Agent-based Simulation for Blood Glucose Control in Diabetic Patients

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Abstract—This paper employs a new approach to regulate the blood glucose level of type I diabetic patient under an intensive insulin treatment. The closed-loop control scheme incorporates expert knowledge about treatment by using reinforcement learning theory to maintain the normoglycemic average of 80 mg/dl and the normal condition for free plasma insulin concentration in severe initial state. The insulin delivery rate is obtained off-line by using Q-learning algorithm, without requiring an explicit model of the environment dynamics. The implementation of the insulin delivery rate, therefore, requires simple function evaluation and minimal online computations. Controller performance is assessed in terms of its ability to reject the effect of meal disturbance and to overcome the variability in the glucose-insulin dynamics from patient to patient. Computer simulations are used to evaluate the effectiveness of the proposed technique and to show its superiority in controlling hyperglycemia over other existing algorithms.

Keywords—Insulin Delivery rate, Q-learning algorithm, Reinforcement learning, Type I diabetes.

I. INTRODUCTION

HUMAN bodies need to maintain glucose concentration level in a narrow range 70-110 mg/dl. If one’s glucose concentration level is significantly out of the normal range, this person is considered to have the plasma glucose problem: Hyperglycemia or hypoglycaemia.

Diabetes mellitus is a disease in glucose-insulin endocrine metabolic system, in which the pancreas either does not release insulin or does not properly use insulin to uptake glucose in the plasma, which is referred as hyperglycemia [1]. The two types of diabetes are Type I and Type II. In this paper the focus is on type I diabetes. In Type I diabetes, the body’s immune system destroys pancreatic beta cells, and the patient is totally dependent on an external source of insulin to be infused at an appropriate rate to maintain the blood glucose concentration.

When a normal person is subjected to a glucose meal, the glucose concentration in plasma increases from basal value and so the pancreatic β-cells secrete insulin. The insulin in plasma is hereby increased, and the glucose uptake in muscles, liver, and tissues is raised by the remote insulin in action. This lowers the glucose concentration in plasma, implying the β-cells to secrete less insulin, from which a feedback effect arises [2]. But, in type I diabetic patients whose pancreas does not release insulin, blood glucose level remains in much more than basal value for long period of time. When glucose level remains high for extended periods of time the patient is at risk for neuropathy, nephropathy, blindness, and other long-term vascular complications. However, the result of the Diabetes Control and Complications Trial (DCCT) showed that an intensive insulin therapy can reduce the risk of developing complications [3]. Consequently, an intensive therapy is encouraged for type I diabetic patients prescribed by a continuous subcutaneous insulin infusion pump.

Control strategies of diabetes treatment can be categorized as open loop control, semi closed-loop, and closed-loop control. Current treatment methods utilizing open loop control in which physicians inject a pre determined dose of insulin subcutaneously based on three or four time daily glucose measurements, usually by an invasive method of finger prick. This method not only is painful and inconvenient but also unreliable because of approximation involved in type and the amount of insulin delivered. In semi closed-loop control insulin infusion rate adjust according to intermittent blood glucose readings. This technique is sub-optimal and unable to accomplish the aforementioned normalization and also suffered from long sampling time problem of missing fast or inter-sample disturbances. However, closed-loop control method which acts as an artificial pancreas is the most effective way of diabetes treatment and could improve the quality of life and life expectancy of patients [4]. Ultimately, a true artificial pancreas is a closed-loop device that enables a person with diabetes to maintain normal glucose levels by providing the right amount of insulin at the right time, just as the pancreas does in non-diabetic individuals [5].

In the near term, we expect artificial pancreases to be external devices comprises of insulin pumps, already widely available; continuous glucose monitors (CGMs), which are coming on the market now and an appropriate control algorithm. Figure 1 shows the block diagram of a closed-loop control system of diabetic patients. In this system, the control algorithm would calculate optimal insulin delivery rate designed to keep the patient under metabolic control, and a signal would drive a mechanical pump to deliver the desired amount of insulin.