ONLINE-TUNED MODEL BASED COMPOUND CONTROLLER FOR BLOOD GLUCOSE REGULATION IN TYPE 1 DIABETIC PATIENT

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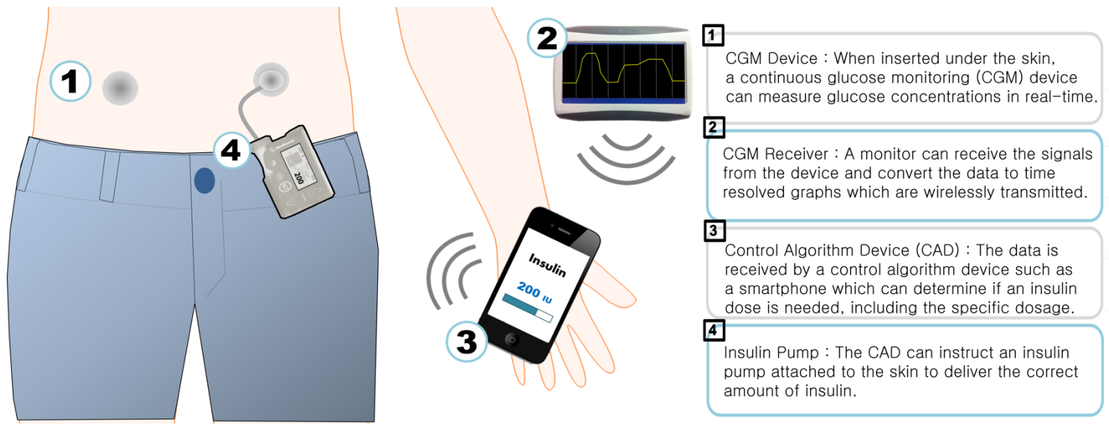
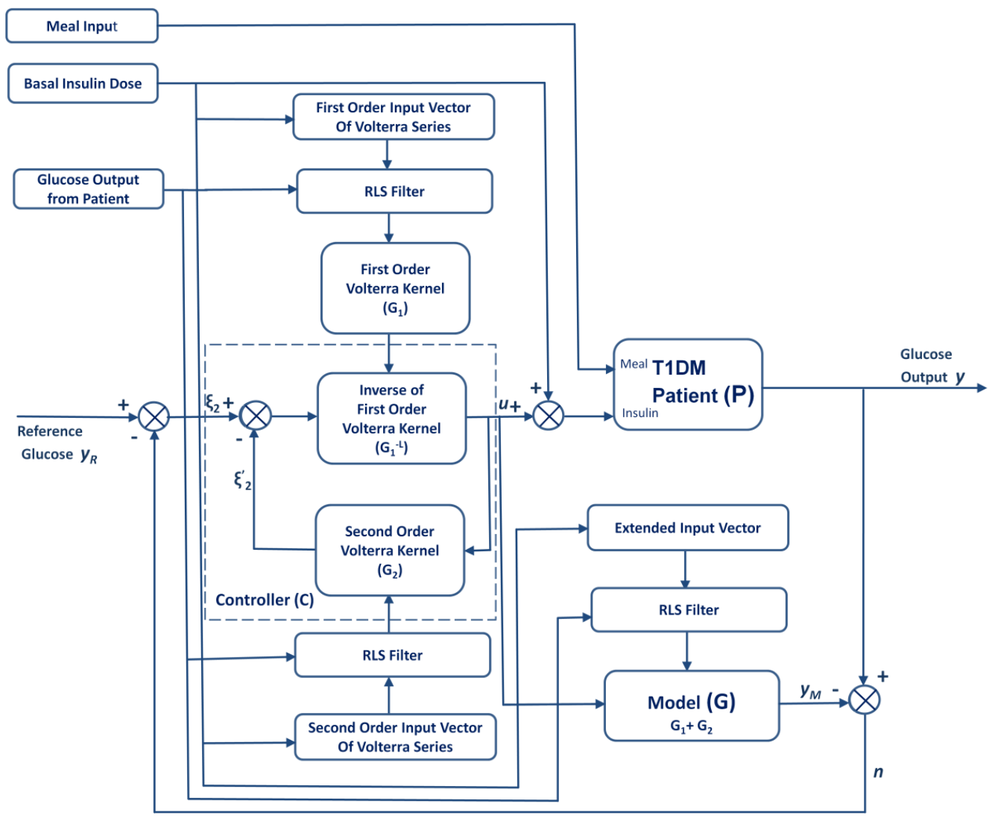
Background



❑ **A major concern of fully-automated Artificial Pancreas (AP) system is the prediction of optimal insulin dose without patients' intervention in the presence of disturbances (e.g., meals).**

❑ **A fully-automated control algorithm is required to develop such an AP system that automatically reacts to disturbances as well as changes in patient dynamics.**

Fully-automated Internal Model Control (IMC) Algorithm

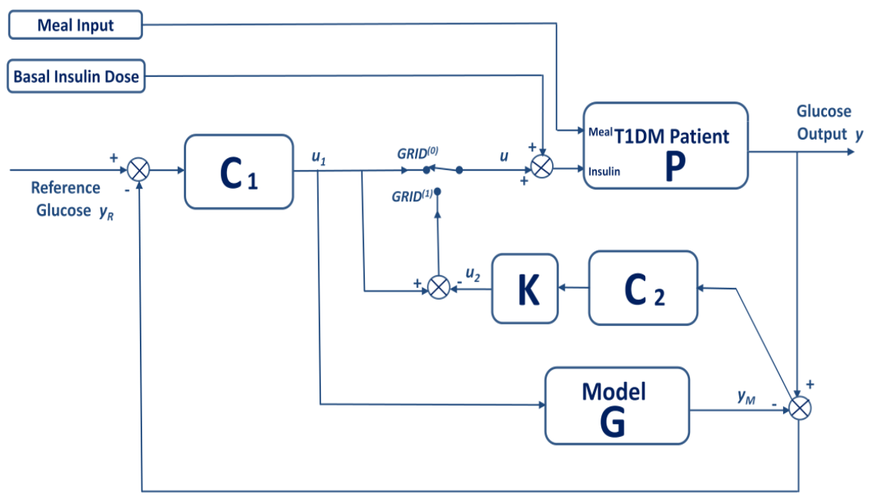


❑ Volterra models are developed using Recursive Least Squares (RLS) algorithm.

❑ Frequency domain Volterra kernels called Volterra Transfer Functions (VTF) are then used to develop IMC.

❑ In offline-tuned IMC models are fixed using previously collected data, whereas in online-tuned IMC models are adapted online based on measured data.

Online-tuned compound IMC controller: *To avoid hyperglycemic events in online-tuned IMC*



❑ **To overcome the shortcoming of slow subcutaneous insulin action causing hyperglycemia with online-tuned IMC, we have integrated an automatic meal detection module such that an enhanced version of IMC with additional gain (eIMC) operates whenever a meal is detected.**

❑ In this compound controller, eIMC will operate only when the Glucose Rate Increase Detector (GRID) of the meal detection module is positive. Otherwise the conventional online-tuned IMC controller will operate.

❑ GRID is used to detect meal disturbances by estimating the Rate of Change (ROC) of glucose level.

❑ Controllers C_1 (conventional online-tuned IMC) and C_2 (eIMC) are developed using VTF, and are equivalent to controller C in the above IMC design.

Scenarios for evaluation of online-tuned compound IMC controller

Scenarios	Simulation time (hours)	Start time of Simulation	Number of meals	Meal disturbances
Scenario 1 (Validation of the controller: nominal scenario)	24	4:00pm	4	50*gms* at 6:30 p.m. 50gms at 7:00 a.m. 15*gms* at 10:30 a.m. 15gms at 1:30 p.m.
Scenario 2 (Robustness analysis under variations in insulin sensitivity)	12	12:00pm	1	80*gms* at 1:00 p.m.

Algorithms are evaluated using 10 in silico adult patients from T1DMS (UVA/Padova).

Advantages of online-tuned IMC over offline-tuned IMC (Scenario 1)

Performance metrics	Offline-tuned IMC	Online-tuned IMC
Mean	143.48	146.49
% time in normoglycemia (70-180 *mg/dl*)	71.55	72.32
% time in tight target (80-140 *mg/dl*)	51.99	53.39
% of time below 70mg/dl	3.25	1.25
% of time above 180mg/dl	25.18	26.41
Number of patients in Hypoglycemia (< 70*mg/dl*)	1	1

❑ Offline-tuned models are developed using a 24h scenario comprising 3 meal disturbances: 75gms at 7:00a.m., 75gms at 1:00p.m., and 50gms at 8:00p.m.

Online-tuned IMC has a much better performance than offline-tuned IMC in handling variations in meal disturbances; on an average patients experience hypoglycemia under online-tuned IMC only 1.25% of the time when compared to 3.25% in the case of offline-tuned IMC.

Results for Scenario 1

Performance metrics	IMC	Compound IMC
Mean	146.49	146.3
% time in normoglycemia (70-180 *mg/dl*)	72.32	77.63
% time in tight target (80-140 *mg/dl*)	53.39	54.12
% of time in normoglycemia during overnight period	95.62	100
% of time in tight target during overnight period	91.73	100
% of time below 70mg/dl	1.25	0
% of time above 180mg/dl	26.41	22.36
Number of patients in hypoglycemia (BG70*mg/dl*)	1	0
Maximum Insulin infusion (*U/h*)	1.77	3.6

Patients do not experience any hypoglycemia, even during the overnight period.

Results for Scenario 2

Performance metrics	+20% insulin sensitivity		-20% insulin sensitivity	
	IMC	Compound IMC	IMC	Compound IMC
Mean	150	124.41	173.6	141.7
% time in normoglycemia (70-180 *mg/dl*)	63.73	85.71	59.04	83.23
% time in tight target (80-140 *mg/dl*)	46.8	78.47	47.61	76.29
% of time below 70mg/dl	4.2	1.81	1.95	0
% of time above 180mg/dl	31.9	12.47	39	16.76

Compound IMC controller significantly reduces hyperglycemia; on an average, patients experience hyperglycemia under compound IMC only 12.47% (16.76%) of the time with +20% (-20%) insulin sensitivity when compared to 31.9% (39%) in the case of IMC.

Conclusions

❑ **We have designed a fully-automated compound model based controller, using online-tuned IMC along with meal detection module.**

❑ **Online adaptation of the model enables the controller to better handle variabilities in patient dynamics and meal disturbance conditions.**

❑ **The combination of compound control strategy with meal detection module is able to manage both hyper- and hypoglycemic events well.**

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