An Adaptive Control Strategy for Blood Glucose Regulation using Linear Models from Patients own Data

Meriyan Eren and Ali Cinar, Illinois Institute of Technology
Lauretta Quinn and Don Smith, College of Nursing, University of Illinois at Chicago.

Diabetes is a disease characterized by deficiency of insulin secretion by pancreas in the body. For patients with the type 1 diabetes, the degradation of insulin releasing cells is total, leading to no insulin release and consequently failure in blood glucose regulation. Therefore, patients with type 1 diabetes are totally dependent on exogenous insulin. For type 1 diabetes, the current therapy includes 3-4 daily insulin injections or insulin infusion by a manual pump, with the insulin dose anticipated according to the diet or physical activity conditions, and 3 to 7 daily blood glucose measurements. Due to the open loop nature of this therapy, patients frequently encounter large variations in blood glucose concentration which may lead to hypo/hyperglycemic episodes. To avoid such large fluctuations, patients are generally forced to follow a strict diet and a very rigid daily lifestyle. Therefore, a novel therapy that gives the patient a freedom in daily life is of great importance. Such therapy may be possible by totally closing the loop (with no-need of patient intervention) with an automated artificial pancreas, a system that should consist of three primary components: a continuous blood glucose measuring device, an automated insulin infusion pump and a control algorithm. In this research, we focus on the last component of such a device and propose a control algorithm based on adaptive control concept which makes use of a linear model developed from patients own glucose data.

Most of the works in literature proposing model based control strategies for closing the loop for the insulin user, make use of non-linear physiological glucose-insulin dynamics models for future blood glucose prediction. Such models generally are representative of only an average patient under specific conditions. However, for the development of the automated artificial pancreas a more realistic description that takes into account the intra- and inter-subject variability is required. Therefore, in the first part of this research we investigate the reliability of simple linear models developed by using the patient’s own blood glucose data for predicting future glucose concentrations. Then we develop adaptive control systems that make use of these models.

The proposed strategy for glucose prediction is based on glucose time series analysis for linear model identification, and for the rejection of unexpected daily life disturbances, it is incorporated with a change detection method. For the disturbance free daily life conditions (such as predefined diet and no variation in daily life), results reported will include low-order autoregressive (AR), autoregressive moving average (ARMA), and subspace state space models with time-invariant parameters. And for the rejection of unexpected disturbances (such as change in the diet, illness, stress, physical activity conditions and many others), the recursive least square (RLS) strategy will be incorporated with a forgetting factor and a change detection algorithm. Here, at each sampling time, the linear model is updated based on the available glucose data and with the detection of change in model parameters, the forgetting factor is decreased to a smaller value. This way, the past observations (the data before the change detection) are rapidly excluded, and the model is derived from the more recent and fresh data only, which makes the model easily adapt to changes. Results will be demonstrated on two sources of data: (1) real subject/patient blood glucose concentration data collected at high frequency (5 minute intervals); (2) simulation data on blood glucose concentration with additional information on food intake and other disturbances.

The second part of the presentation will cover the development of the control strategy for closing the loop. A model-based control strategy where the model is adaptively identified from the frequently sampled patient blood glucose data, is proposed. At each step, the RLS method with a forgetting constant and incorporated with a change detection algorithm is utilized for blood glucose prediction, and based on the predicted values the necessary insulin infusion rate is determined. The reported results will compare the three well-known control algorithms: generalized predictive control (GPC), linear quadratic Gaussian control (LQGC) and model predictive control (MPC). The primary objective of all three strategies is to minimize the deviation of the predicted glucose values from a set point by adjusting the next insulin infusion rate. Instead of using a constant reference point, a linearly declining trajectory is proposed when the blood glucose levels are above normal. And for a faster recovery from low blood glucose conditions, a more aggressive control movement is accomplished with the use of an exponential trajectory. Real time glucose concentration is sampled at 5 minute intervals and the corresponding subcutaneous or intraperitoneal insulin infusion rate is modified every 5 minutes. The performances of the proposed control strategies (GPC, LQGC and MPC) will be demonstrated on a simulated type 1 diabetic patient data for elevated and low blood glucose conditions. Additionally, without any prior information about the meal disturbances, the effectiveness of the algorithms for disturbance rejection will be investigated.

Due to the adaptive nature of the strategy and the use of a linear model derived from patient's own data, the proposed control algorithm can dynamically respond to the intra- and inter-subject variations, which makes it a valuable approach for closing the loop for the insulin user.