EECE 441

CONTROL SYSTEM DESIGN PROJECT

Glucose Control in Type 1 Diabetes

Due April 7, 2017

Type-1 diabetes mellitus (TD1M) is an autoimmune disease affecting the ability of a person to produce insulin for efficient regulation of glycemia, leading to periods of hyperglycemia, potentially resulting in vascular disease, heart attack, strokes, blindness and kidney damage. Optimizing glycemia in persons with TD1M usually consists in taking blood samples for glucose measurement and administering insulin, typically in multiple daily injections. A closed-loop control system able to continuously infuse insulin to maintain the measured blood glucose content at safe values has the potential to reduce the rate of diabetic complications while easing the burden of therapeutic regimen for the patient. Such an "artificial pancreas" has ben the object of intense research for 40 years, see Figure 1 for a recently tested system which uses subcutaneous (SC) insulin delivery.

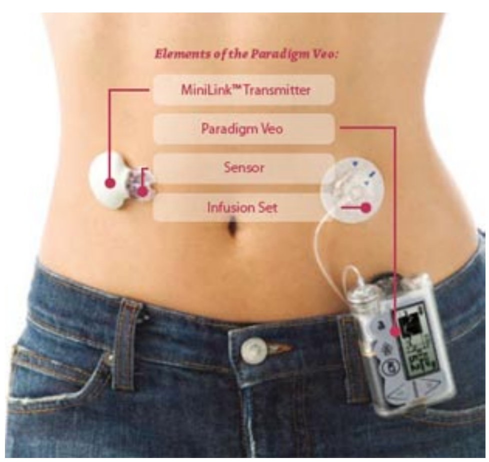

Figure 1: The proposed Medtronic "Artificial Pancreas"

Although a number of sophisticated control algorithms have been proposed to solve this problem, a PID controller is attractive in the sense that it mimics the actual pancreas reasonably well. There are a number of challenges though in tuning the PID controller: i) SC insulin delivery introduces a delay of approximately 1 h, which does not exist in the natural pancreas which delivers directly to the portal vein; ii) physiological parameters vary among individuals, especially insulin sensitivity. Here we will simply consider control of glucose using insulin, with the main disturbance consisting of carbohydrates orally ingested at meal time (CHO).

A simplified overall model is:

$$Y(s) = \frac{K_M e^{-\tau_{DM} s}}{s(\tau_M s + 1)} U_M(s) + \frac{K_I e^{-\tau_{DI} s}}{s(\tau_I s + 1)} U_I(s)$$

where U_M is the carbohydrate input (disturbance) in grams; U_I is the insulin input in mU/min; Y is the glucose concentration in mg/dl. Note that the integrator assumption is a simplification only valid over a relatively short time scale. The nominal model parameters are:

Table 1: Model Parameters

K_M	τ_M	τ_{DM}	K_I	τ_I	τ_{DI}
4	50	15	-0.075	140	25

The meal model gain K_M is expressed in mg/dl per g CHO, the insulin model gain K_I is expressed in mg/dl per mU/min, the time constants and delays are expressed in min.

The simulated protocol to be used for testing the closed-loop control system covers a 48h period from 6 a.m to 6 a.m, assuming steady state at a concentration of 110 mg/dl, which is the setpoint.

- Meals are assumed to be taken at 7 a.m., 1 p.m., and 7 p.m. Breakfast consists of 25 g CHO ingested over 10 min, lunch of 40 g CHO ingested over 15 min, and dinner of 60 g CHO ingested over 20 min.
- The controller will have to be robust under the following uncertainty: $\pm 25\%$ variation in K_I, 25% variation in meal size, ± 15 min in meal time.
- The maximum insulin infusion rate is 10 U/h, or 166 mU/min.
- The desirable range for the blood glucose concentration is 70 - 180 mg/dl. Above, the subject is in hyperglycemia, below the subject is in hypoglycemia. Hypoglycemia is more dangerous than hyperglycemia and should be avoided particularly during the night when the subject is asleep.

- For the purpose of this project, we will consider a setpoint of 110 mg/dl.

You are asked to do the following, showing the details of your design, justifying you choices, and showing simulation results using either Matlab or Simulink.

1. Design a feedback control scheme, that minimizes the episodes of hyperglycemia and particularly of hypoglycemia. Your scheme should be robust to the uncertainty mentioned above.
2. Investigate the use of feedforward control, in which case the subject could announce meals up to 15 min in advance. Once again, your scheme should be robust to the above uncertainty.

In all simulations, show both the glucose concentration, the carb input and the insulin infusion rate. Give the details of your designs, showing and justifying all the steps and choices of parameters. Include your Matlab code as appendix to the final report. Email the final report by 23:59 on April 7 as a pdf file (word files not accepted) to guyd@ece.ubc.ca with as subject line:

EECE441 - Final Project - firstname lastname