Optimizing Glucose Control in Diabetes – MPC Approach

Mohammad Tavakoli, Department of Mechanical Engineering

Introduction

This project introduces a Model Predictive Controller (MPC) for optimizing glucose regulation in diabetic patients, motivated by the need for effective management strategies in diabetes. By leveraging control theory and predictive modeling, the MPC aims to balance glucose levels while minimizing medication input, addressing the challenges of chronic hyperglycemia and medication-related side effects. Overall, the project seeks to contribute to improving health outcomes and quality of life for individuals with diabetes through advanced control strategies.

Key: Use MPC to optimize glucose regulation in diabetic patients while minimizing medication input.

Problem Description

The problem revolves around optimizing glucose regulation in diabetic patients by developing effective control strategies, like Model Predictive Control, to balance glucose levels while minimizing medication input and addressing chronic hyperglycemia and medication-related side effects. The dynamics of the system is non-linear, which we linearize around the initial points. Therefore, the main assumption is that the linearized system has the same behavior as the original system.

- $\frac{dG}{dt} = -(p1 + X) \cdot G + ug$
- $\frac{dX}{dt} = -p2 \cdot X + p3 \cdot I$
- $\frac{dI}{dt} = ui$

System dynamic

The glucose-insulin regulation model encompasses three fundamental variables: glucose concentration (G), insulin effect (X), and insulin concentration (I). Integral to the model are constant Ps which are crucial in determining the dynamics of glucose and insulin regulation within the system.

Background

Diabetes disrupts blood glucose regulation, with type 1 lacking insulin due to beta cell destruction, and type 2 facing insulin resistance and reduced production. Genetics, obesity, and lifestyle influence diabetes onset. Treatment emphasizes insulin balance restoration via medication, lifestyle changes, and insulin therapy.

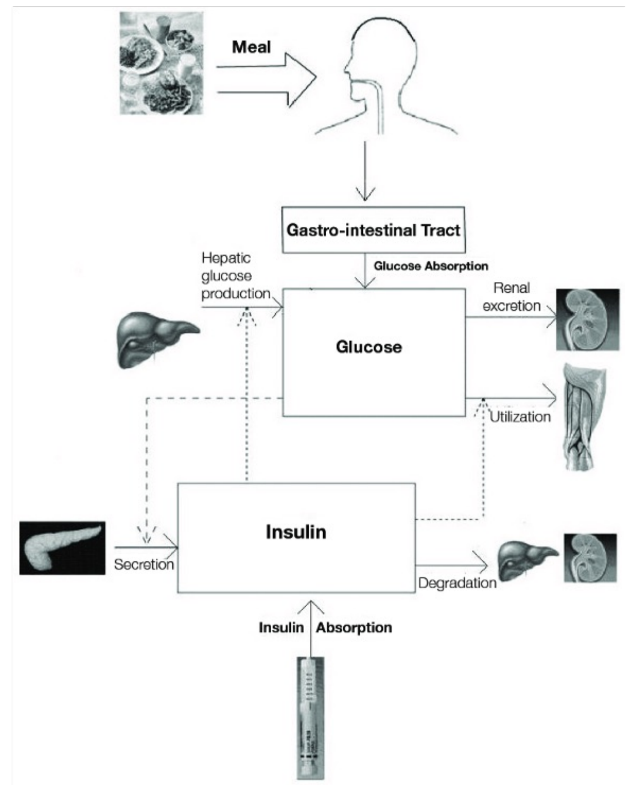

Figure1 - Insulin-Glucose system

Proposed Approach

In this project, the focus is on optimizing glucose control in diabetic patients using Model Predictive Control (MPC). The approach involves developing a dynamical model of the glucose-insulin system specific to diabetic patients and formulating a cost function that balances glucose level regulation with minimizing medication input. Through MPC, optimal control inputs are calculated at each time step to minimize the cost function, considering both the current state of the system and its predicted future behavior.

Cost function: $J = \Sigma\, ||y_k - y_{ref}||^2{}_Q + ||u_{ik}||^2{}_R$

Through optimization-based control, MPC balances multiple control objectives, such as regulating glucose levels and minimizing medication input, by formulating a cost function that weighs these objectives. Overall, the design emphasizes personalized control strategies tailored to individual patient needs, with the goal of improving glucose regulation and enhancing health outcomes in diabetes management.

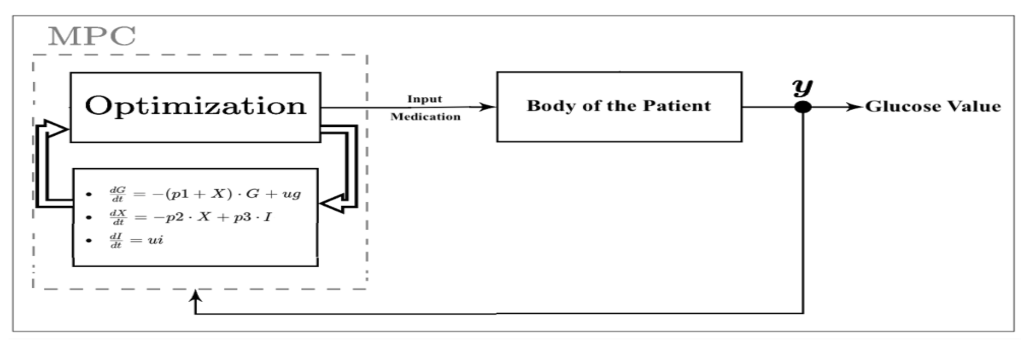

Figure2 - Controller schematic system

Experimental results

Linearized continuous and discrete system matrices and transfer function:

$$A = \begin{bmatrix} -0.05 & -400 & 0 \\ 0 & -0.5 & 1e-4 \\ 0 & 0 & 0 \end{bmatrix} \quad B = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \quad C = [1 \quad 0 \quad 0]$$

$$\mathrm{G(s)} = \left[\frac{1s + 0.5}{1s^3 + 0.55s^2 + 0.025s}, \frac{-0.04}{1s^3 + 0.55s^2 + 0.025s} \right]$$

$$Ad = \begin{bmatrix} 9.95e-1 & -3.89e1 & -1.96e-4 \\ 0 & 9.51e-1 & 9.73e-6 \\ 0 & 0 & 1 \end{bmatrix} \quad Bd = \begin{bmatrix} 9.98e-2 & -6.57e-6 \\ 0 & 4.91e-7 \\ 0 & 1 \end{bmatrix} \quad Cd = [1 \quad 0 \quad 0]$$

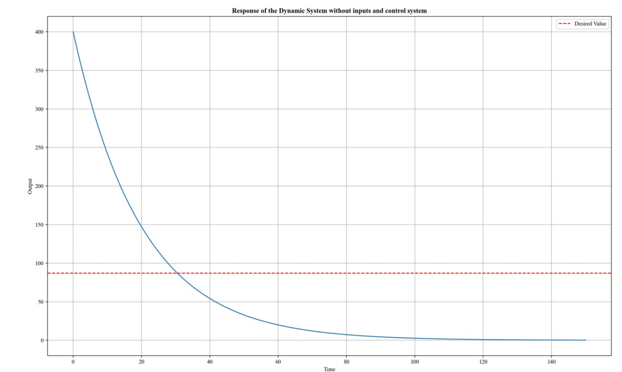

Figure3 - System response of the original system

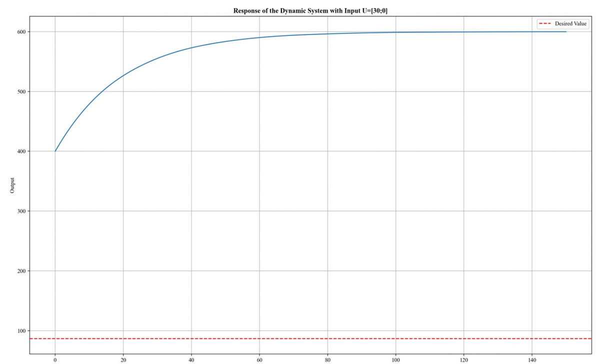

Figure4 - System response with glucose (ug) input

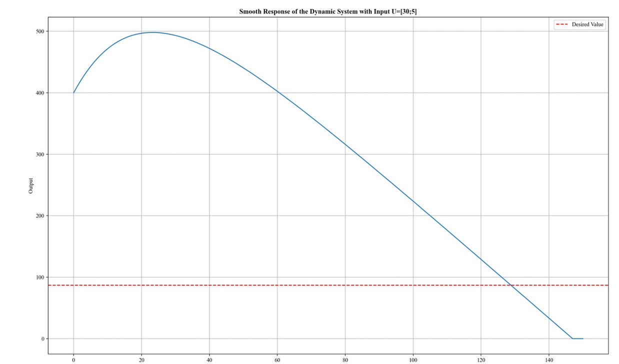

Figure5 - System response with both inputs

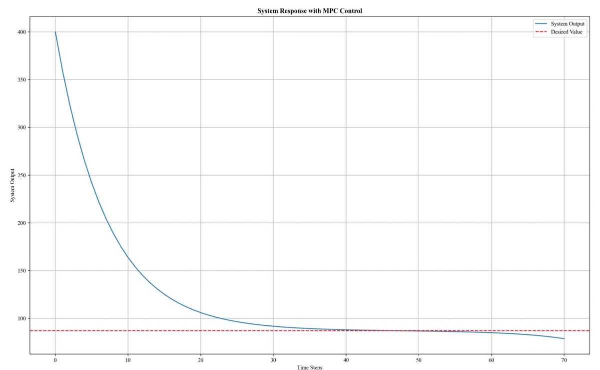

Figure6 - System response by using MPC controller

The MPC controller effectively regulates glucose levels towards the target of 87 mg/dL while minimizing medication input, showcasing its potential in diabetes management. However, challenges arise due to the complexity of control processes, exacerbated by real-world clinical variability and computational demands. Future research could explore advanced drug delivery methods like implantable devices or closed-loop systems to improve glucose regulation accuracy and continuity, offering promising avenues for enhancing diabetes care.

Conclusions

The study confirms the MPC's success in regulating glucose levels near the target of 87 mg/dL while reducing medication usage. Future research may explore personalized strategies and advanced drug delivery methods to enhance control and address complexities. Additionally, integrating adaptive control methods and novel technologies could further improve glucose regulation and revolutionize diabetes management..

References

The GitHub repository at https://github.com/fardintvk/ME548Project contains the entire project, including the complete report, references, and programming code, for easy access and exploration.