Fuzzy Logic-Based Modeling of the Biological Regulator of Blood Glucose

José-Luis Sánchez Romero, Francisco-Javier Ferrández Pastor, Antonio Soriano Payá, and Juan-Manuel García Chamizo

Department of Computing and Information Technology, University of Alicante
Apdo. 99, E-03080 Alicante, Spain
{sanchez,fjferran,soriano,juanma}@dtic.ua.es

Abstract. This paper proposes the utilisation of fuzzy logic so as to design a system which models the biological regulator of blood glucose. That system consists of several fuzzy relations, each one of them modeling a component of the biological glycemia regulator, that is, pancreatic insulin production, net hepatic glucose balance, insulin dependent and independent glucose uptake, and kidney function. A set of experiments has been carried out by means of a simulation of the proposed model, checking that fuzzy control provides good results for the studied cases. The system could be a basis for developing artificial glycemia control mechanisms to be applied as a therapy for different pathologies, as well as for the development of simulators and monitors to aid diagnosis.

1 Introduction

Glucose is essential for cellular nutrition; its normal concentration in blood is within the range of 3.9-6.7 mmol/l. Hyperglycemia (high glucose level) can damage patients' health in the long term; hypoglycemia (low level) can make complications arise in the short term [1, 2]. The pancreas plays a main role in glycemia regulation: it secretes insulin, a hormone which reduces glycemia by enabling glucose to penetrate cells, thus maintaining normoglycemia [2]. A common illness related to an impaired glycemia regulation is Diabetes Mellitus (DM), mainly due to an insufficient insulin secretion or action. DM patients must control their diet and, frequently, follow a therapy to regulate glycemia externally that, in case of insulin dependent DM patients, usually consists of daily injection of insulin to compensate their own inefficient production of this hormone [3, 4]. The financial costs related to DM therapies are high, both for the patient and for the National Health System [3].

In this paper, we will first describe some significant aspects regarding the biological glycemia regulation system. Next we will review some artificial methods for achieving the same aim. Finally, we will propose a Fuzzy Logic model which enables the glycemia regulation system to be studied in different conditions and show the results obtained from simulations carried out with Matlab©. Despite its strong medical basic, the development of the study is closely related to Artificial Intelligence.

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1.1 The Biological Blood Glucose Regulation System

Insulin takes part in insulin-dependent glucose utilisation, performed mostly by muscle and adipose tissue. There is also an insulin-independent glucose utilisation carried out mainly by the central nervous system and red blood cells.

Glucose enters the extracellular space via both intestinal absorption and hepatic production. In the first case, glucose is absorbed by the gut to enter the portal circulation, with a rate related to ingested carbohydrates. Depending on glucose and insulin levels, the liver removes glucose from blood to synthesize glycogen or spills glucose to blood by means of glycogen breakdown and gluconeogenesis. The kidney excretes glucose through the urine when glycemia surpasses a threshold (about 9 mmol/l).

1.2 Artificial Blood Glucose Regulators and Regulation Models

Most research related to Diabetes is addressed to improve the metabolic control by using artificial regulation mechanisms that compensate the biological regulating system. The most usual mechanism is the injection of several daily doses of insulin [3]. This therapy does not achieve good results: it is difficult to adapt the insulin a patient needs along the day with punctual external supplies of it, so hypoglycaemic and hyperglycaemic episodes appear in an alternated way. In order to adapt the insulin supply to the patient's necessities, the *insulin pump* has been designed [3, 4]. This device supplies previously and remotely programmed insulin doses. Despite the positive results of this therapy, it lacks a feedback in the insulin infusion related to the glucose level. This non-autonomous operation points out the possibility of designing a device that was able to measure the glucose level and to react for achieving normoglycemia.

We must consider how much each regulation model fits the system we deal with. Its dynamics is not well-known, so the behaviour and the application results of a classical PID regulator could be inadequate [5]. Models based on neural networks or genetic algorithms can be applied to poorly structured systems, but they need a wide set of empiric data to infer regulation mechanisms based on their typical learning algorithms [6, 7]. Regulation models based on fuzzy sets are mainly applied to systems whose knowledge base could be virtually equal to the one a specialist has, where decisions are made depending on the combination of values of some factors [6, 7]. We will apply these fuzzy inference features to the problem of glycemia regulation.

2 Model Specification Oriented to Fuzzy Design

We will base on the components described in subsection 1.1 so as to model the glycemia regulation system. The model (shown in figure 1) consists of five fuzzy modules, each one representing a component of the biological system. Five fuzzy variables connect the modules: *Iout*, *Ghep*, *Gdep*, *Gind*, and *Gren*; these variables provide three derived ones: *Gin*, *Gadd*, and *Gout*. An input variable, *Gpre*, is assumed to be a previous glucose absorption by the gut (carbohydrate ingestion). We