Optimal Control of Blood Glucose Concentrations under Uncertainty for Patients with Type 1 Diabetes

Motivation & Objectives
The pancreas of the patient with type 1 diabetes cannot synthesize insulin. Insulin injection is required to decreased blood glucose (BG) to avoid hyperglycemia, for which the BG is higher than 8 mmol/L; however, BG can be decreased too low if hypoglycemia occurs, the BG value for which is lower than 3.9 mmol/L. Even hyperglycemia is dangerous, however, hypoglycemia is much more severe. Several strategies have offered for BG control; results from some previous work which are based on open-loop optimal control shows that improvement must be done in order to lead better and safer results. The objective of this project is to consider the uncertainty in the optimal control and it should be proven that after such consideration better results can be obtained.

Reason for considering uncertainty
In the figure left, the blue dash curve is the simulated BG from a deterministic model; the blue solid is the measured BG. Even the two curves have similar trends, clearly there is a variability between them. One reason of this situation is the existence of uncertainty. Hyperglycemia and hypoglycemia has been found in the measured BG (1 mmol/L=18mg/dL). Simulation based on deterministic model is not enough to give safe insulin injections.

Stochastic model simulation
In the stochastic model simulation, two sources of uncertainty are mainly considered:
1. Sensor noise: comes from the BG measurement
2. Parametric noise: comes from identification of the parameters
In the left figure, 95% confidence interval is used. It is thought that if there is no hypoglycemia in this interval, its probability of occurrence will be very small (less than 2.5%). Simulation of the stochastic model based on a certain risk function shows that hypoglycemia will occur with rather high probability. Improvement is essentially required.

Improvement Approaches
Two different approaches have verified to improve the performance of the optimal open-loop control:
1. Design new risk function
2. Use nonlinear constraints
Both of these two approaches require the information of uncertainty. In order to verify the their effect, the performance of each approach is compared with that of original risk function.

Performance of new risk function
The performance after using one certain new risk function ABPM1 is better, from a general view both the probability of hyper- and hypoglycemia are decreased. Hypoglycemia still occurs in the 95% confidence interval (at about 90min).

Performance of nonlinear constraints
Better results have been found after the use of nonlinear constraints. The idea of nonlinear constraints can ensure that there is no hypoglycemia in the 95% confidence interval. The disadvantage lies in the fact that it would take a longer time for simulation.

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