Fuzzy logic for physiological modeling: application to the anesthetic process

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Abstract. This study addresses the problem of modeling physiological systems using fuzzy logic. As an application we consider the problem of modeling the anesthetics process. In particular we consider the problem of modeling the evolution of the bispectral index in patients undergoing anesthesia with intravenous propofol. An identification based on fuzzy inference system is proposed. One of the main advantages using fuzzy logic is the simplicity to include the experience of the expert in the model. The resulting system was validated using patient data.

1 Introduction

To achieve adequate anesthesia and compensate the effect of surgical manipulation while maintaining the patient's vital functions, anesthesiologists regularly adjust the configuration of different drug infusion devices and the parameters of the breathing system. This is done based on certain objectives and from the readings of the monitors.

Hypnosis is a general term that indicates the loss of consciousness and absent of post-operative memory of the process. Recently, the development of hypnosis closed-loop anesthesia systems is attracting many researchers due to its potential to improve the efficiency of the anesthetic process [1],[2],[3],[4]. From a general point of view we can distinguish two different approaches for closed-loop control: signal based and model based controllers. The first group uses basically proportional-integral and derivative (PID) strategies. The second group uses controllers that compute the adequate drug infusion rate based on a model to predict the patient response. So the interest in providing an accurate model for each patient is important when model-based control is considered.

This paper deals with the modeling problem of BIS in intravenous anesthesia with propofol. Most of current modeling approaches in anesthesia are based on the use of compartmental models [5],[6]. The main advantage of using fuzzy logic stands on the possibility to include the experience of the anesthetist in the model.

2 Methods

This model was obtained using patient data collected from several surgical procedures, and including information from the experience of specialists.
The model was obtained in the following steps:
1- Design of a fuzzy model with 3 inputs and one output. Input 1 is the infusion rate delivered to the patient in mg/kg/h (u). This input includes a transport delay r, to include the processing time in the BIS monitor. We considered two fuzzy sets for this variable with triangular membership function, and with a membership degree overlap of 50%. Input 2 is the BIS at the current instant t (BIS). We define to fuzzy sets with two overlapping triangular membership function with a membership overlap degree of ½. Input 3 is the BIS change in one sample instant (□BIS). Three fuzzy sets where considered with membership functions that fairly cover the universe of discourse for maximum and minimum BIS change.
2. - Generation of rules and rule weights. The rule has the form

If u(t-r)=A and BIS(t)=B and □BIS(t)=C then □BIS(t+1)=D

where A,B,C and D represents any of the fuzzy sets defined for each variable. The definition of the rule base was done using information provided by the anesthetist about the dynamics of the BIS and also analyzing registered data from real patients. The base rule was finally implemented using 24 rules

3 Results

Validation of the proposed method was done using real data from patients undergoing general anesthesia. Results obtained confirmed satisfactory performance of the proposed model and an accurate trajectory prediction. As an example, observe Figure 1, where the dashed line represents the model response and the solid line is the measured BIS. The period analyzed corresponds to the drug maintenance phase in which the BIS is already around the BIS target (50) for general anesthesia. As can be observed, the tracking error obtained is relatively small and good enough to compute the predictions of a model predictive controller

4 Conclusions

In this work a novel approach to physiological modelling is presented. The method is based in the use of fuzzy logic. A successful application to the anesthesia problem is presented. The method proposed was able to predict the trajectory of the BIS signal with a small error. The efficiency of the proposal was tested using real data from the operating room. Results attest the potential use of this methodology to model complex physiological systems.

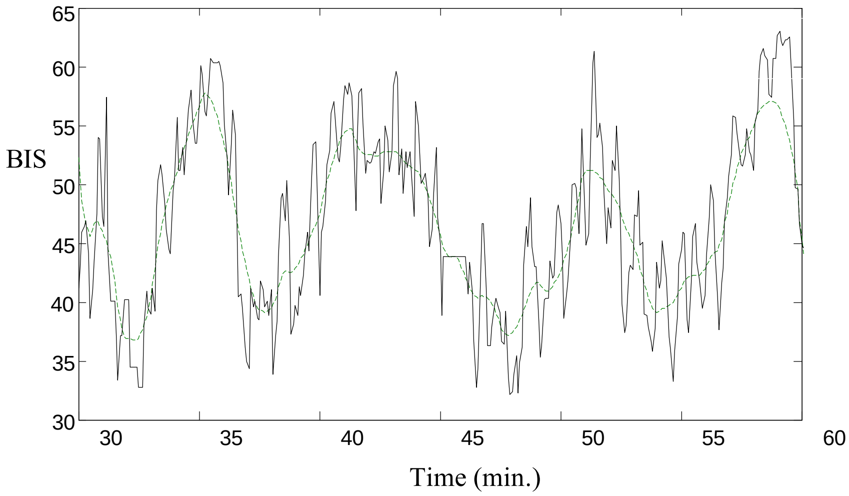

Fig. 1. Comparison of real BIS evolution (solid line) and modelled BIS (dashed line) using fuzzy logic.

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