Closed-Loop and Semi Closed-Loop Strategies for Control of Blood Glucose in People with Type 1 Diabetes

Dimitri Boiroux[a], Daniel A. Finan[a], John B. Jørgensen[a], Niels K. Poulsen[a] and Henrik Madsen[a]

[a] DTU Informatics, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

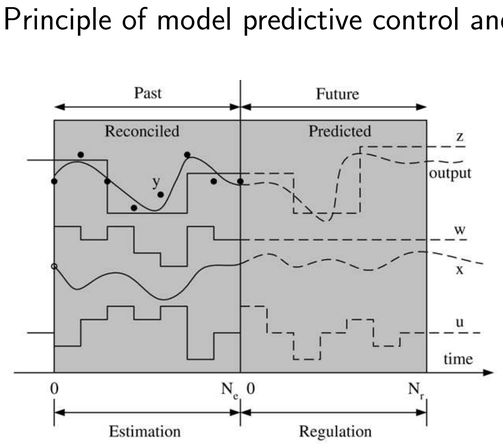
Abstract

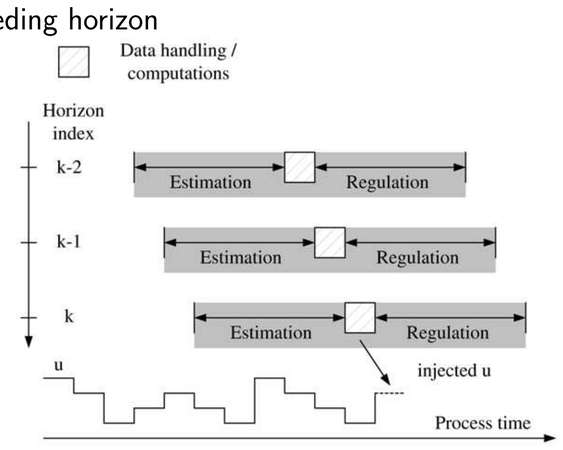
Comparison between 4 insulin administration strategies

- Nonlinear model predictive control (NMPC) without meal announcement.
- NMPC with meal announcement in advance.
- NMPC with meal announcement at mealtime.
- Feedforward-feedback controller.

Nonlinear Model Predicitve Control (NMPC)

Principle of model predictive control and receding horizon





Discrete-time formulation

$$\min_{\{u_k\}_{k=0}^{N-1}} \quad \phi = \frac{1}{2}\sum_{k=0}^{N-1}\int_{t_k}^{t_{k+1}} g(x(t),u(t))dt$$

$$\begin{aligned} s.t. \qquad & x(t_0) = x_0 \\ & \dot{x}(t) = f(x(t),u(t),d(t)) \\ & y(t) = g(x(t)) \\ & u(t) = u_k \qquad t_k \le t < t_{k+1} \end{aligned}$$

$$u_{\min} \le u_k \le u_{\max}$$
$$\Delta u_{\min} \le \Delta u_k \le \Delta u_{\max}$$

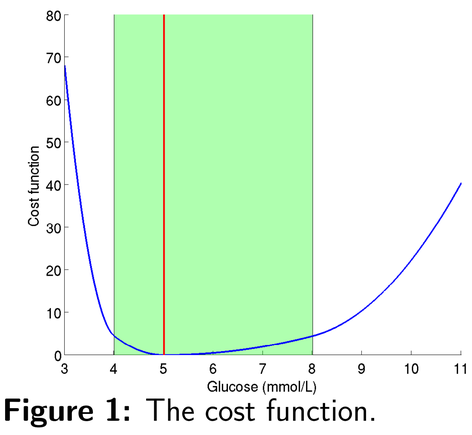


Figure 1: The cost function.

Numerical simulations of NMPC

Scenario

Meal sizes and times

- Breakfast 62g CHO at 6AM
- Lunch 55g CHO at 12PM
- Dinner 50g CHO at 6PM

Simulations

Insulin administration strategies

- Meals are not announced.
- Meals are announced in advance.
- Meals are announced at mealtimes only.

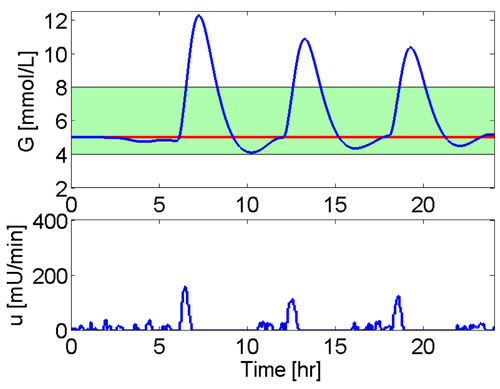


Figure 2: The case without meal announcement.

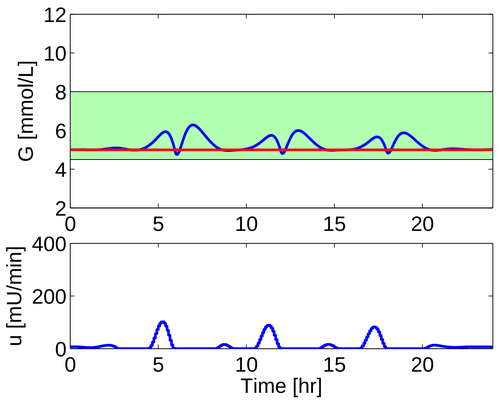


Figure 3: The case with meal announcement in advance of the meal.

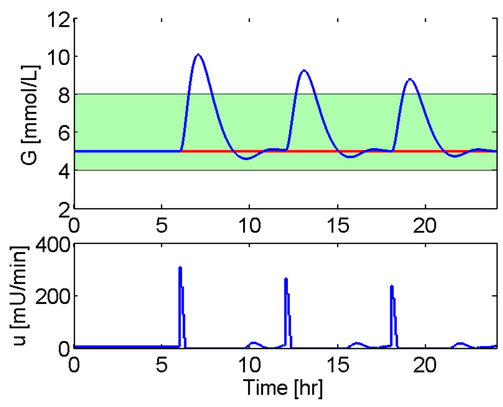


Figure 4: The case with meal announcement at mealtimes.

Feedforward-feedback controller

- A time-varying reference signal based on meal announcement reduces the risk of hypoglycemia
- Feedback from a glucose sensor
- Differentiate between basal insulin and boluses
  - Basal insulin compensates for small mismatches
  - Boluses are given at mealtimes

Numerical simulations of the feedforward-feedback controller

Scenarios

- A decrease by 50% in insulin sensitivity while fasting
- A 75g CHO meal with sensor noise
  - right meal announcement
  - meal size underestimated by 50%
  - meal size overestimated by 50%

Simulations

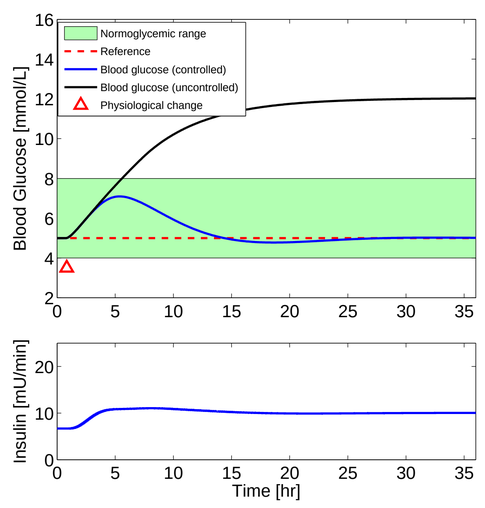


Figure 5: Insulin sensitivity is decreased by 50%.

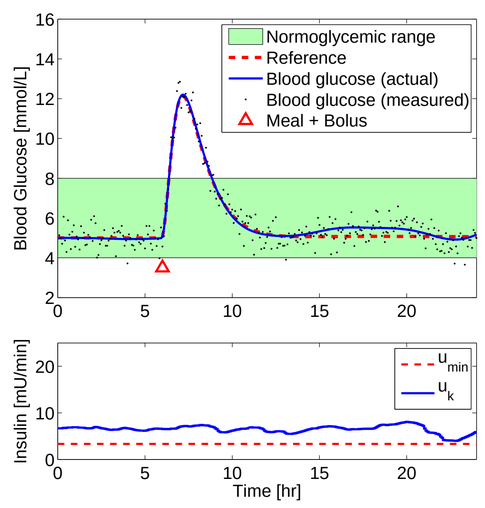


Figure 6: Exact meal size announced.

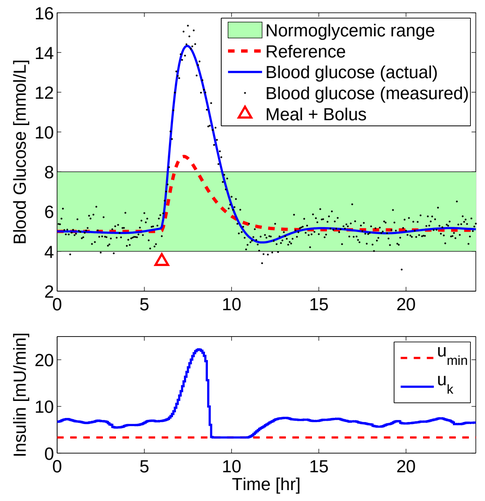


Figure 7: Meal size underestimated by 50%.

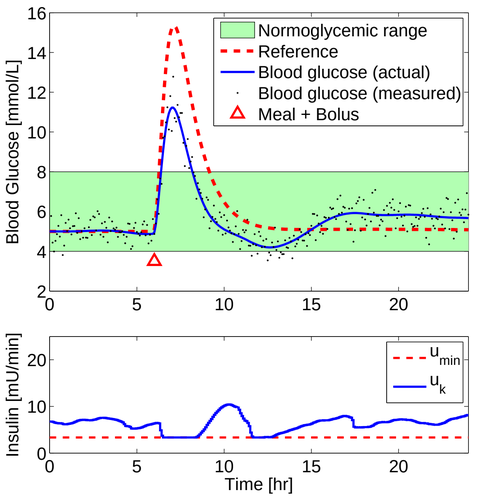


Figure 8: Meal size overestimated by 50%.

Conclusion

- NMPC simulations give an upper-bound on the maximal achievable performance for different meal announcement strategies.
- Utilization of the bolus-like nature of the optimal insulin profile to design a feedforward-feedback controller based on linear MPC.
- Demonstration of the robustness of the feedforward-feedback controller wrt. changes in insulin sensitivity and mismatches in meal announcement in the case where an accurate enough model of the patient is available.

ATTD-4 conference, February 17-19 2011

Contact: jbj@imm.dtu.dk