

Zone Model Predictive Control: A Strategy to Minimize Hyper- and Hypoglycemic Events

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Abstract

Background:

Development of an artificial pancreas based on an automatic closed-loop algorithm that uses a subcutaneous insulin pump and continuous glucose sensor is a goal for biomedical engineering research. However, closing the loop for the artificial pancreas still presents many challenges, including model identification and design of a control algorithm that will keep the type 1 diabetes mellitus subject in normoglycemia for the longest duration and under maximal safety considerations.

Method:

An artificial pancreatic β -cell based on zone model predictive control (zone-MPC) that is tuned automatically has been evaluated on the University of Virginia/University of Padova Food and Drug Administration-accepted metabolic simulator. Zone-MPC is applied when a fixed set point is not defined and the control variable objective can be expressed as a zone. Because euglycemia is usually defined as a range, zone-MPC is a natural control strategy for the artificial pancreatic β -cell.

Clinical data usually include discrete information about insulin delivery and meals, which can be used to generate personalized models. It is argued that mapping clinical insulin administration and meal history through two different second-order transfer functions improves the identification accuracy of these models. Moreover, using mapped insulin as an additional state in zone-MPC enriches information about past control moves, thereby reducing the probability of overdosing. In this study, zone-MPC is tested in three different modes using unannounced and announced meals at their nominal value and with 40% uncertainty. Ten adult *in silico* subjects were evaluated following a scenario of mixed meals with 75, 75, and 50 grams of carbohydrates (CHOs) consumed at 7 am, 1 pm, and 8 pm, respectively. Zone-MPC results are compared to those of the "optimal" open-loop preadjusted treatment.

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Abbreviations: (ARX) autoregression with exogenous input, (CHO) carbohydrate, (CM) control moves, (CV) controlled variables, (FDA) Food and Drug Administration, (IOB) insulin-on-board, (MDI) multiple daily injections, (MPC) model predictive control, (Padova) University of Padova, (PH) prediction horizon, (ST) settling time, (SD) standard deviation, (T1DM) type 1 diabetes mellitus, (TO₁₈₀) time (min) over 180 (mg/dl), (UVa) University of Virginia

Keywords: artificial pancreas, type 1 diabetes mellitus, zone model predictive control

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Abstract cont.**Results:**

Zone-MPC succeeds in maintaining glycemic responses closer to euglycemia compared to the “optimal” open-loop treatment in the three different modes with and without meal announcement. In the face of meal uncertainty, announced zone-MPC presented only marginally improved results over unannounced zone-MPC. When considering user error in CHO estimation and the need to interact with the system, unannounced zone-MPC is an appealing alternative.

Conclusions:

Zone-MPC reduces the variability of control moves over fixed set point control without the need to detune the controller. This strategy gives zone-MPC the ability to act quickly when needed and reduce unnecessary control moves in the euglycemic range.

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