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DEPTH CONTROL OF SEVOFLUORANE ANESTHESIA WITH MICROCONTROLLER BASED FUZZY LOGIC SYSTEM

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***Abstract*-This system was designed for anesthetic agent, sevofluorane, which is among the first choices of anesthesiologist for inhalation anesthesia. Sevofluorane is a halogenated volatile anaesthetic with a low blood gas solubility. This facilitate smooth and rapid induction of anesthesia, allow easear titration of anesthetic dose to the desired effect during the maintenance period and permit rapid emergency and recovery at the end of the anesthesia.**

In this study, sevofluorane depth of anesthesia was examined through a microcontroller-based fuzzy logic control system according to the blood pressure and heart rate taken from the patient. The potential benefits of the systems are as follows:

1)To increase patients' safety and comfort,
2)To direct anesthesiologist' attention to other physiological variables which they have to keep under control by abating their tasks,
3)To make the optimum in the area of anesthetic agent,
4)To help protect the environment by using optimum anesthetic agent,
5)To economize by lessening the costs of an operation.

This study will serve as a guide in developing new anesthesia control systems for patients who are in different agent and different risk groups. All the details concerning the system design were given in paper.

***Keywords* – FLC, Biomedical, Control of Anesthesia**

I. INTRODUCTION

Since the 1980s new techniques have appeared from which fuzzy logic has been applied extensively in medical systems. The last couple of decades have witnessed a significant developments in control systems theory. In the meantime, developments in electronics and computers have resulted in many application areas of control theory. Although medicine is a science which isn't related to control engineering, it is being affected to such an extent that it is now possible to use available control techniques for on-line devices, especially during surgical operations and in intensive care units [1,2].

General anesthesia is the most common type of anesthetic performed at hospitals. There are several different ways to start the anesthetic, a process referred to as "induction of anesthesia." One of the most common types of anesthetic induction used at hospitals is an inhalation induction. This simply means that the patient breathes himself to sleep. The patient, will accompany the anesthesiologist to the operating room. There, after attaching monitors, the anesthesiologist will help hold a clear plastic mask over the patient's nose and mouth. The mask is attached to the anesthesia machine which delivers oxygen and anesthetic gases. The advantage of an inhalation induction is that there are no needles or anything else that is painful until after the patient is completely anesthetized [3,4,5].

In this study a fuzzy logic controller was used to control depth of sevofluorane anethesia, which was taken as a measure of the systolic blood pressure and hearth rate. The main reason for automating the control of depth anesthesia is to release the anesthesiologist so that he or she can devote attention to other tasks as well (controlling fluid balance, ventilation, and drug application) that can't yet be adequately automated and thus to increase the patient's safety.

A primary advantage of an embedded fuzzy logic system is that even complicated functions and adaptive control loops can be implemented with limited resources by using low-cost 8-bit microcontrollers. PIC16C71 microcontroller of Microchip firm was used in the system owing to its cheap price, functionality and its easy availability [6]. The responses of the system to the real values were compared by some anesthesia specialists and they were satisfactory.

II. PATIENTS AND APPLICATION

The study was approved by the Hospital Ethics Committee. In Akdeniz University, in the operating room of the Emergency and Trauma Hospital, for three and a half months, data were collected from the ASA I-II patients, who underwent an arthroscopy operation, and who were administered sevofluorane. 40 operations were recorded and 25 of them (operation time under 2 hours) were used for the system. 25 patients were studied, 15 females and 10 males, mean age 43.0 (range 16-69) yr, mean weight 68.6 (44-94) kg, mean height 156.2 (148-183) cm. During the operation every five minutes the blood pressure, the heart rate, and the rate of anesthetic agent were recorded. The membership functions and the rule base of the fuzzy logic system were determined under the inspection of specialists by abiding by the data base information. The system was

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designed for anesthetic agent, sevofluorane, which is among the first choices of anesthesiologist for inhalation anesthesia. Sevofluorane is a halogenated volatile anaesthetic with a low blood gas solubility [7]. This facilitate smooth and rapid induction of anesthesia, allow easear titration of anesthetic dose to the desired effect during the maintenance period and permit rapid emergency and recovery at the end of the anesthesia [8,9]. Because a biological process like anesthesia has a nonlinear, time-varying structure and time-varying parameters, modeling it suggests the use of rule-based controllers like fuzzy controllers. The control rules made use of the systolic blood pressure and the heart rate[10,11].

Fuzzy rule-based systems include many aspects of fuzzified values, such as the rules antecedents and consequence. The rules structure are usually of the form of *if.. then*. In its basic form this type of the control is equivalent linguistically to a PI controller, and depending on the output, whether it is incremental or absolute, the controller is known as PI or PD respectively. An example of such a rule is *if the blood pressure is above the target and decreasing slowly, then reduce the drug infusion.* A more sophisticated structure is a PID, where the input, its derivative, and integral are considered as three inputs.The rules are composed either from the expert (anesthesiologist) or crafted by hand depending on the experience of the programmer [12]. This includes tuning the membership functions in terms of the shape, width and position. This type of controller is widely used and is the most applicable control type in anesthesia [13,14,15,16,17]. In anesthetic practice, the systolic pressure has greater significance than the diastolic pressure, which isn't frequently recorded, particularly if access to the arm is difficult No "normal" blood pressure can be specified for the anaesthetized patient; in general the systolic pressure should be stable in the range 90-140 mmHg (12.0-18.7 kPa) [9,18]. Blood pressure value always contrast to depth of anesthesia. If the depth of anesthesia in deep blood pressure goes down. In other case, it goes up[10,11]. Depth of anaestesia is controlled by using a mixture of drugs that are injected intravenously or inhaled gases. Sevofluorane is widely used, most often in a mixture of 0 to 4 percent by volume of sevofluorane in oxygen and/or nitrous oxide. Figure.1. shows the system block diagram. System has two inputs and one output.

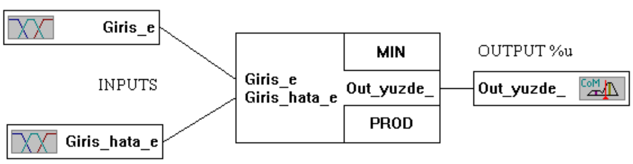

Fig. 1.System block diagram

We used fuzzyTECH 3.16 MP Explorer and MPLAB 3.01 programs for this application. MPLAB is a windows based application which contains a full featured editor, editor, emulator and simulator operating modes and a project manager. MPLAB allows us to edit our source files and one touch assemble and download to PIC16/17. But designer have to write main program byself.

Collected data were used to produce membership functions for blood pressure, hearth rate and anesthetics gas out. Figure 2.,3., and 4. shows these membership functions. Linguistic variable ranges on the functions were determined by anesthesia specialist from the collected data.

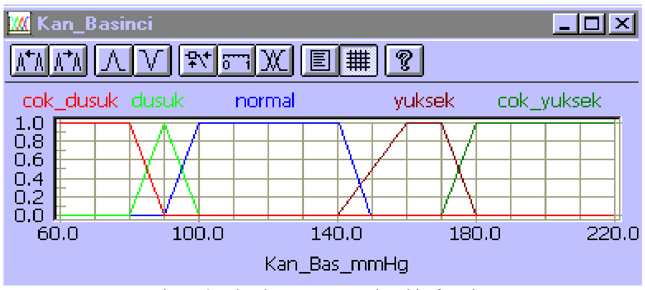

Figure.2. Blood pressure membership function

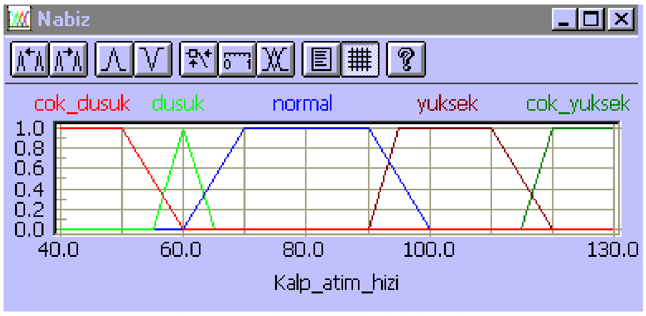

Figure.3.Hearth rate membership function

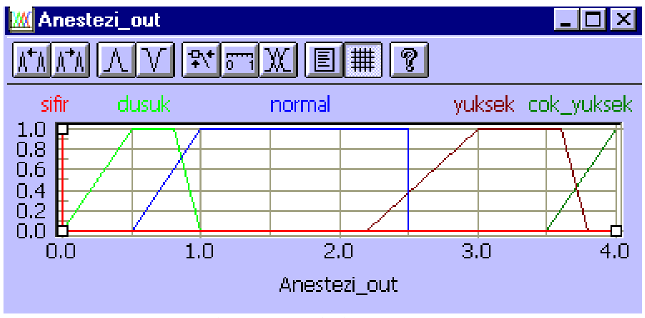

Figure.4. Anesthetics gas out %

Rule base includes 17 rules. 8 rules are eliminated by specialist. Eliminated rules are related to conditions which never happened. Input variable ranges imply 8-bit for 256 steps and 16 bits for 65536 steps. We decided to use 8-bit range. Because this range is enough for adequate appraisal.

Most fuzzy logic based application solutions use production rules to represent the relationship between the linguistic variables and to derive actions from sensor inputs. Production rules consist of a precondition (IF-part) and a consequence (THEN-part). The IF-part can consist of more than one condition linked by linguistic conjunctions like AND and OR. The computation of fuzzy rules is called fuzzy rule inference. The software which we used for this application fuzzyTECH, calculates the inference in two steps: aggregation and composition. Aggregation uses fuzzy logic operators to calculate the result of the IF part of a production rule when the rule consists of more than one input conditions. One of the linguistic conjunctions, AND or OR, links multiple input conditions. Composition uses the fuzzy logic operator, PROD, to link the input condition to the output condition.

Composition links the validity of the entire condition with the Degree of Support (DoS). Thus, composition, the second calculation step of each production rule, uses the validty of the condition to determine the validity of the consequence. In standart MAX-MIN or MAX-PROD inference methods, the consequnce of a rule is considered equally as true as the condition.

The Center-of-Maximum (CoM) defuzzification method is an approximation of the more computationally-intensive Center-of- Area method. Let R be the linguistic variable to be defuzzified, let μ_{Ri} be the membership functions of all linguistic terms i defined for the base variable internal X ($x \in X$), and let μ_{Ii} be the inference result for every term i. The crisp output value $r \in R$ is computed by the following equation:

$$r = \frac{\sum_i [\mu_{Ii} \bullet \max_x(\mu_{Ri}) \bullet \arg(\max_x(\mu_{Ri}))]}{\sum_i \mu_{Ii}} \qquad (1)$$

This method can be shown as identical to Center-of-Area (CoA) using singleton membership functions when each membership function for the linguistic variable to be defuzzified has been defined so that its maximum is 1 and is located at the position of the respective singleton.

To check the performance of fuzzy system, debug interactive window is used. The debug interactive window is active with most debug modes. This window shows the input and output variables of the system. Time plot analyser is used in debug mode and also transfer plot analyser is used. Figure. 5. shows interactive test results. Solution is obtained by using Formula 2.

$$\%u = \frac{(D.DoS \times D.An\_out) + (N.DoS \times N.An\_out)}{D.DoS + N.DoS} \qquad (2)$$

Where:
%u: Crisp out value (produced by CoM defuzzification),
D.DoS: Degree of support for low linguistic value,
D.An_out: Anesthesia out for low linguistic value,
N.DoS: Degree of support for normal linguistic value,
N.An_out: Anesthesia out for normal linguistic value,

$$\%u = \frac{(0.435 \times 0.64) + (0.315 \times 1.74)}{0.435 + 0.315} = \frac{0.2784 + 0.5481}{0.75} = 1.102$$

The system solution is made by Matlab 4.0 program for comparision Fuzzytech interactive system responses. The comparision showed each program gives same response on same input conditions. Figure. 6. shows 3D surface analysis is obtained from Matlab 4.0 program.

We prefered to use for this system 8-bit PIC16C71 microcontroller. The PIC16C71 devices have 36 bytes of RAM and 13 I/O pins. In addition a timer/counter is available.

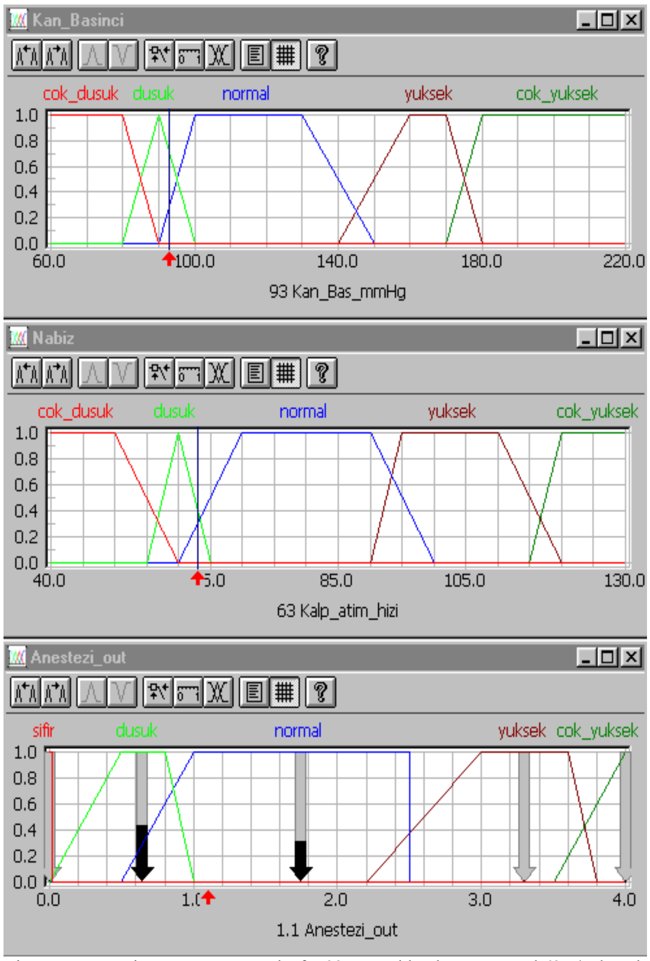

Figure.5. Interactive system test results for 93mmHg blood pressure and 63 p/m hearth rate values. System anesthetics gas out % 1.1

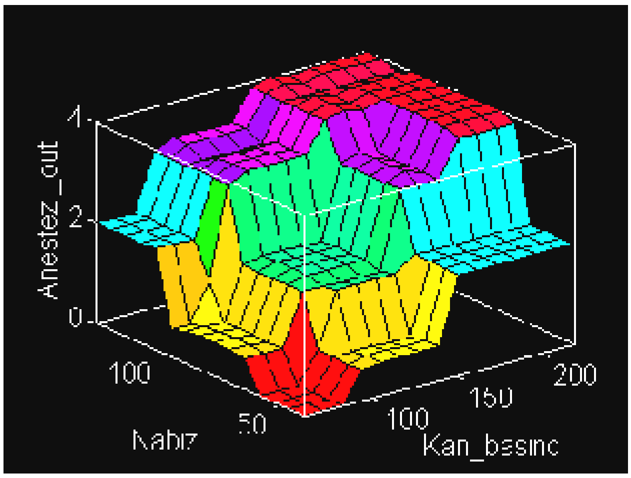

Figure.6. 3D surface analysis

Also a 4-channel high-speed 8-bit A/D is provided. The 8-bit resolution is ideally suited for applications requiring low-cost analog interface, e.g. pressure sensing, thermostat control, etc. Its A/D convertors were used to convert analog blood pressure and hearth rate signals to digital 8-bit data. These digital data were used as crisp real world data by fuzzy system.

Figure 7., 8., 9., shows the compare between the system response and manuel response during the operations.

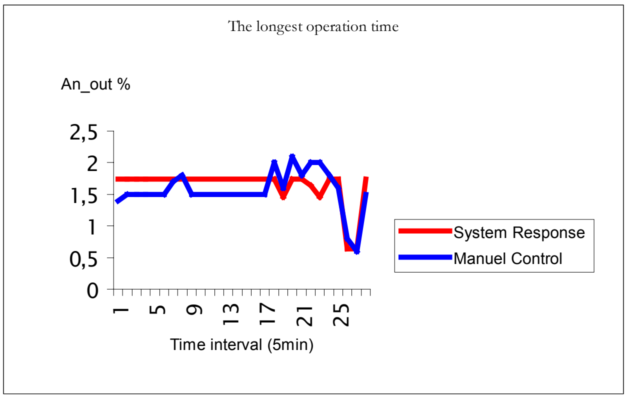

Figure.7. Anesthesia_out during the longest operation

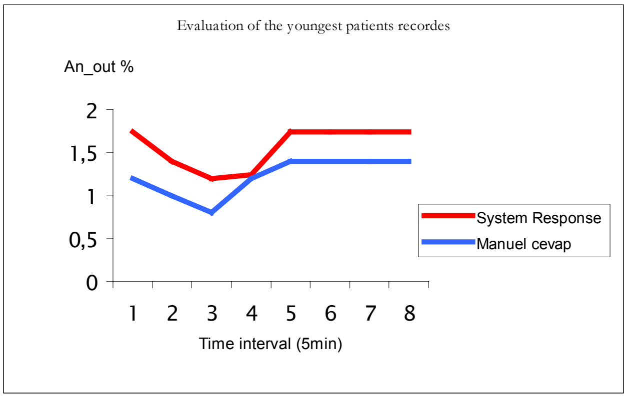

Figure.8. Anesthesia_out during the youngest patient operations

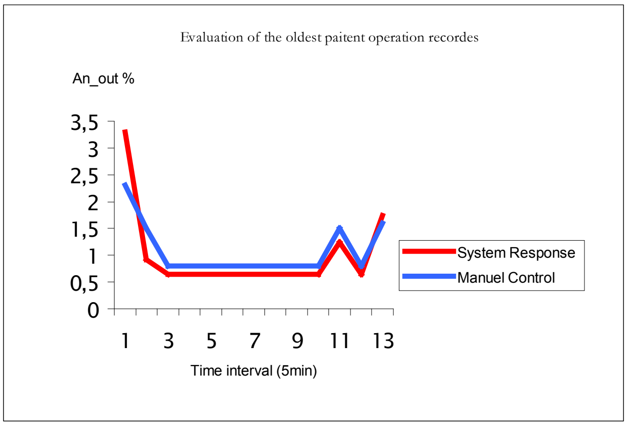

Figure.9. Anesthesia_out during the oldest patient operation

VII.CONCLUSION

Fuzzy logic simplifies the design of a control strategy by providing an easy to understand and intuitive approach to solve control problems. The potential benefits which are aimed at the beginning of the study were achieved. The sevofluorane anesthesia fuzzy logic control system can be used as an equipment which controls the depth of anesthesia. If it doesn't seem to ensure the patient's safety as an euipment which works independently without the anesthesiologist, it can easily be used as a monitor which helps keep track of depth of anesthesia. The system is to relase the anesthesiologist so that he or she can devote attention to other tasks.

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