Fuzzy Logic Control System in Medical Field

Brahmi Samira
Laboratory of Automation and Manufacturing LAP
Industrial Engineering Department
Batna 2 University
Shahid Boukhlouf Avenue, 05000
Batna, Algeria
brahmi.samira@gmail.com

Zermane Hanane
Laboratory of Automation and Manufacturing LAP
Industrial Engineering Department
Batna 2 University
Shahid Boukhlouf Avenue, 05000
Batna, Algeria
hananezermane@yahoo.fr

Abstract

Since the work of Lotfi Zadeh in 1965, the fuzzy logic continues to interest researchers and industrialists who gather around the "theories of uncertainty". The ramifications of fuzzy logic extend to fields as varied as control, the diagnosis of complex systems, bioinformatics, decision support. Research work is done in bio-informatic field where a system for decision support of anesthetic depth fuzzy basic. This study was carried out under general anesthesia with propofol. We use in our work some parameters influencing the patient's condition during the course of surgery to control their effects on the depth of general anesthesia by fuzzy logic. In this paper, we propose using the environment MatLab R2017a to realize this application. A comparison between the predictions of the anesthesiologist and anesthetic predictions according to fuzzy logic of our work is done. This study will serve as a guide in developing new anesthesia control systems for patients.

Keywords
Anesthesia, Control, Fuzzy Logic, MatLab R2017a, Propofol.

1. Introduction

The knowledge whose humans have about the world is almost never perfect. This is why it is important to be able to express a set of uncertain and insecure information in a system driven from a set of rules and knowledge using developed methods and techniques. These techniques are based on computer tools that combine artificial intelligence methodologies such as fuzzy logic, expert systems [1]. The fuzzy logic aims to formalize and implement the reasoning of a human. For this, it is classified in the artificial intelligence field [2], [3], [4]. The anesthetic management of a surgical patient is a process that relies on the experience of an anesthesiologist, since currently there is no direct means of assessing a patient's level of consciousness during surgery. The decision for the initial anesthetic level is generally made by using the recommended drug dosages based on various patient characteristics, such as age and weight. The anesthesiologist determines any subsequent alteration in the anesthetic level by observing signs from the patient. These signs, the indirect indicators of the depth of anesthesia (DOA), may include changes in blood pressures or heart rate. [1] Depth of anesthesia (DOA) for a patient can change according to anesthetic agent and characteristic properties of a patient such as age, weight, etc. During the surgery, depth of anesthesia of a patient is determined by the experience of anesthetist controlling of many parameters. For this reason, an inappropriate depth of anesthesia could be applied to patients. [1] The purpose of our paper is using other relevant parameters in our work that influence the patient's state of health during the course of surgery to control their effects on the depth of anesthesia (DOA) by fuzzy logic.

2. Problematic

Recently, fuzzy logic has found applications in DOA control and some preliminary results have been obtained [5], [6]. An automated closed-loop control system [6] has been constructed at Rensselaer based on their previous studies of fuzzy logic in multiple drug hemodynamic control [7], [8] and DOA control [7]. The testing results using dog experiments [6] is promising: The system monitors multiple variables for meaningful changes, integrates this information with anesthesiologist's knowledge and experience, and continually make decisions concerning present status, appropriate interventions, and expected results. A fuzzy logic-based anesthetic depth decision support system (ADDSS) was realized for anesthetic depth control to help anesthetists in surgeries [9].

The study in [9] effectively demonstrated the use of fuzzy logic in establishing a fuzzy decision-making system for inhalation anesthesia using sevoflurane[1], the fuzzy system did not show the contribution of fuzzy logic for inhalation anesthesia by decreasing the dose of anesthetic product in the gas, in addition the two parameters taken are not sufficient for a patient, it misses an important criterion for the anesthesia via sevoflurane which is the age, because the given dose to a baby is different from that given to an adult, a young man / woman, or an old man. Based on [9], another decision support system is realized concerning inhalation anesthesia using Fuzzy logic [10], [11]. Based on the works cited earlier, we use in our work other parameters and another anesthetic agent which is Propofol[2]. In this paper, the use of fuzzy logic concepts in DOA control will first be illustrated through a simple fuzzy control system. This simplified system emulates the thought processes of an anesthesiologist in managing anesthesia for patients under surgery. [1] In our work, we study anesthesia with propofol agent using 4 parameters inputs to show the depth of anesthesia (DOA) for a patient. The detailed results obtained by this model during surgery under propofol anesthesia [12] are shown later.

3. Fuzzy logic

Fuzzy logic is an extension of Boolean logic based on its mathematical theory of fuzzy sets, which is a generalization of classical set theory. By introducing the notion of degree into the verification of a condition, thus allowing a condition to be in another state than true or false, fuzzy logic distinguishes an infinity of truth values (between 0 and 1) [3], [13], [14].

4. Fuzzy controller

A fuzzy controller behaves like an approximator able to compute a non-fuzzy result from several non-fuzzy variables as well, but through a fuzzy reasoning process. This fuzzy reasoning has three functional steps summarized in Figure 1 which shows the structure of a fuzzy controller [15].

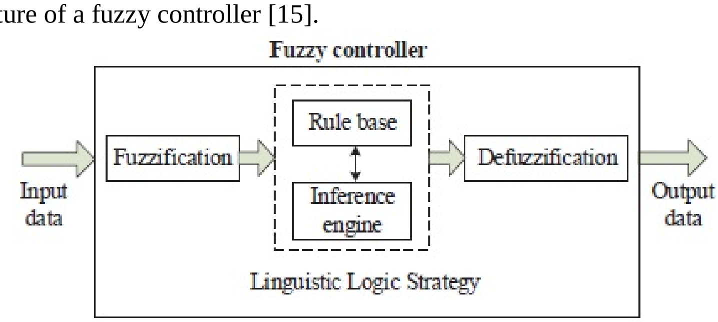

Figure 1. Structure of Fuzzy controller. [15]

[1] Sevoflurane is a volatile anesthetic product belongs to halogenated ether family, used for induction and maintenance of general anesthesia. It is widely used worldwide.
[2] Propofol Propofol, marketed as Diprivan among others, is a short-acting medication that results in a decreased level of consciousness and lack of memory for events. Propofol can be given in adults, children and infants older than 1 month.

4.1. Fuzzification

It consists of associating with each input value one or more fuzzy subsets as well as the associated degrees of belonging. This step transforms numeric values into fuzzy symbolic information. [4], [15], [16], [17].

4.2. Fuzzy reasoning

The mechanism of inference consists of calculating the degree of truth of the various rules of the system, by using the formulas given in the Fuzzification phase, and associating each rule with an output value. The most used inference mechanisms are the fuzzy inferences of Mamdani and Sugeno. Usually, the fuzzy rules are deduced based on a knowledge base derived from human expertise, which can be used in a fuzzy inference process. A rule is of the type: IF "predicate" THEN "conclusion". [15], [4]

4.3. Defuzzification

After obtaining the sub-set fuzzy solution of the command, it is necessary an exploitable physical quantity (numerical value) for the command, it is the role of Defuzzification [4], [15], [16], [17].
Several methods of Defuzzification exist but the most used are:

- The center of gravity method
- The method of maximum

5. Fuzzy logic fields application

The areas application of fuzzy logic mainly concerns problems where data can't be formulated explicitly, as well as technical control and settings, when conventional means have reached their limits and also for systems controlled by human experts. Among these applications, there are [4] [15] [16]:
• Applications exist in very different fields such medical diagnosis;
• Applications in appliances and electronics;
• Applications in automobile industry;
• In diagnosis, prognosis and monitoring, using fuzzy logic as fuzzy expert systems;
• Etc.

6. Use of fuzzy logic for anesthesia

6.1. Introduction

General anesthesia (GA) is a medically induced coma with loss of protective reflexes, resulting from the administration of one or more general anesthetic agents.
A variety of drugs are given to the patient that have different effects with the overall aim of ensuring unconsciousness, amnesia[1] and analgesia[2].

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[1] loss of memory
[2] loss of response to pain

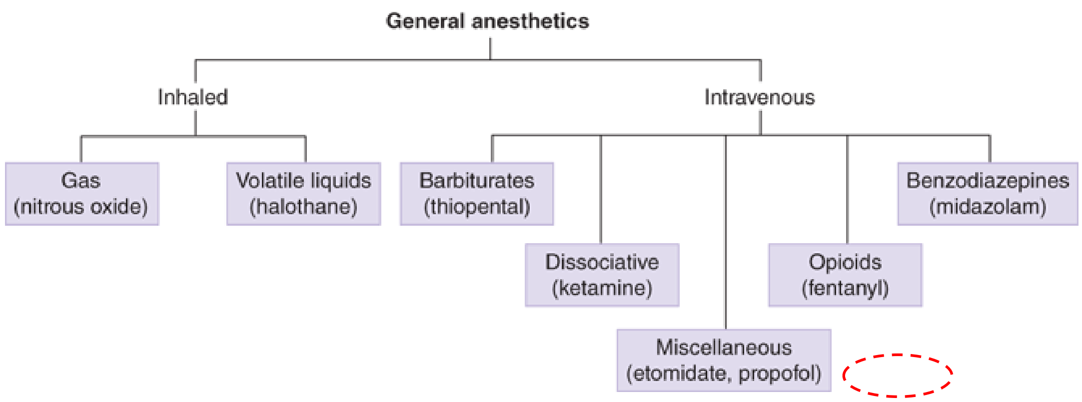

Figure 2. Classification of general anesthetics. [18]

Propofol is the newest intravenous hypnotic agent offered to the anesthetic community. Its chemical structure is original and it has only a hypnotic effect. It is characterized by a fast-falling asleep time and a short duration of action. Its side effects are arterial hypotension and injection pain during anesthetic induction.

6.2. Application on MATLAB

The application is implemented in MatMab which is a development environment, using the Fuzzy Toolbox. Figure 3 shows the basic approach of the problem, the fuzzy controller takes the inputs (Blood Pressure: SAP, HRP Heart Rate, AGE, WEIGHT), processes the information and outputs a depth of anesthesia (DOA).

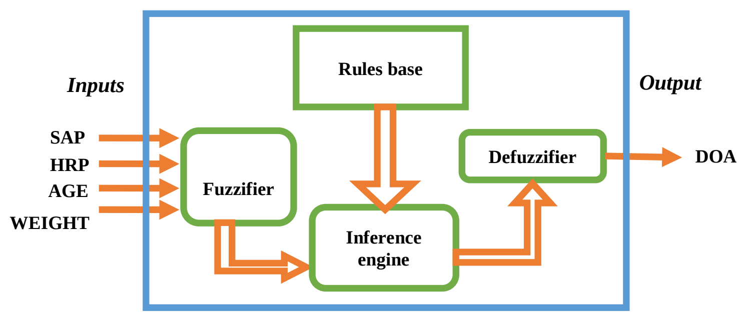

Figure 3. The fuzzy Controller. [19]

We used a Mamdani fuzzy inference method, a Defuzzification with center of gravity, the aggregation by the maximum, the subsets of the input and output variables are in trapezes form.

6.3. Sets and rules applied

Before the details of the fuzzy control are processed, the range of possible values for the input and output variables are determined. These are the membership functions used to map the measurements of the true values to fuzzy values, so that operations can be applied to them. Figure 4 shows the input and output variables and their associated membership functions. The values of the input variables **SAP** and **HRP** are normalized and included respectively in the two intervals [80-190] (unit of measurement is mm-Hg: millimeter of mercury) and [50-120] (unit of measure is p / m: pulse / minute) [4], [9]. We added the values of the input variable **AGE** included in the interval [0-100] (whose unit of measure is year). We added the values of the input variable **WEIGHT** included in the interval [0-100] (whose unit of measure is Kilogram). [1], [12] The values of the output variable DOA are normalized and in the range [0.7-5] (unit of measurement is mg/Kg) reference [1].

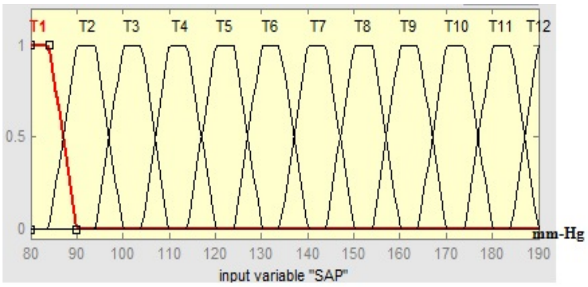

Figure 4. (a) Membership function of the SAP input. [19]

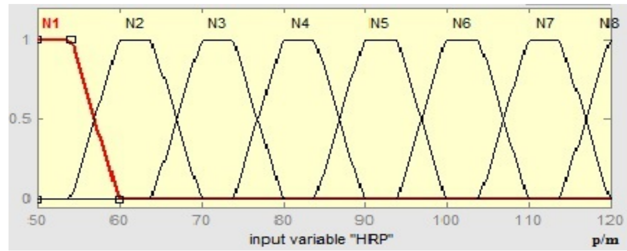

Figure 4. (b) Membership function of the HRP input. [19]

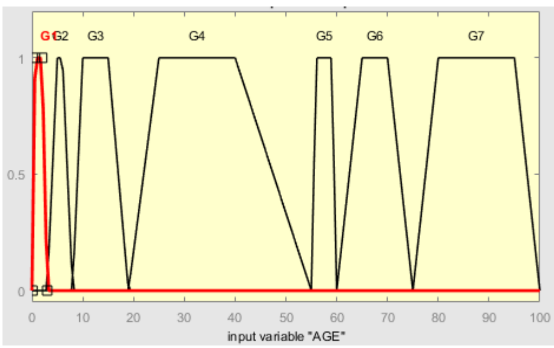

Figure 4. (c) Membership function of the AGE input. [1], [12]

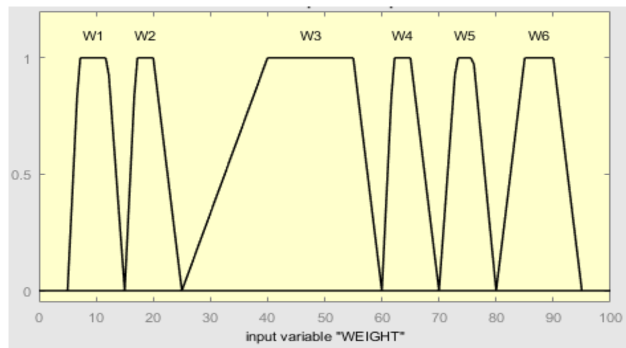

Figure 4. (d) Membership function of the WEIGHT input. [1]

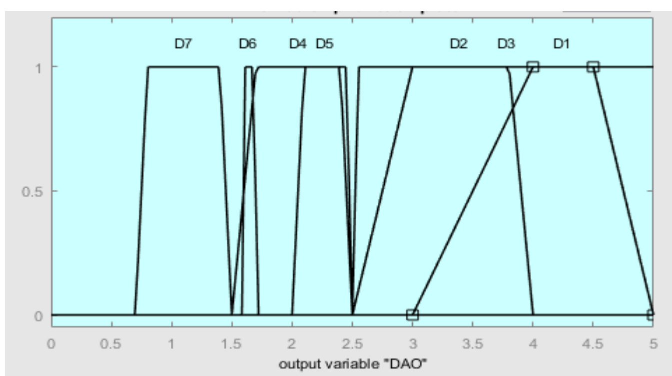

Figure 4. (e) Membership function of the DAO output. [1]

The decision that the fuzzy controller makes is derived from the rules database. The rules used in our work are based on common sense, data from experimentation in a controlled environment. The rule sets used here to obtain the output are detailed in Table 1.

6.4. Decisions Matrix

The decision rule is as follows, for example:
If T1 and N4 and G4 then we decide A3, as it is shown in the table 1 [19]:

Table 1. Decisions rules

N°	SAP	HRP	AGE	WEIGHT	DAO
1.	T1	N7	G1	W1	D1
2.	T2	N5	G2	W2	D2
3.	T2	N6	G2	W2	D2
4.	T3	N5	G3	W3	D3
5.	T3	N6	G3	W3	D3
6.	T4	N5	G3	W3	D3
7.	T4	N6	G3	W3	D3
8.	T5	N5	G3	W3	D3
9.	T5	N6	G3	W3	D3
10.	T5	N2	G4	W4	D4
11.	T5	N3	G4	W4	D4
12.	T6	N2	G4	W4	D4
13.	T6	N3	G4	W4	D4
14.	T6	N2	G5	W5	D5
15.	T6	N3	G5	W5	D5
16.	T6	N2	G6	W6	D6
17.	T6	N3	G6	W6	D6
18.	T7	N2	G6	W6	D6
19.	T7	N3	G6	W6	D6
20.	T6	N2	G7	W4	D7
21.	T7	N2	G7	W4	D7

If we take the following values: SAP = 96 → T2, HRP = 90 → N5, N6, AGE = 6 → G2 , WEIGHT = 24 → W2
So: we decide D2 = 3.26

The results presented in Figure 7 show how will differ the administered dose that will be the answer in different conditions compared to two parameters: weight and age.

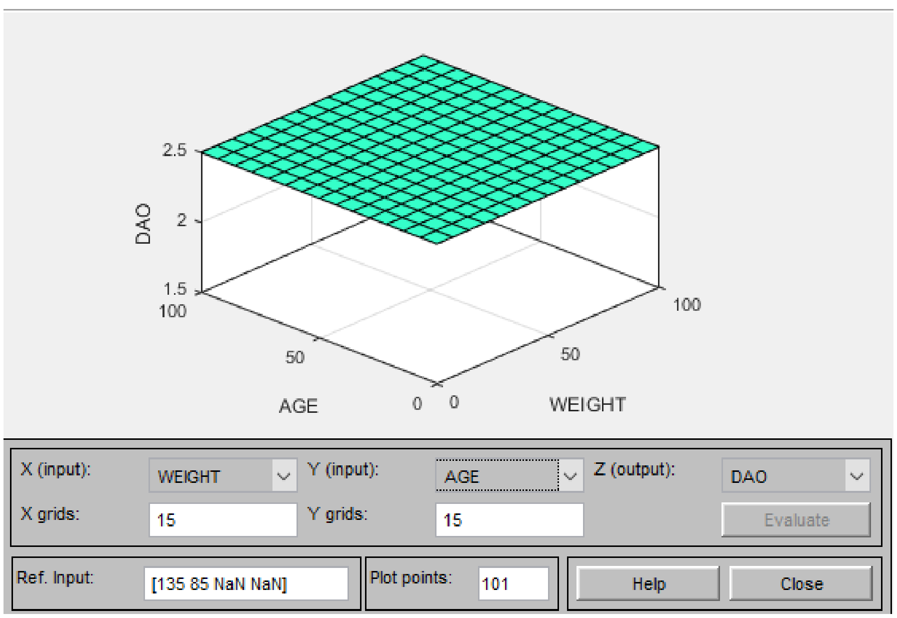

Figure 7. Surface of the DAO output according to the WEIGHT & AGE inputs

7. Conclusion

According to the study of the case we have chosen, we confirmed the importance of the studied parameters to the study which is AGE and WEIGHT and how the doses of the anesthesia are very related to these parameters. Thus, we observed a sharp decrease in anesthetic doses by the fuzzy system compared to the choice of anesthetists in references, and that the fuzzy system is powerful to imitate the decisions anesthetists. Fuzzy reasoning gives good results in relation to Boolean reasoning, or other systems, especially in continuous phenomena that had no choice to be treated only by rigid systems that accept only two cases: confirmation of the phenomenon or its negation. Our perspective is to install this type of fuzzy decision system at the surgical blocks of hospitals and its exploitation for a better decision and the availability of the service offered even if the anesthetist doctor is absent in case of emergencies.

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Biographies

Brahmi Samira is PhD Student at Industrial Engineering Department, Batna 2 University. She is a currently works at professional formation center, Batna, Algeria. Her research interests include Knowledge Management, Intellectual Capital measurement, industrial systems, organization.

Zermane Hanane is a currently works at Industrial Engineering Department, Batna 2 University. She does research in Electronic Engineering, Electrical Engineering and Control Systems Engineering. Her research interests include manufacturing, simulation, manufacturing, automation, process control, fuzzy logic and expert systems.