BE 301– Final Project

The BE 301 final project is a design project. One of the main purposes of this project is to allow you to see how things that you have learned in this course can be practically applied. A large part of this project will include playing around with data in Matlab

Final Project

- Due at 11:59 PM December 9. Submit a PDF on Canvas.
- Should be 3 to 5 pages, including both text and figures.
- There is an in-class demonstration that you will do on the last day of class 12/6.
- In addition to doing the design work and analysis detailed below, you are required to write your rationale for each design choice and describe the insights gained from each of your analyses
- Since the purpose of this project is for you to learn something, your description of what you learned and what insights you gained by doing this project will be an important part of the report.

You are a member of a medical instrumentation company based in Philadelphia. Your small but promising company has just been given a very big opportunity! You have been awarded a small pilot award from the National Institutes of Health (NIH). The NIH has written a Request for Application (RFA) for an instrument that can improve the lives of those with type I or type II diabetes. Currently, hypoglycemia during sleep, when it is not easy for patients to manually monitor and control their blood sugar, can lead to poor sleep, seizures, interference with breathing, and brain damage or death in severe cases.

When blood glucose levels fall below 0.7 g/L while asleep, the person experiences a condition called nocturnal hypoglycemia. Almost half of all episodes of low blood glucose, and more than half of all severe episodes, happen while the subject is asleep. Nocturnal hypoglycemia is more likely to affect people who have skipped dinner, have exercised that evening, drank alcohol, or have a current infection. Some of the associated symptoms include restless sleep, sweaty skin, trembling, erratic breathing, nightmares, and/or a racing heartbeat.

You are tasked with creating a closed loop system that incorporates a glucose sensor, a micro-controller, and an automated glucose delivery system. As part of this project, you are given a model devised by basic scientists that describe the relationship between insulin and glucose in the patient's body.

$$\frac{dx}{dt} = p(t) - \alpha x(t) + \beta y(t)$$
$$\frac{dy}{dt} = q(t) - \gamma x(t) - \eta y(t)$$

x(t): blood insulin level [units/L]
p(t): insulin input rate [U/(L/hr)]
α : sensitivity of insulinase activity to insulin concentration [1/hr]
β : sensitivity of pancreatic insulin output to glucose concentration [units / (hr * g)]
y(t): glucose concentration [grams/L]
q(t): rate of glucose injection [g / (L * hr)]
γ : sensitivity of liver glycogen storage and tissue glucose utilization to insulin concentration [g / (hr * units)]
η : combined sensitivity of liver glycogen storage and tissue glucose utilization to elevated glucose concentration [1/hr]

During sleep, a patient inputs no insulin (p(t) = 0) and you can assume the following initial conditions: x(0) = 0.01 U/L and y(0) = 1g/L.

As part of the RFA, the NIH has characterized four patients and obtained the following parameters for four patients.

patient	1	2	3	4
α [1/hr]	0.5	0.8	0.7	0.9
β [units / (hr * g)]	0.00	0.00	0.00	0.01
γ [g / (hr * units)]	0.10	0.05	0.15	0.10
η [1/hr]	0.15	0.18	0.06	0.19

The following components are to be included in your lab report:

a. In the case where the insulin input rate p(t) =0, please write the transfer function for a patient where the input is q(t), the rate of glucose injection, and the output is y(t) the glucose concentration.

b. Please plot the transfer function $|H(j\omega)|$ over the frequency ranges that are relevant for your project.

c. Please plot the poles and zeros of the transfer function and the region of convergence.

d. A typical initial blood concentration level at sleep is y(0) = 1 g/L and the patient's blood sugar is intended to stay above 0.7 g/L and below 1.4 g/l. For the four patients characterized by the NIH, please plot their glucose level from the time they fall asleep until 8 hours later assuming no glucose is input.

e. Design a control system that has an input y(t) the glucose level and an output q(t) the rate of glucose injection. Design the system so that it can give each of the four NIH patient's a good night's sleep. For each patient, plot the glucose level over time and overlay this with the output of the glucose pump.

f. In reality, a person's blood glucose level before falling asleep will fall along some distribution. Assuming the initial blood glucose level could be randomly distributed between 0.8 and 1.2 g/L, how, if at all, does your controller need to be changed to account for this? Plot the blood glucose level and pump output for patient 1 in this case.

g. You will be given four unknown patients, which have parameters that are not more than two standard deviations away from any of the four patient's given to you. The TAs will give you the data, and you will have to demonstrate in front of them that your control system can keep the patient's glucose levels within their intended range. For each patient, plot the glucose level over time and overlay this with the output of the glucose pump.

h. You are also exploring a less expensive glucose pump that can only inject glucose at a constant rate q(t) = 100 g / (L * hr) and can be in one of two states, either pumping or not pumping. Can you adapt your control system to work with this pump? How? For each patient, plot the glucose level over time and overlay this with the output of the glucose pump.

i. Suppose patient 1 also uses an insulin pump to help manage their blood glucose. Typically it is turned off at night, but suppose it malfunctions and turns on to input a constant 2 U/(L/hr) insulin starting at hour 4 of sleep, Comment on the ability of your controller to account for this.

Writing Your Final Report

- Including figures in your final report is good!
- Any relevant Matlab code can be included as "Supplementary Material", i.e. it won't count towards your pages limits. Please make sure you reference the code and explain its functionality in the report. All code must be well commented.
- If you are using other people's code (for example, sample code that you find posted online or code that I have posted) as part of your project, that's fine, but make sure that you explain where the code came from and what is happening and why – I need to be sure that you understand what is going on
- As I read your final report, I want to see things "clicking" in your head
- Your insights, what you learn, and the connections you make are more important than just doing something fancy
- You can learn from (and write about in your final report) things that didn't work…especially if you have insight into why they didn't work

Point Breakdown

Just so that you know what I'll be looking for as I grade your final reports, below is a rough point breakdown that I plan on using (though I might modify it somewhat). This is somewhat vague/subjective, but the point is to give you a feel for what I will be looking for and emphasizing as I look at your final projects. (Please do not break up your final report into sections based on these categories.)

Intro/Background/Context (10 points)

What You Did (60 points)

Correctness (15 points)
Appropriate Means (15 points)
Plotting (15 points)
In class Demonstration (15 points)

What You Learned (25 points)

Connection of the design challenge to principals we learned in class (10 points)
Insights into specific concepts (10 points)
creativity (5 points)

Organization/Length/Appropriateness of What was Included (5 points)