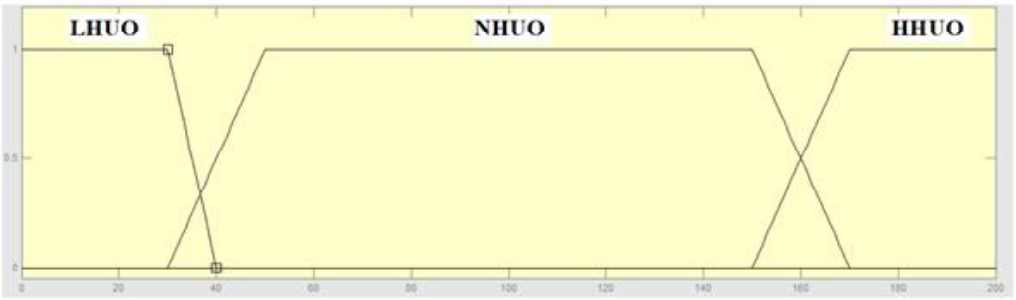
MAP (Mean Arterial Pressure)

$$\mu_{LMAP} = \begin{Bmatrix} 1 & 0 \le x \le 50 \\ -0.1x + 6 & 50 \le x \le 60 \end{Bmatrix}$$

$$\mu_{NMAP} = \begin{Bmatrix} 0.05x - 2.5 & 50 \le x \le 70 \\ 1 & 70 \le x \le 100 \\ -0.05x + 6 & 100 \le x \le 120 \end{Bmatrix}$$

$$\mu_{HMAP} = \begin{Bmatrix} 0.05x - 5 & 100 \le x \le 120 \\ 1 & 120 \le x \le 200 \end{Bmatrix}$$

Figure 2: Membership plot function for input variable '2'



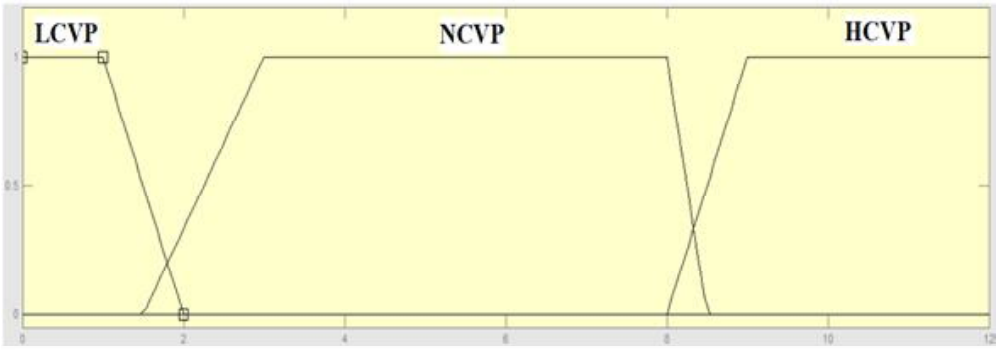
HUO (Hourly Urine Output)

$$\mu_{LHUO} = \begin{Bmatrix} 1 & 0 \le x \le 30 \\ -0.1x + 4 & 30 \le x \le 40 \end{Bmatrix}$$

$$\mu_{NHUO} = \begin{Bmatrix} 0.05x - 2.5 & 30 \le x \le 50 \\ 1 & 50 \le x \le 150 \\ -0.05x + 8.5 & 150 \le x \le 170 \end{Bmatrix}$$

$$\mu_{HHUO} = \begin{Bmatrix} 0.05x - 7.5 & 150 \le x \le 170 \\ 1 & 170 \le x \le 200 \end{Bmatrix}$$

Figure 3: Membership plot function for input variable '3'



Central Venous Pressure (CVP)

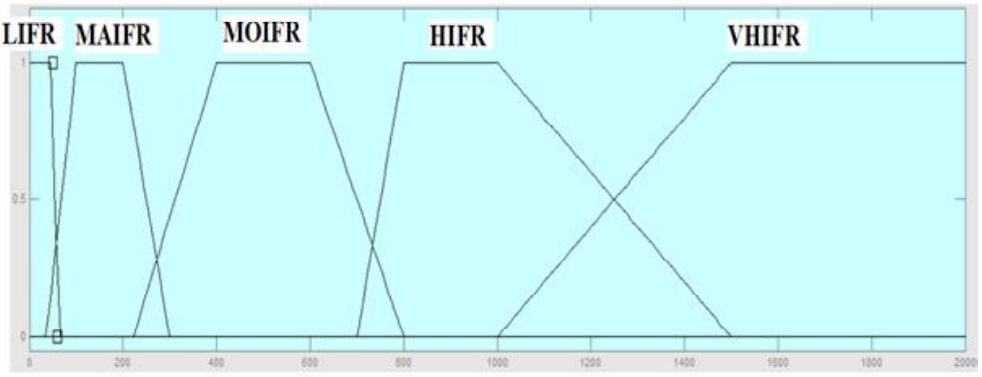
$$\mu_{LCVP} = \begin{Bmatrix} 1 & 0 \le x \le 1 \\ -x + 2 & 1 \le x \le 2 \end{Bmatrix}$$

$$\mu_{NCVP} = \begin{Bmatrix} 0.05x - 2.5 & 1.75 \le x \le 3 \\ 1 & 3 \le x \le 8 \\ -4x + 3 & 8 \le x \le 8.25 \end{Bmatrix}$$

$$\mu_{HCVP} = \begin{Bmatrix} x - 8 & 8 \le x \le 9 \\ 1 & 9 \le x \le 12 \end{Bmatrix}$$

6. Membership plot function of output variable:

Figure 4: Membership plot function for output variable



$$\mu_{LIFR} = \begin{Bmatrix} 1 & 0 \le x \le 60 \\ -x+2 & 60 \le x \le 70 \end{Bmatrix}$$

$$\mu_{MAIFR} = \begin{Bmatrix} 0.025x - 1.5 & 60 \le x \le 100 \\ 1 & 100 \le x \le 200 \\ -0.01x + 3 & 200 \le x \le 300 \end{Bmatrix}$$

$$\mu_{MOIFR} = \begin{Bmatrix} 0.01x - 3 & 300 \le x \le 400 \\ 1 & 400 \le x \le 600 \\ -0.005x + 4 & 600 \le x \le 800 \end{Bmatrix}$$

$$\mu_{HIFR} = \begin{Bmatrix} 0.01x - 7 & 700 \le x \le 800 \\ 1 & 800 \le x \le 1000 \\ -0.002x + 3 & 1000 \le x \le 1500 \end{Bmatrix}$$

$$\mu_{HIFR} = \begin{Bmatrix} 0.002x - 2 & 1000 \le x \le 1500 \\ 1 & 1500 \le x \le 2000 \end{Bmatrix}$$

7. Fuzzy Rule Base :

Fuzzy inference systems rely on the rule base for their operations, and the quality of their output is determined by the fuzziness of the rules they use. All together, there are 27 guidelines in our system. All rules have a single paragraph that serves as an antecedent. The expert's conclusion and the laboratory findings are supported by the outcomes using the 27 rules.

Using the Mamdani method, we made the following predictions based on fuzzy rules: Total fuzzy rules$= 3 \times 3 \times 3 = 27$

Table-2: Rules for Fuzzy inference system

Rules	MAP	HUO	CVP	IFR
1	LOW	LOW	LOW	VERY HIGH
2	LOW	NORMAL	LOW	VERY HIGH
3	LOW	HIGH	LOW	HIGH
4	NORMAL	LOW	LOW	VERY HIGH
5	NORMAL	NORMAL	LOW	MAINTAIN
6	NORMAL	HIGH	LOW	MODERATE
7	HIGH	LOW	LOW	HIGH
8	HIGH	NORMAL	LOW	MODERATE
9	HIGH	HIGH	LOW	LOW
10	LOW	LOW	NORMAL	VERY HIGH
11	LOW	NORMAL	NORMAL	MAINTAIN
12	LOW	HIGH	NORMAL	MODERATE
13	NORMAL	LOW	NORMAL	MAINTAIN
14	NORMAL	NORMAL	NORMAL	MAINTAIN
15	NORMAL	HIGH	NORMAL	MODERATE
16	HIGH	LOW	NORMAL	MODERATE
17	HIGH	NORMAL	NORMAL	MODERATE
18	HIGH	HIGH	NORMAL	LOW
19	LOW	LOW	HIGH	HIGH
20	LOW	NORMAL	HIGH	MODERATE
21	LOW	HIGH	HIGH	LOW
22	NORMAL	LOW	HIGH	MODERATE
23	NORMAL	NORMAL	HIGH	MAINTAIN
24	NORMAL	HIGH	HIGH	LOW
25	HIGH	LOW	HIGH	LOW
26	HIGH	NORMAL	HIGH	LOW
27	HIGH	HIGH	HIGH	LOW

8. Estimated values of output variable IFR for different input variables MAP, HUO and CVP:

The input values of a variety of variables utilized in a medical expert system to manage general anesthesia are depicted in Figures 5 and 6 respectively. These figures also display the output that corresponds to the given inputs using fuzzy inference system toolbox through MATLAB.

Figure 5: Output-rule mapping for low IFR

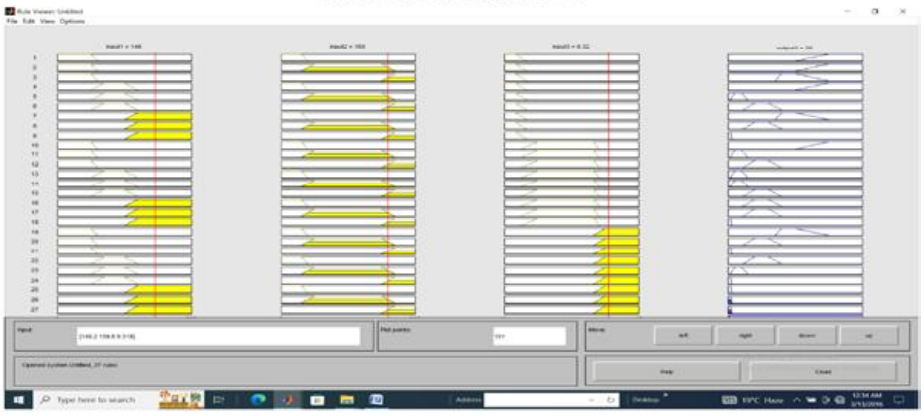


Figure 6: Output-rule mapping for maintain IFR

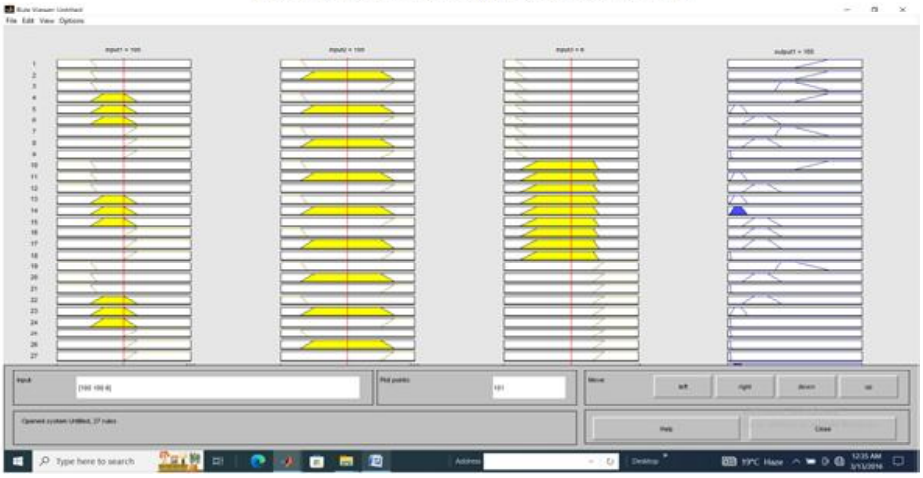


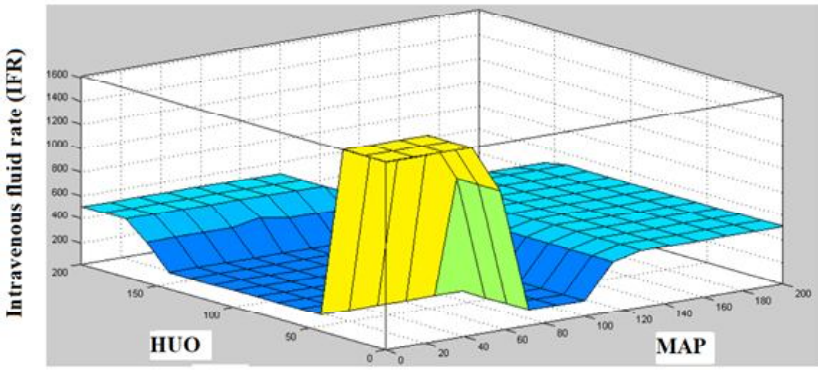
Table-3: Simulation Results for intravenous fluid rate

S.No.	MAP	HUO	CVP	IFR
1	100	100	6	160
2	146	160	9.32	20
3	42.2	44.9	1.35	1580
4	105	32.4	1.78	1060
5	83.1	78.7	0.823	160
6	106	29.8	9.96	480
7	86.7	68.9	10.6	160
8	168	121	3.69	506
9	140	20.9	1.83	808
10	112	172	3.21	429
11	25.3	20.9	11.5	1020
12	5.78	192	11.2	20
13	84	36.9	8.47	399
14	97.3	47.6	4.81	161
15	135	132	8.36	445
16	102	95.6	7.73	238
17	55.6	40.4	9.85	435
18	39.6	112	1.41	1570
19	71.6	33.3	11.3	471
20	52.9	166	5.12	465
21	19.1	28.9	544	1620
22	100	107	6.45	160
23	120	118	1.78	496
24	118	36.9	1.88	896
25	61.8	128	4.65	163

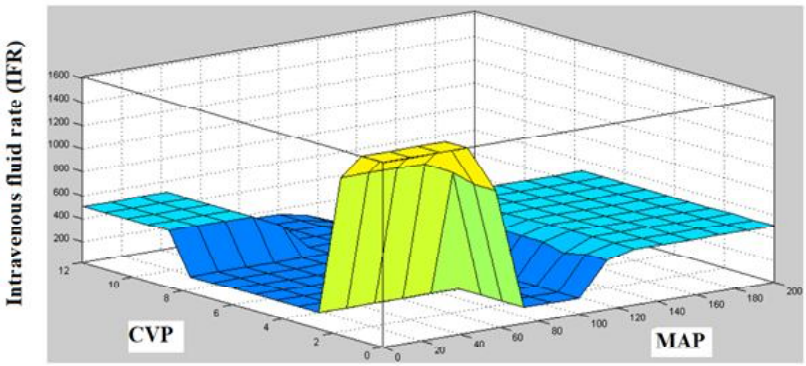
Intravenous fluid rate (IFR) has been computed in table (3) using a variety of inputs including mean arterial pressure (MAP), hourly urine output (HUO), and central venous pressure (CVP). The results show that the IFR is low at 146 mmHg MAP, 160 ml/hr HUO, and 9.32 mmHg CVP, and high at 19.1 mmHg MAP, 28.9 ml/hr HUO, and 544 mmHg CVP (1620 ml/kg).

9. Graphical Results using Fuzzy inference system (FIS) :

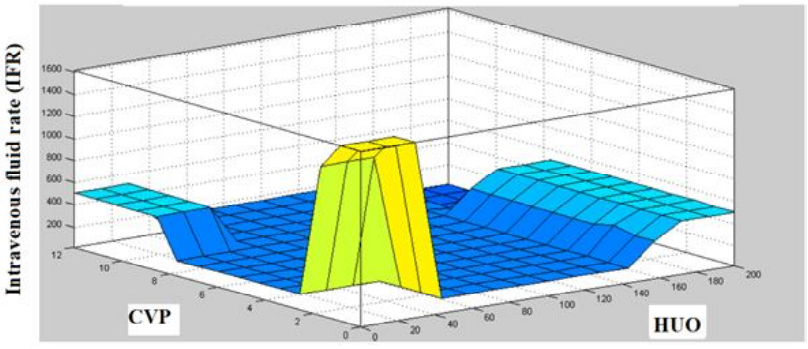
Graph 1: Surface plot of IFR for input variables MAP and HUO



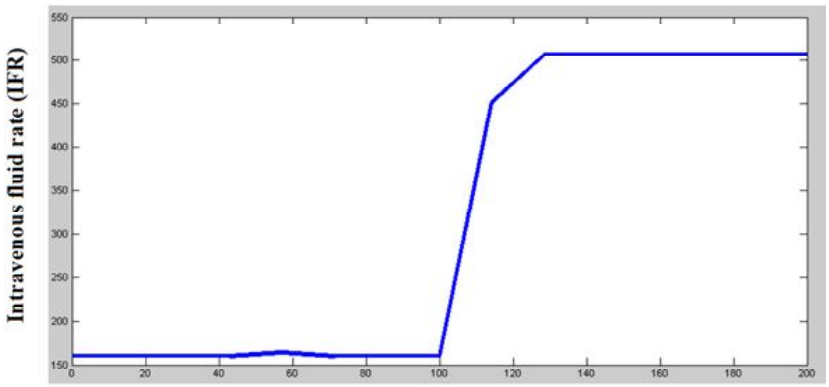
Graph 2: Surface plot of IFR for input variables MAP and CVP



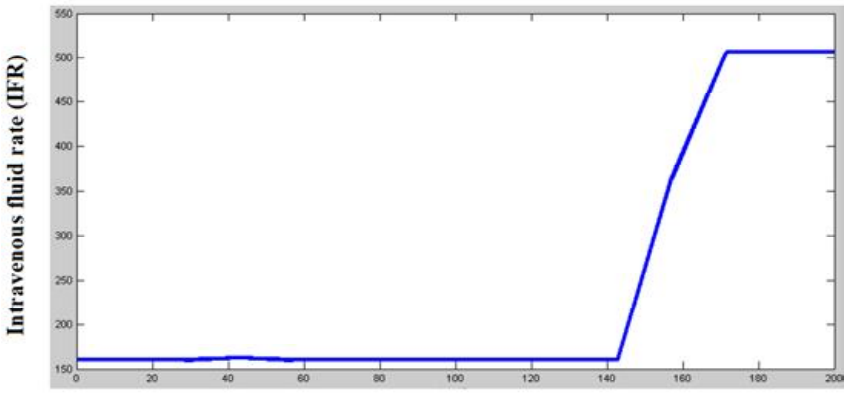
Graph 3: Surface plot of IFR for input variables HUO and CVP



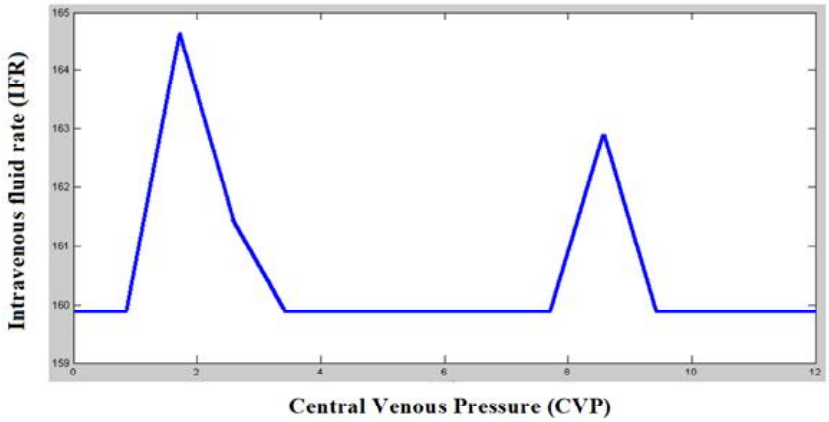
Graph 4:2D plot of IFR with MAP



Graph 5:2D plot of IFR with HUO



Graph 6:2D plot of IFR with CVP



The primary objective behind the creation of this expert system is so that medical professionals would have an easier time injecting intravenous fluid into their patients. This medical expert system is able to detect the ailment and can assist specialists in developing a treatment that is appropriate and appropriate for the disease.

The response surface is a tool that is utilized to depict the behavior of two provided variables on a surface that is three-dimensional. This analysis will focus on three different storylines. The first thing to look at in graph 1 is the plot between the HUO functionality and the MAP functionality. Analyses are performed on the response surface plots of the variables HUO and MAP functionality. The value of HUO is determined to be 28.9, while the value of MAP functionality is determined to be 19.1. It is possible to get at a reasonable approximation, based on the plot, that the IFR is exceptionally high at these values.

In addition to this, the result can be approximated using graphs[2] by taking into consideration CVP with MAP functionality. The response surface plot of the variables CVP and MAP functionality is investigated, and the value of CVP is found to be 9.32, while the value of MAP functionality comes in at 146. It is possible to draw a reasonable conclusion from the figure that the IFR is low at these values.

When looking at graphs[3], one can estimate the output by considering CVP in conjunction with HUO functionality. Analyses are performed on the response surface plots of the variables HUO and CVP functionality. The value of HUO is determined to be 68.9, and the value of CVP functionality is determined to be 10.6. It is possible to make a rough estimate from the plot that the IFR will be maintained at these numbers.

The influence that MAP, HUO, and CVP have on IFR is depicted graphically in graphs 4, 5, and 6, respectively. Graph 4 shows that the IFR is constant between MAP values of 0 and 100 mmHg, rises progressively between MAP values of 100 and 130 mmHg, and then drops back to its original value between MAP values of 130 and 200 mmHg. Graph 5 shows that the IFR is 500 over the whole range of HUO from 0 to 145 ml/hr, gradually rises from 145 to 170 ml/hr, and then returns to 500 for HUO from 170 to 200 ml/hr. Looking at graph 6, we can observe that the IFR is constant between 0 and 0.7 mmHg of CVP, rises steadily between 0.7 and 2 mmHg, falls between 2 and 3.75 mmHg, and then rises again between 3.75 and 7.75 mmHg. For some values of CVP, the IFR exhibits a periodic feature.

10. Concluding Remarks:

Using fuzzy logic, we can codify our fuzzily-defined decision-making process into a computer-friendly method. Thus, it seems to be very useful for some types of medical decision making. Moreover, fuzzy logic is simple in principle and easy to apply in software. Yet, there aren't many examples of how this fuzzy logic can be used in the medical field. Our view is that more medical professionals should be introduced to fuzzy logic. To even begin to fathom the possible uses of fuzzy logic in medicine, more study is required. This study will need to be carried out in stages, starting with the creation of a fuzzy logic algorithm tailored to a specific application, then moving on to the validation of the algorithm in actual patients. Although this process can be lengthy and difficult, it could lead to standardized protocols for medical decision making, which would help eliminate unnecessary variations

in patient care. In addition, some medical equipment utilized in the provision of healthcare may benefit from automation that is made possible by the application of fuzzy logic.

Future scope of the work: Fuzzy logic may find future application in situations when a fully qualified anesthesiologist is not immediately available, such as in the management of patients. Even in a huge medical facility, a single anesthetist could potentially move from operating room to operating room, overseeing many procedures and handling unforeseen complications, all while fuzzy logic systems made automatic adjustments based on predetermined protocols. Fuzzy logic could be used in any number of creative ways.

Acknowledgements

Funding: No government or non-government organization supported the current study financially.

References

1. Antel R., Sahlas E., Gore G., Ingelmo P., Use of artificial intelligence in paediatric anaesthesia: a systematic review. *Systematic review/Meta-analysis*, *5(C):* 100125 (2023).
2. Bates J.H.T., Young M.P., Applying fuzzy logic to medical decision making in the intensive care unit. *Critical Care Perspective*, *167,* 948-952 (2003).
3. Farivar F., Jolfaei A., Manthouri M., Haghighi M.S., Application of fuzzy learning in IoT-enabled remote healthcare monitoring and control of anesthetic depth during surgery. *Information Sciences*, *626,* 262-274 (2023).
4. Kumar R.B., Suresh P., Hemakumar V.S., Automated anesthesia level Controller using fuzzy logic for injectable type. Journal of Applied Science and Engineering, *24(5),* 749-755 (2021).
5. Liu Y.X., Doctor F., Fan S.Z. Shieh J.S., Performance Analysis of Extracted Rule-Base Multivariable Type-2 Self-Organizing Fuzzy Logic Controller Applied to Anesthesia. *BioMed Research International*, Article ID 379090, 19 pages (2014).
6. Mendez J.A., Leon, Marrero A., Gonzalez-Cava J.M., Reboso J.A., Estevez J.I., Gomez-Gonzalez J.F., Improving the anesthetic process by a fuzzy rule based medical decision system. Artificial intelligence in medicine, *84,* 159-170 (2018).
7. Miyaguchi N., Takeuchi K., Kashima H., Morita M., Morimatsu H., Predicting anesthetic infusion events using machine learning. *Scientific Reports*, *11,* 23648 (2021).
8. Rahim F., Deshpande A., Hosseini A., Fuzzy expert system for fluid management in general anaesthesia. Journal of Clinical and Diagnostic Research, *4,* 256-267 (2007).
9. Samira B., Hanane Z., Fuzzy Logic Control System in Medical Field. Proceedings of the International Conference on Industrial Engineering and Operations Management, Paris, France, July 26-27, 392-399 (2018).
10. Tomer J.A., Dubey R.P., Mathematical modeling and fuzzy logic control of inspired isoflurane to obtain minimal flow of anesthesia. International Journal on Computer Science and Engineering, *3(11),* 3652-3655 (2011).
11. Tsutsui T., Seizaburou A., Fuzzy logic control of blood pressure through enflurane anesthesia. Journal of clinical monitoring, *10,* 110-117 (1994).