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Department of electrical engineering

The final project of linear control

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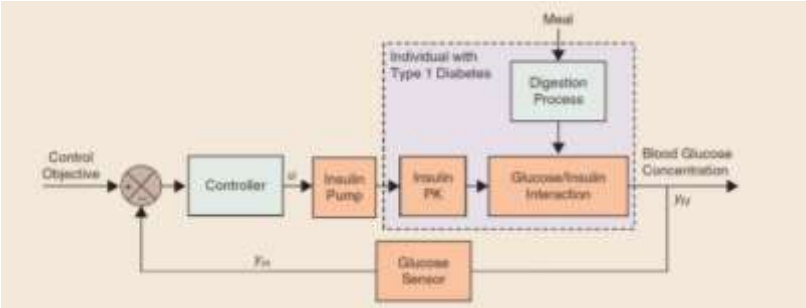
Step 1)

(a)

In type 1 diabetes, one of the cases that is very able to diagnose and operate on the patient's disease that can follow or is a continuous crack in the patient's blood sugar level, which is a system in the pancreas system, which is located next to the pancreas. The inefficient patient helps the patient's body to have a similar control mechanism that, if the patient has high blood pressure, can cause the correct pressure and increase the strength of the blood sugar.

The control system that is normally placed in the human body is the pancreas, which actually regulates the production of blood sugar by measuring the overcoming of blood sugar and is a kind of feedback process with the allowable amount of insulin production in the blood. Insulin is actually a standing substance that increases the concentration of sugar in the human blood, and there is no such thing as our control system (controller) that the pancreas in the body by increasing the amount of production can somehow increase to be more suitable in the blood. .

The artificial pancreas system (artificial pancreas) is no exception to this trend and is actually trying to not change your gift while this pancreas is currently briefly discussing the control components of this artificial pancreatic system.



In fact, first we need a sensor to be able to measure the number of blood sugar in the body and let us know. In addition to this system, we need a controller that can adjust the insulin pump based on the current blood sugar level. So that we can regulate the amount of blood sugar in some way.

So, in general, our system has three components: a sensor, a controller, an insulin pump, and the fourth, which was the most important and which we did not address, is the sick body.

The patient's body is one of the elements of this system that undergoes significant changes in blood sugar levels during exercise after or before eating, such as an external factor, and in fact, the purpose of this system is to be able to suppress changes in blood sugar. He controls it sensibly to stay within the permissible area.

The important thing is that so far we have only dealt with the feedback method in controlling the blood sugar system, but in fact another possible method is the feed forward method (feed forward), which I will elaborate on a little now.

One way to fix some of the possible bugs in the feedback method (mainly the problem of delay) is to predict the future, that is, somehow we as the artificial pancreas are aware that the person is going to eat and start eating before they start eating. Increase insulin to prevent suspected blood sugar in the patient's body system; Normally, this can be done by notifying the patient through the device buttons. Of course, it is worth noting that this method is by no means a conventional method and is somewhat competitive in its use (it means using the forward feed system alone, although it is

common in combination); Because this system is dependent on human error and if the patient is not informed about changes in blood sugar (eating, etc.) may cause irreparable damage to the patient's body, so we are interested in building a system that can Alone in controlling blood sugar.

(b)

The main challenges of using artificial pancreas treatment are many, but the main one is the issue of delay. In fact, the delay in the element of measuring blood sugar can greatly overshadow the efficiency of the device.

This is because patients with type 1 diabetes's basic health criteria are actually exposed to blood sugar levels above 180, which are beyond the standard range of human suffering. Now, when the sensor and our system in general are aware of the problem, raising the insulin dose is delayed and the patient is exposed to high blood sugar for a longer period of time.

The next major challenge is the issue of stability and resistance of the system to possible changes so that the system can correctly identify the possible changes due to changes in the environment and usage or various problems in the system itself or not enter into an unstable state at all. It can cause severe problems in the patient.

Another important challenge is the fact that the human body responds to insulin depending on the time of day, hormonal changes, exercise and other factors that are part of daily life. Changes in insulin sensitivity up to 50% have been observed experimentally. Therefore, the AP control system must be stable in the range of uncertainty due to differences in insulin response

Step 2)

(a)

The conversion function of changes in injectable insulin in terms of blood sugar is as follows, and using Table 2 we can calculate its value, which is given below.

$$M_c = k' * \frac{(TDI)^{-1}}{(\tau_1 * s + 1) * (\tau_2 * s + 1)\text{^}2}$$

TABLE 2 Parameters for the discrete, continuous, and reduced models of intraperitoneal (IP) and subcutaneous (SC) insulin action [37].

	Discrete			Continuous		
	K (h · mg/dL)	A_1	A_2	K' (h · mg/dL)	τ_1 (min)	τ_2 (min)
IP	−15	0.98	0.75	−12,000	247	17
SC	−0.30	0.98	0.965	−12,294	247	140

	Reduced		
	τ_1 (min)	τ_2 (min)	θ (min)
IP	247	26	11
SC	247	210	73

$$M_{cIP} = -12000 * \frac{(TDI)^{-1}}{(247 * s + 1) * (17 * s + 1)\text{^}2}$$

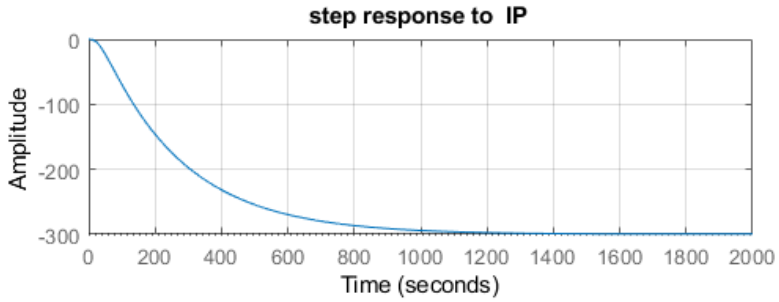
$$M_{cSC} = -12294 * \frac{(TDI)^{-1}}{(247 * s + 1) * (140 * s + 1)\text{^}2}$$

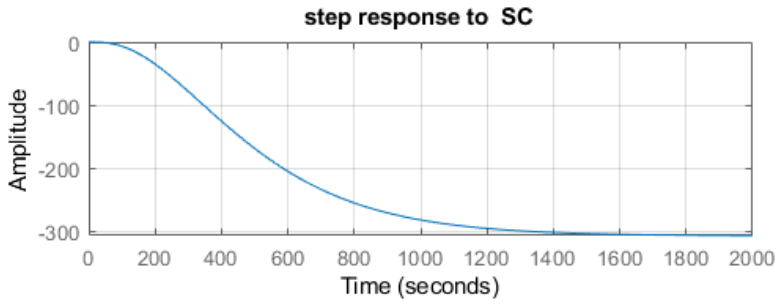
According to the announcement made by the teacher's email, we consider the value of tdi to be 40 for a healthy adult. Of course, we know that this number can be different for people with different conditions and age and medical conditions. The tdi unit is the same as u.

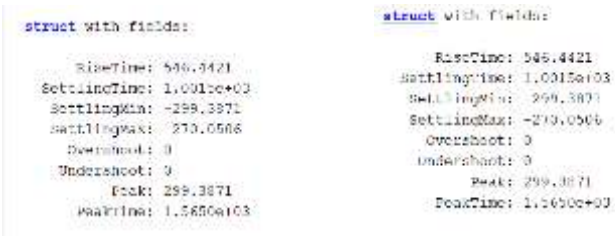
$$M_{cIP} = \frac{-300}{(247 * s + 1) * (17 * s + 1)^2} (\frac{h*mg}{dl*u})$$

$$M_{cIP} = \frac{-307.35}{(247 * s + 1) * (140 * s + 1)^2} (\frac{h*mg}{dl*u})$$

To study the behavior of these two responses and a kind of comparison of their performance, I entered them in MATLAB and plotted their response to the step response, which can be assumed in the sense of a constant dose of insulin, and their shape was shown as shown below (Its file is available in step2part1.m)







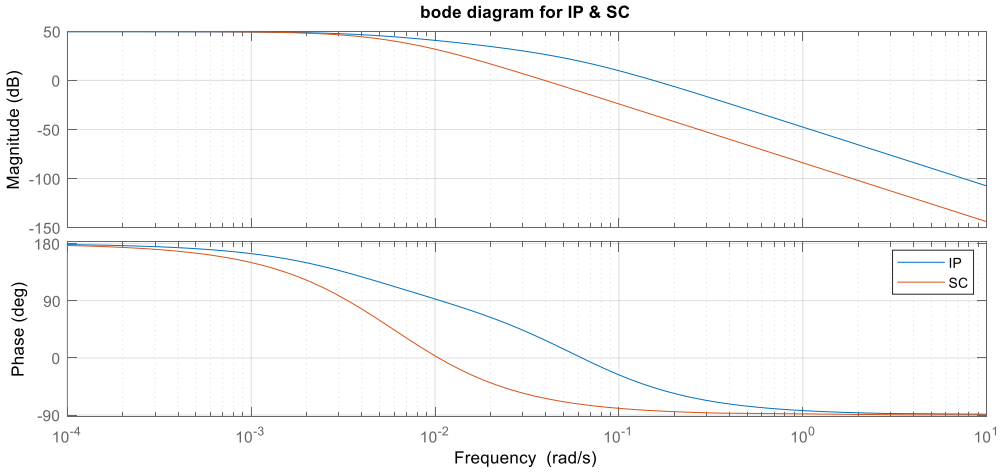
IP SC

In the chart, by default, seconds are the horizontal unit, which is exactly minutes*

As expected, in sc our system slows down and somehow changes are smoother and smoother, while in IP we behave more efficiently and faster according to what we expected from our system due to its internal performance. he does.

This is one of the trade-offs between these two methods. Better and more effective performance) against word usage)

Now we examine the system by drawing a bode diagram in the frequency domain



As expected at low frequencies, the operation of the two systems is similar because the speed of change is low and the sc system, which is slower, can somehow reach the ip control system, or in other words, the speed of change is such that the speed difference The response of the two systems is not yet visible, but when we discuss at higher frequencies, this game changes drastically because the frequency of changes is high and we have a kind of rapid change that the speed difference between the two systems becomes clear. Regarding the phase curve, according to the number of poles equal to the two systems, the beginning and the end of the work are equal, but in the middle frequencies, due to the speed of operation, the sc phase mode is somewhat behind.

(b)

As in the previous section, we will have the above relation from the article and place it in it through the table of values.

$$M_c = k' * \frac{(TDI)^{-1} * e^{-\theta\hat{}s}}{(\tau\hat{}_1 * s + 1) * (\tau\hat{}_2 * s + 1)\hat{}2}$$

Now we have two options

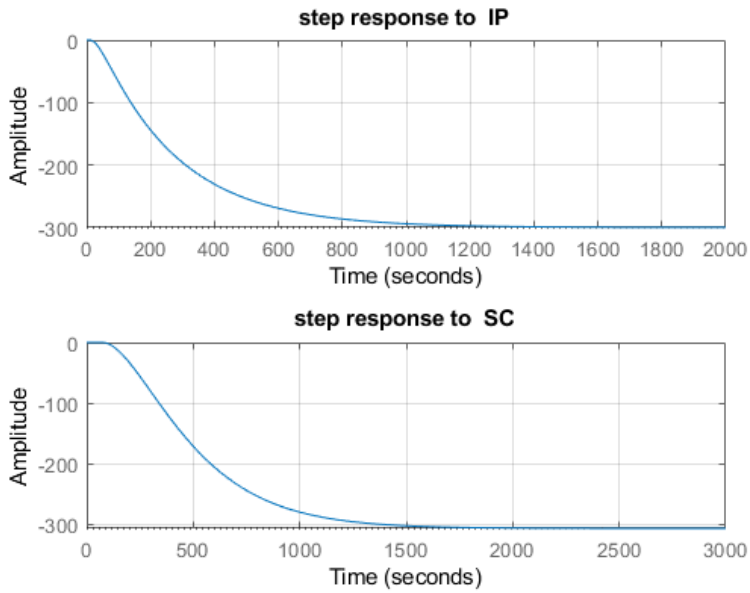
IP

$$M_{cIP} = k' * \frac{(TDI)^{-1} * e^{-11*s}}{(247 * s + 1) * (26 * s + 1)\hat{}2}$$

SC

$$M_{cIP} = k' * \frac{(TDI)^{-1} * e^{-73*s}}{(247 * s + 1) * (210 * s + 1)\hat{}2}$$

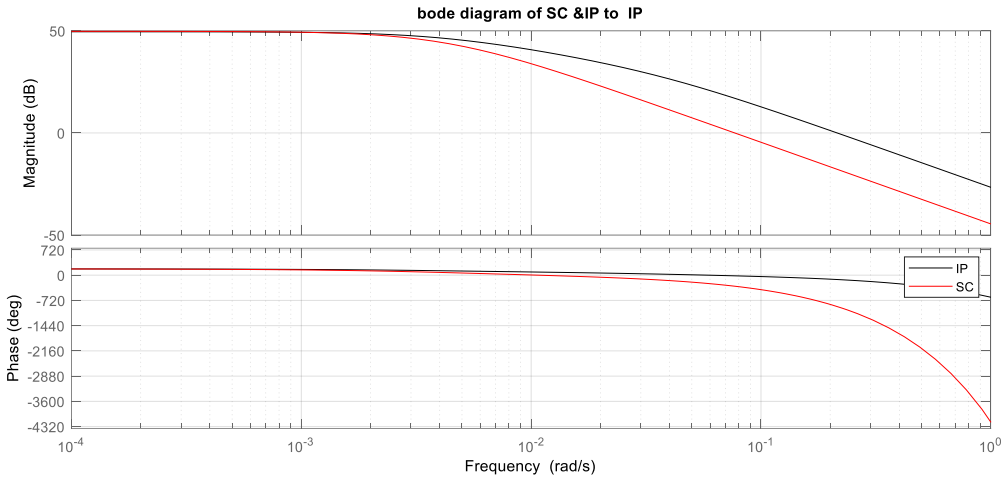
Now we re-enter the above functions in MATLAB so that we can analyze their answers



In the chart, by default, seconds are the horizontal unit, which is exactly minutes *

As we saw in the previous section, the results for this case are also true in the time domain. In fact, the IP curve behaves faster, and conversely, the SC step response curve is much slower, which is clearly clear from the figure. The reason is in the way they work, that IP actually works faster due to the injection into the system.

Now, for this part, we will analyze the frequency domain, and to do this, I will first draw the bad curves of the two states sc and ip at the bottom, and then I will analyze their behavior.

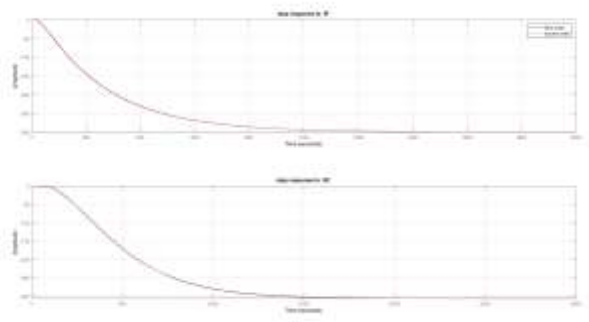


As expected, at low frequencies the performance of the two systems is reasonably similar because the speed of change is low; In other words, the speed of change is such that the difference in response speed of the two systems due to your structure is not yet apparent, but when we discuss at higher frequencies, this game changes drastically because the frequency of change is high and somehow changes. We have a speed when the speed difference between the two systems becomes clear. Regarding the phase curve, according to the number of poles equal to the two systems, the beginning and the end of the work are equal, but in the middle frequencies, due to the speed of operation, the sc phase mode is somewhat behind.

)MATLAB code of this part is available in step2part1.m file)

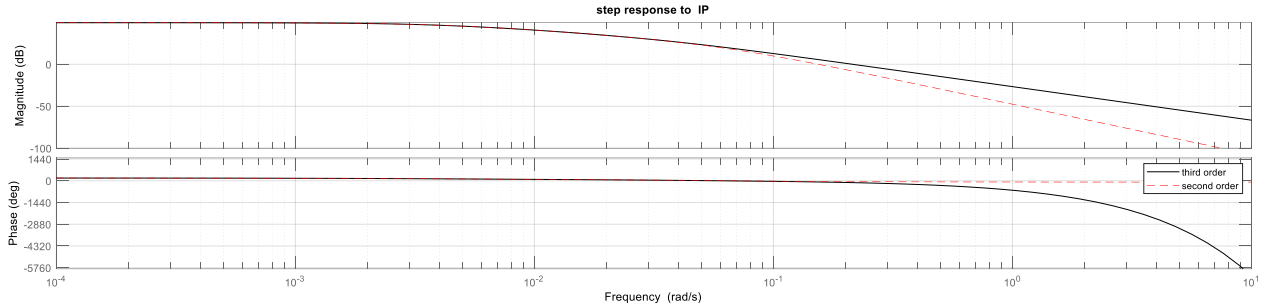
(c)

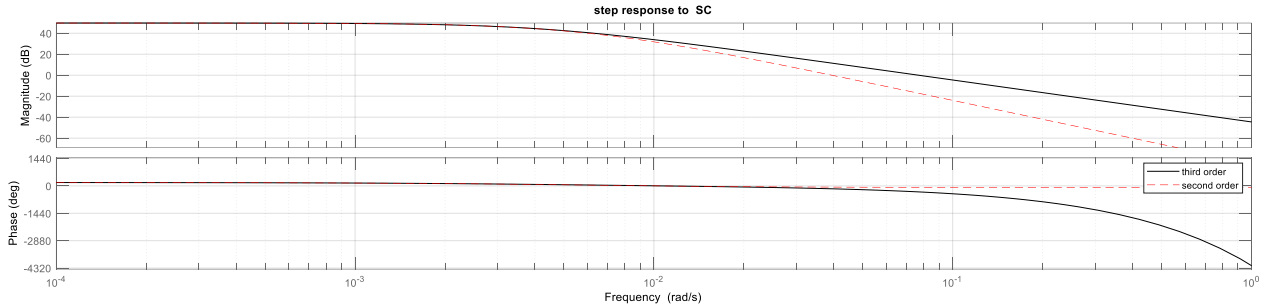
In this section, to better compare the two systems, we can draw them in a diagram. At the bottom, for both SC and IP modes, I plotted two types, one type of double and three times, on a shock response diagram so that I could check the similarity of the two modes in the time domain for the .two approximations.



It can be seen that the system behaves very well similar to the previous part, and in fact our approximation is very close to the original state. In addition, as mentioned in the previous part, the system in IP mode has a smoother and more effective effect than It has sc mode.

We draw the bad curves of these two on each drawing so that we can see the differences. To do this, for both IP and SC, we have to draw both the second and third order states on a curve. Which we have as shown below





As we can see, at low frequencies our approximation works great and the phase and charge curves are almost the same, but at higher frequencies this trend does not continue and the curves are spaced apart. In fact, we are here from a three-degree curve. We reach a degree 2 curve with a delay. As we saw in the lesson, we clearly have a bipolar system at high frequencies turns into a slope of -40db (it should be noted that the delay has no effect on size) and the reason for the difference in the final slope. This is because the main relation can be three poles and its slope is -60db.

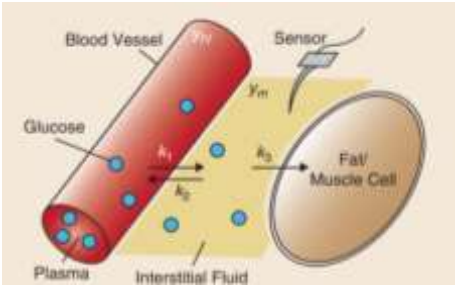
The phase curve is practically the dominant term of the delay, which continuously reduces the amount of phase and is clearly visible in the figure.

With these interpretations, we can generally conclude that our approximation works well for low-frequency changes, but in high-frequency changes such as unwanted distortions, the behavior of the two systems may be quite different, and it is no longer correct to use the second-order approximation.

Step3)

(a)

Our sensor is actually a module that measures the amount of blood sugar in the blood and gives it to us, but in fact this is not possible quickly and cheaply, so we put our blood sugar in the ISF layer, which is the interstitial fluid. We place the sensor so that we can determine the level of blood sugar through it. To do this, we practically used the following model



For the above image, we can easily model the differential equation to study its behavior as a function.

I can easily see that the amount of sugar entering and leaving the interstitial water can be modeled by coefficients in different regions and somehow derive the amount of your derivative change..

$$\frac{\mathrm{d}y_m(t)}{\mathrm{dt}} = -(k_3 + k_2) * y_m(t) + k_1 * \frac{V_b}{V_{isf}} * y_{IV}(t)$$

Now we can express the above equation in the Laplace domain

$$G_s(s) = \frac{k}{T_s s + 1}$$

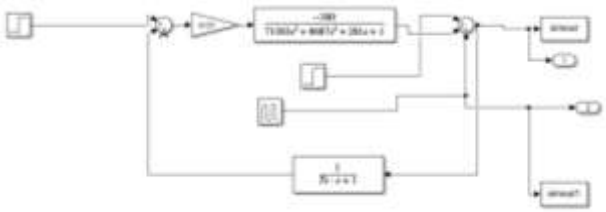
If we want to find out the reason for the delay, we can easily refer to the process that blood sugar actually changes inside the blood due to the inputs of the body system, but due to the limitations of our structures, we must measure it in Isf or interstitial water. Suppose this means that our first delay (which accounts for the bulk of the delay) is somehow inevitable. Let's quantify the theorem to find better intuitions.

In total, achievable systems have a delay of about 11 minutes, ranging from 3 to 12 minutes (manually) due to physiological error (delay of interstitial water in showing the effect of changes in blood sugar) and the rest of about one to ten minutes. The delay of our system is in obtaining the answer, which together cause this amount of delay.

(b)

For this part, we consider the controller as a gain block and give it some kind of citizenship. Of course, it should be noted that this citizenship should still be in a way that the nature of the system feedback is not damaged and can have a feedback effect for us. Therefore, we assume it to be a negative gain smaller than one so that it can modify the system and be a kind of negative feedback.

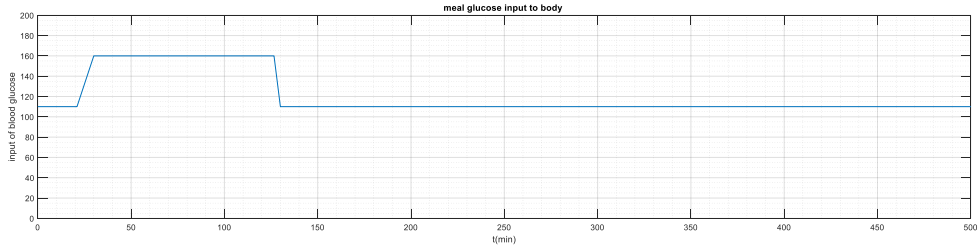
Now we simulate the system remaining from the main system in Simulink space and the diagram block is as follows

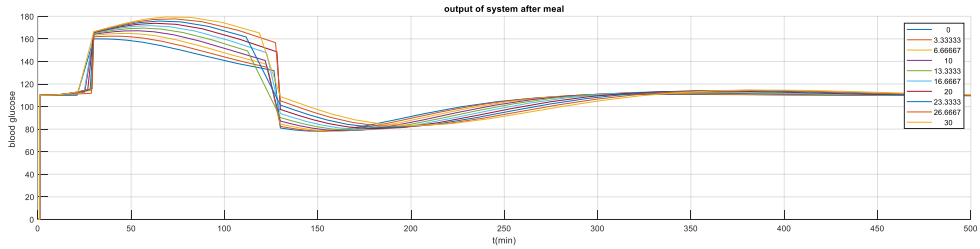


*We easily get the attention of the values of the pump conversion function through the multib.

)The simulation file is called step3.slx and its code is in a file called step3part2.m)

Now for different values of Ts we draw the system response and display it on the graph. In the requested range, we display zero to 30 for ten values





The lower the value of Ts, the more agile the system is and the better it neutralizes the input.

Step 4

(a)

For SC mode, the value of τ_dom = 564 is mentioned in the article, which for the value of tc in this section, we consider half of this value, that is, the average is 282.

To get started, we first get the PID controller parameters

$$k_c = \frac{\hat{\tau_1} + \hat{\tau_2}}{\hat{k}(\tau_c + \hat{\theta})} \cong -4.188 * 10^{-3}$$

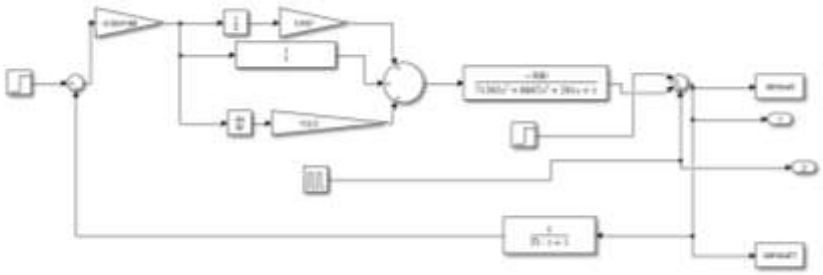
$$\tau_1 = \hat{\tau_1} + \hat{\tau_2} = 247 + 210 = 457$$

$$\tau_d = \frac{(\hat{\tau_1}\hat{\tau_2})}{\hat{\tau_1} + \hat{\tau_2}} \cong 113.50$$

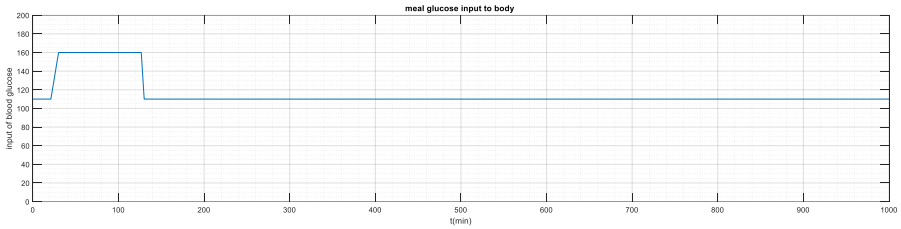
Based on the calculated constants, we will consider the PID controller as follows.

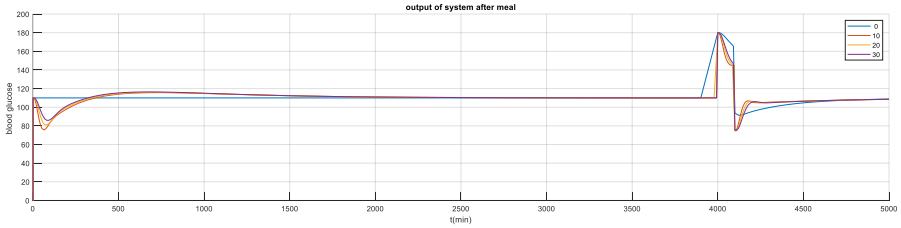
$$k(s) = k_c\left(1 + \frac{1}{T_i * s} + \tau_d * s\right) = -4.188 * 10^{-3} * (1 + \frac{1}{113.5 * s} + 457 * s)$$

Now, in order to simulate the system in Simulink, we draw a system block diagram, the image of which is as follows: (Simulation is available in step4.slx file)

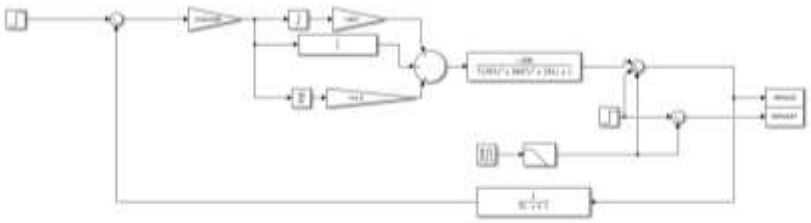


First we have to give some time (about a few thousand minutes) for the system to balance. As a meal, we can give a square pulse, but we get a strange result, exactly contrary to our expectations, that is, with increasing ts, the system improves!



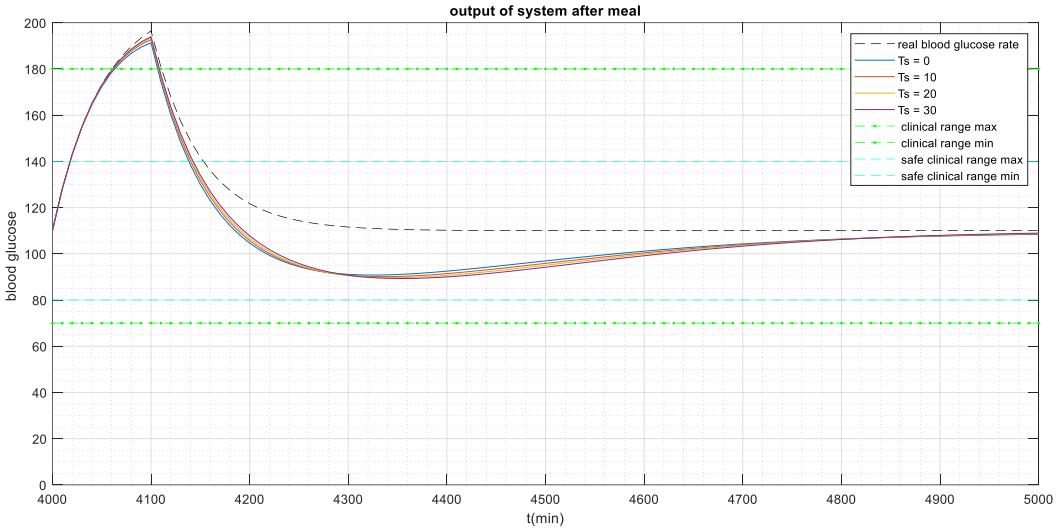


But after a little more study and re-reading the article, I realized that the system is not good for very high frequencies, and this vaccine is included in the system due to the high frequencies, so we change the pulse a bit and soften it and We remove the high frequencies and redraw the glucose lump to see the result.

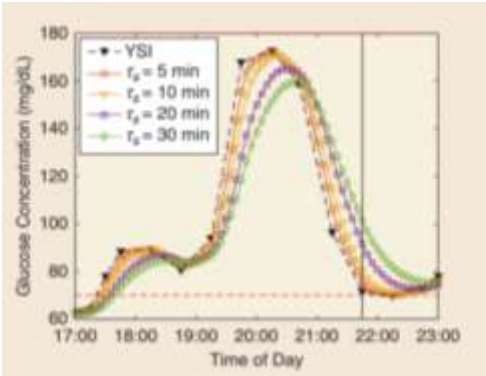


I filtered the signal attention to 20 Hz *

Now we have a graph of glucose levels



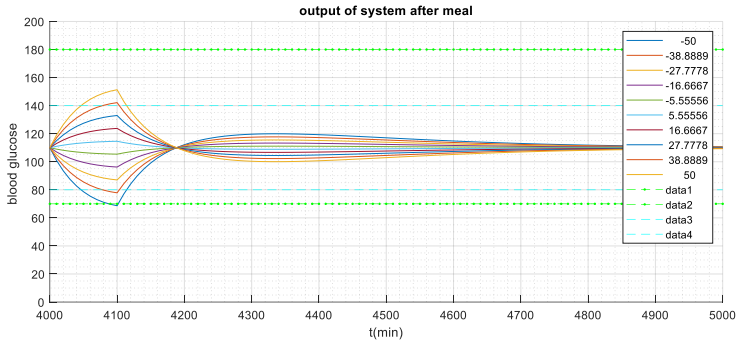
As we can see, we can see the same behavior mentioned in the article. I used the image of the same diagram in the article for comparison below.



Clearly, the result of our simulation matches the data received from the system, so the more we can reduce Ts, the better our system performs.

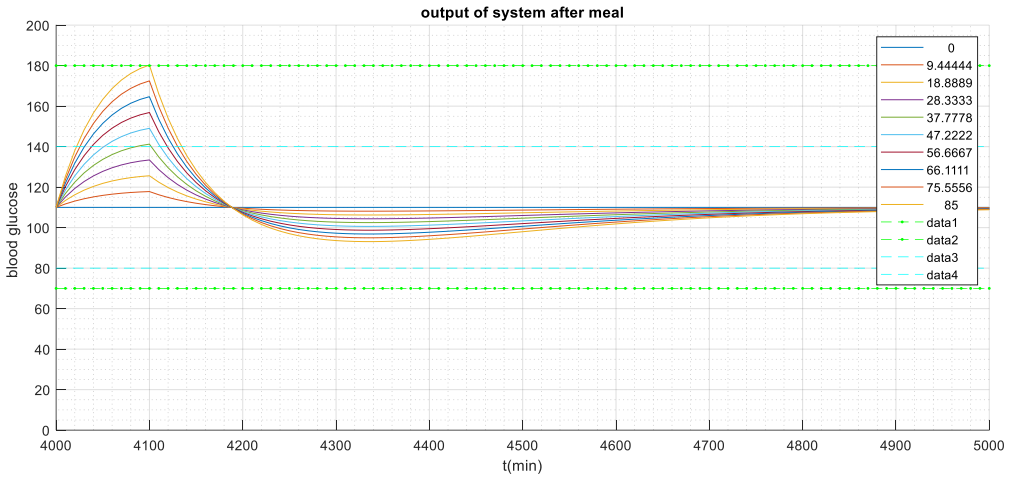
Find intervals

In order, we start from the lower limit of safe clinical range, change the range and remember the place that meets the limits.



Here we reach -50 for the lower limit of sugar, which for the subcutaneous method we practically increased from -40 to -50, and our device has practically increased the amount of negative glucose tolerance (exercise) by 10, now we go to the positive limit.

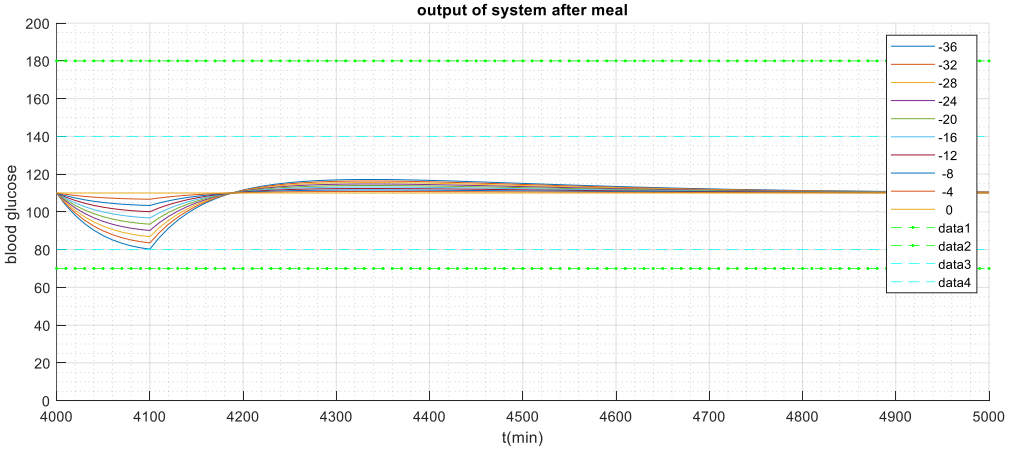
High clinical range



In this part, we raised the upper limit, which was normally 180 minus 110, ie 70, to 85 with a subcutaneous device, and practically up to the range of +85 (eating), our system prevents the exit from the permissible range.

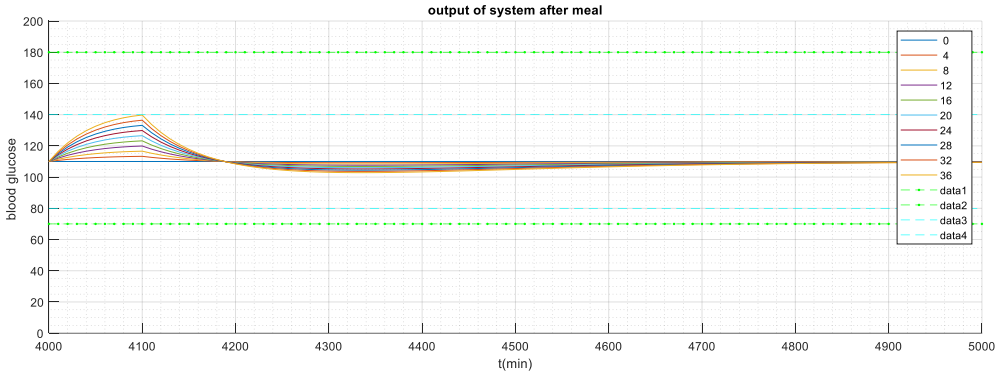
In total, our allowable range for the safe clinical range increased from (-40.70) to the new range (-50, 85).

Let us now examine the lower limit of the clinical range.



The lower limit for the clinical range is -36, which is actually 6 less than the limit without the device.

حال به سراغ حد بالای(140) میرویم

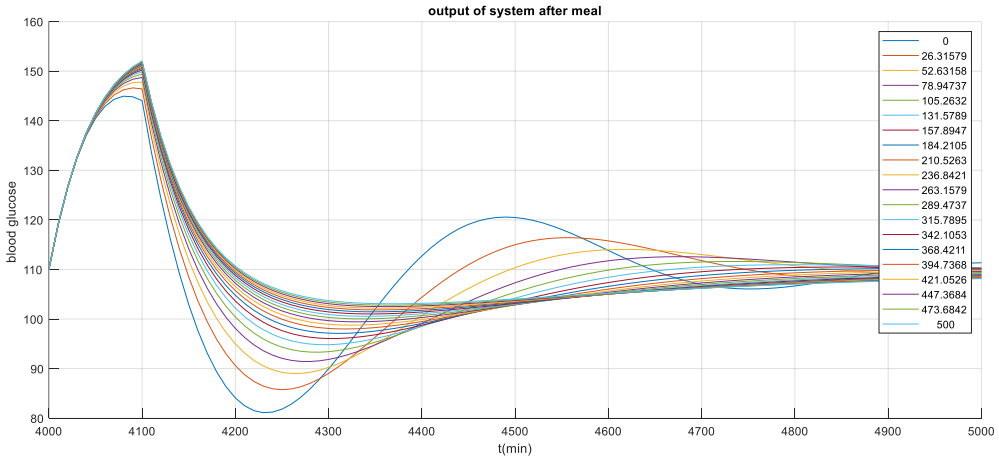


The upper limit of the system also reached +36, so finally, instead of playing (-30, 30), we reached the extended range (-36, + 36), which was obtained due to the activity of the device.

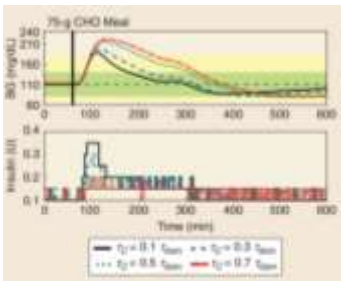
It should be noted that the device is of low quality in SC mode and can practically increase the allowable value by a small amount, but it has better performance for IP mode, which, of course, is not required in the case of the project..

(b)

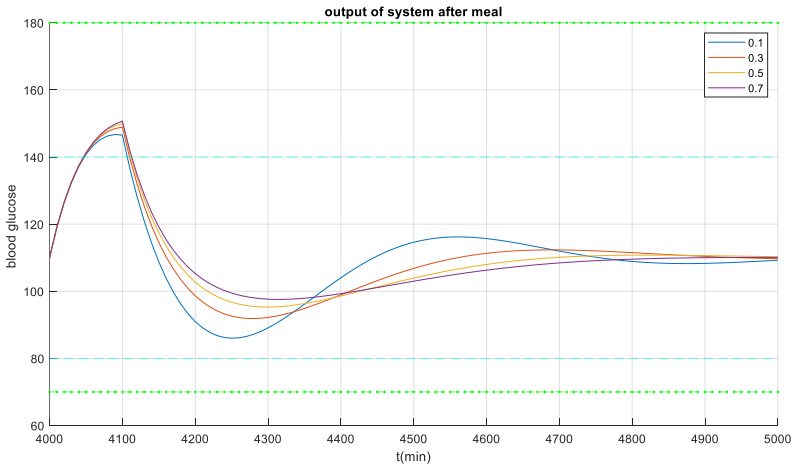
For this part, we assume ts to be a constant value of 10. Now we change the value of tc once in the range -10 to 500 and draw the result according to the following figure.



Now it is observed that the higher the tc, the higher the shot and the general suffering of high blood sugar. As a result, our result gets worse, and the lower the Tc, the system is in a smaller range. Let's experiment



As we can see here, in practice, the higher the tc, the worse the performance of the system. Now, to match the result, I draw the same so that we can fully compare.

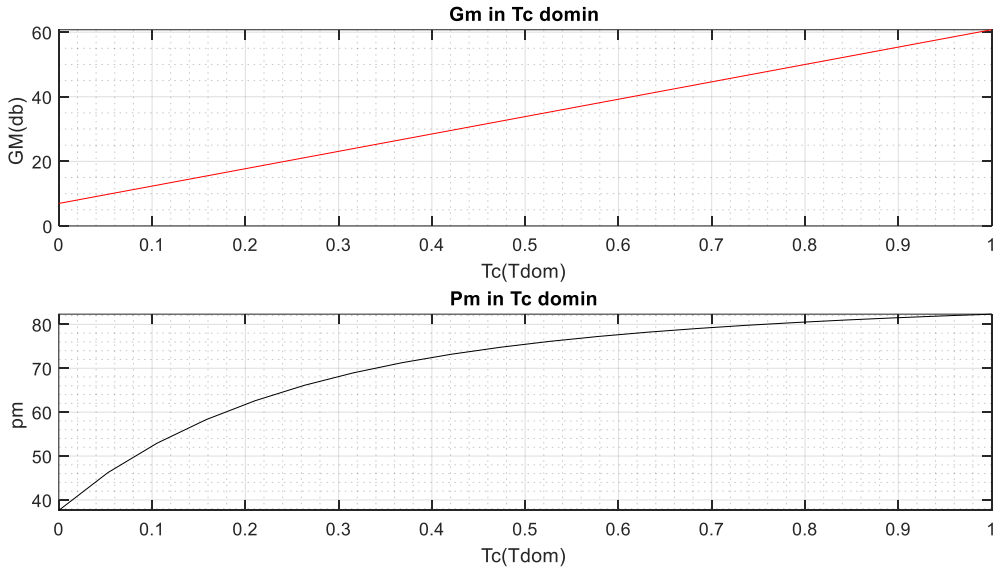


STEP 5

(a)

We want the system resistance to change is high. One of the criteria for determining this issue is the gain limit and phase limit, which we examine in this section. For Ts = 10, we want to see what the relationship between GM and Pm is with TC. As a reminder, in the previous section we learned that the smaller the TC, the better for us in terms of performance. Now I have to see what it has to do with the resistance of the system.

Now enter the conversion functions in MATLAB and using the margin command, we can easily calculate the gain limit and phase limit and draw their diagram.



It can be seen that the gain and phase limits increase with increasing Tc, which is consistent with the data in Article 4 in Table 4.

TABLE 3 The gain margin for varying sensor time constants and tuning parameters [37].

Intraperitoneal Delivery

τ_s	$0.1\tau_{dom}$	$0.3\tau_{dom}$	$0.5\tau_{dom}$	$0.7\tau_{dom}$
0 min	5.7	14	22	30
10 min	4.1	10	16	22
20 min	3.9	9.5	15	21
30 min	3.8	9.3	15	20

Subcutaneous Delivery

τ_s	$0.1\tau_{dom}$	$0.3\tau_{dom}$	$0.5\tau_{dom}$	$0.7\tau_{dom}$
0 min	2.8	5.2	7.6	10
10 min	2.5	4.7	6.8	9.0
20 min	2.3	4.4	6.4	8.4
30 min	2.2	4.2	6.1	8.0

TABLE 4 The phase margin for varying sensor time constants and tuning parameters [37].

Intraperitoneal Delivery

τ_s	$0.1\tau_{dom}$	$0.3\tau_{dom}$	$0.5\tau_{dom}$	$0.7\tau_{dom}$
0 min	74°	83°	86°	87°
10 min	61°	78°	82°	84°
20 min	51°	72°	79°	82°
30 min	44°	67°	75°	79°

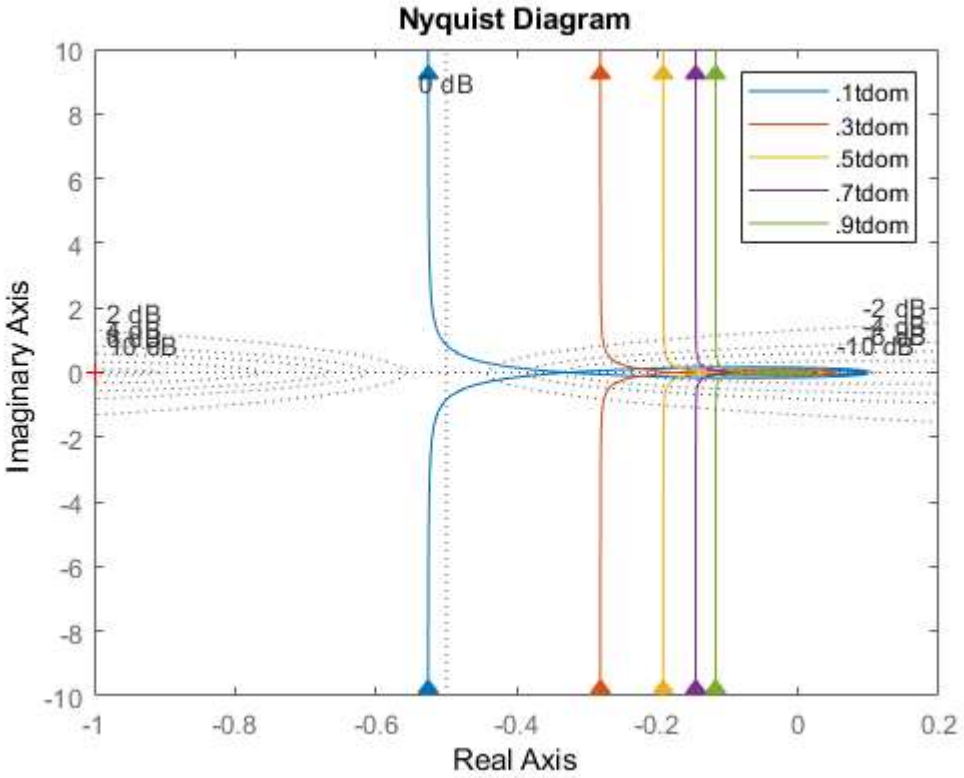
Subcutaneous Delivery

τ_s	$0.1\tau_{dom}$	$0.3\tau_{dom}$	$0.5\tau_{dom}$	$0.7\tau_{dom}$
0 min	58°	73°	78°	81°
10 min	53°	70°	77°	80°
20 min	49°	68°	75°	79°
30 min	46°	66°	73°	77°

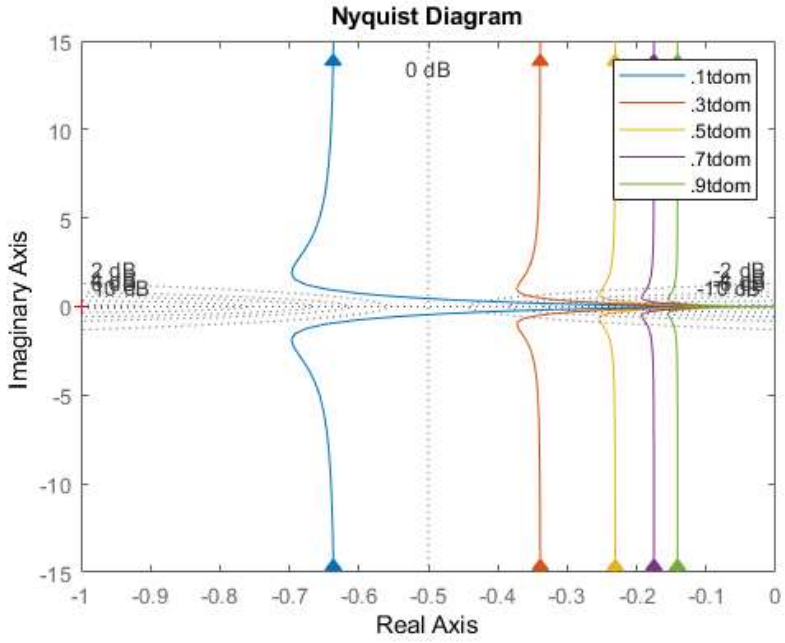
As can be seen in increasing the Tc, the gain limit and the phase limit (the recovery slope decreases) both get better. In fact, there is a trade-off between this result and the previous result, which is in line with logic. If the sensitivity of the device increases, it will follow the input better and the resistance of the device will decrease, which is what has happened here as well.

(b)

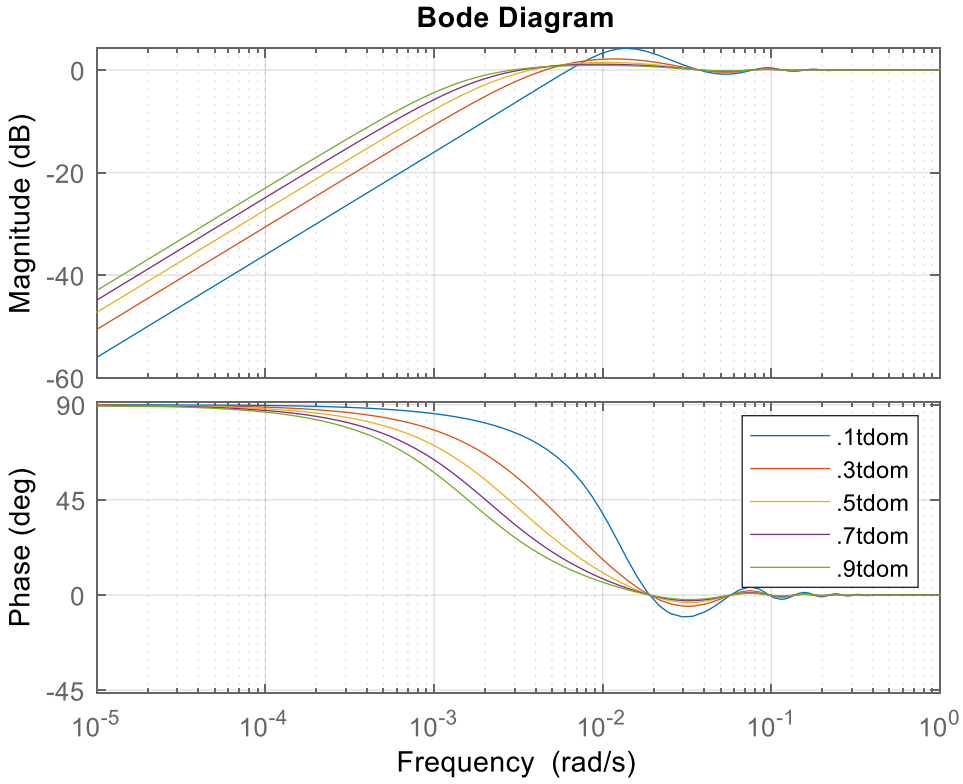
We can easily draw and draw Nightquist curves with the command for a few tc



I plotted these curves for the double-digit function, and it went up according to the figure.

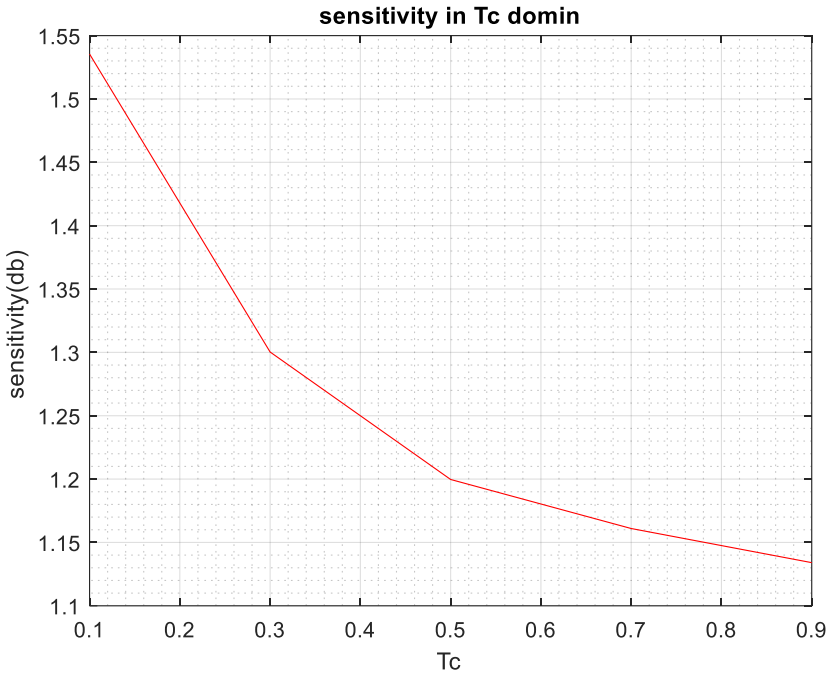


Now we draw the curves of the bads for different tc



τ

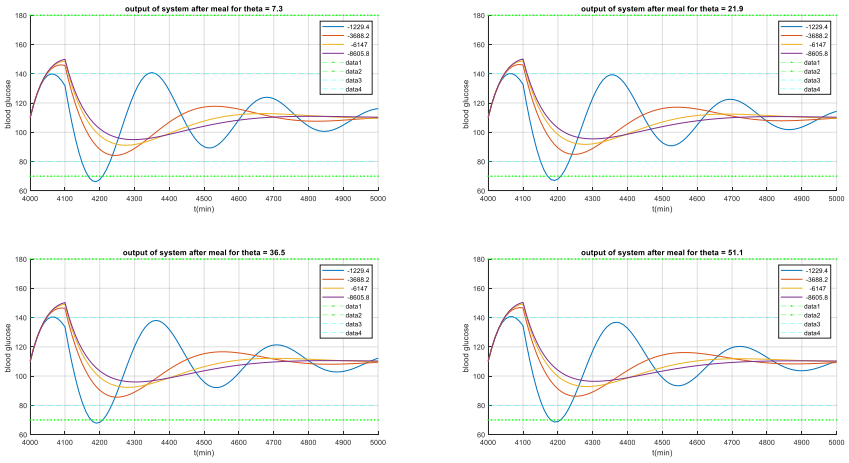
Now we want to draw the sensitivity curve in the Tc domain. To do this, we can easily draw the maximum curves of the above curve using the peakgain function.

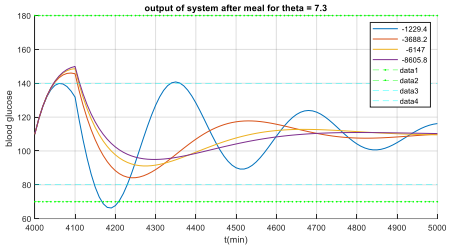


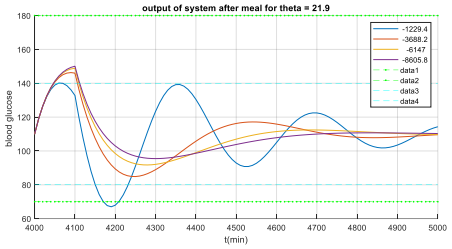
(c)

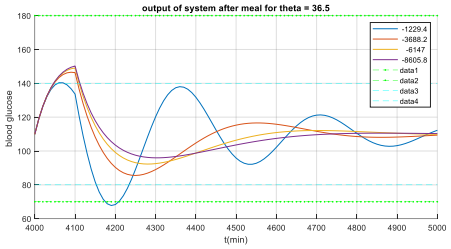
In the previous two sections, it was observed that with increasing Tc value, we are facing the phenomenon of increasing resistance and stability against changes. Therefore, with increasing Tc value, the uncertainty of our system clearly decreases, but it should be noted that this change This does not increase the efficiency of our system. This is because in the previous section we saw that the range of activity of our system decreases due to the increase of Tc, but our stability clearly increases, and this is what we want from a secure system.

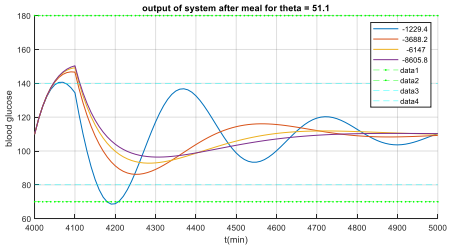
)d)For different values, I draw the system.

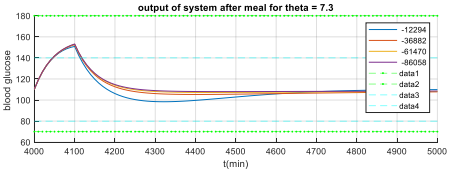


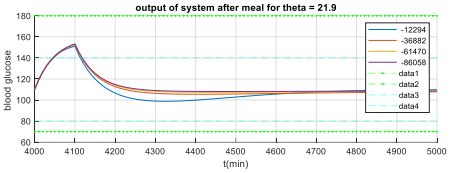

output of system after meal for theta = 7.3
blood glucose
t(min)
-1229.4
-3688.2
-6147
-8605.8
data1
data2
data3
data4

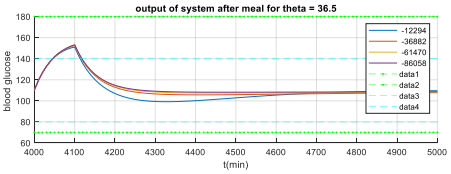

output of system after meal for theta = 21.9
blood glucose
t(min)
-1229.4
-3688.2
-6147
-8605.8
data1
data2
data3
data4

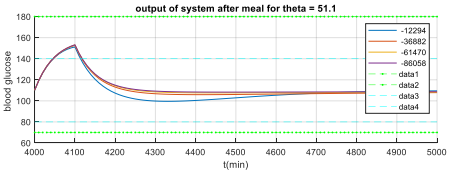

output of system after meal for theta = 36.5
blood glucose
t(min)
-1229.4
-3688.2
-6147
-8605.8
data1
data2
data3
data4

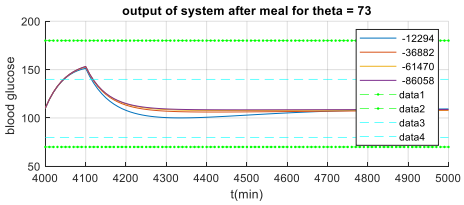

output of system after meal for theta = 51.1
blood glucose
t(min)
-1229.4
-3688.2
-6147
-8605.8
data1
data2
data3
data4

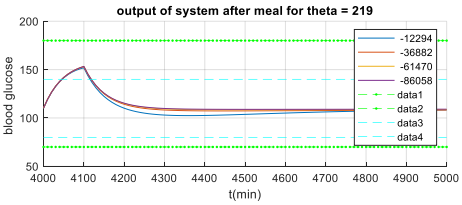

output of system after meal for theta = 7.3
blood glucose
t(min)
-12294
-36882
-61470
-86058
data1
data2
data3
data4

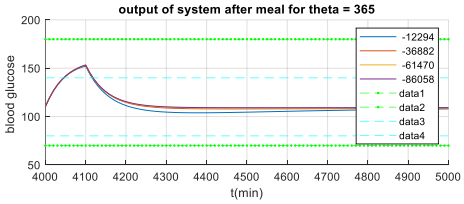

output of system after meal for theta = 21.9
blood glucose
t(min)
-12294
-36882
-61470
-86058
data1
data2
data3
data4

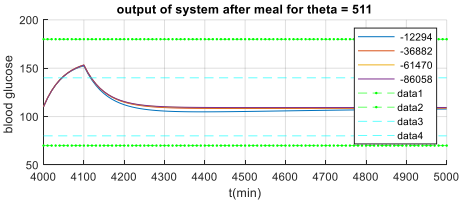

output of system after meal for theta = 36.5
blood glucose
t(min)
-12294
-36882
-61470
-86058
data1
data2
data3
data4

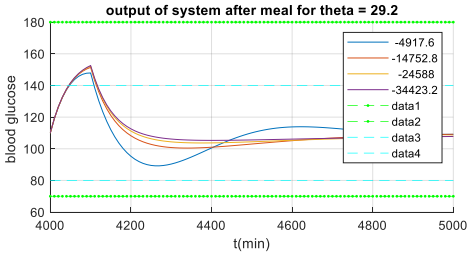

output of system after meal for theta = 51.1
blood glucose
t(min)
-12294
-36882
-61470
-86058
data1
data2
data3
data4

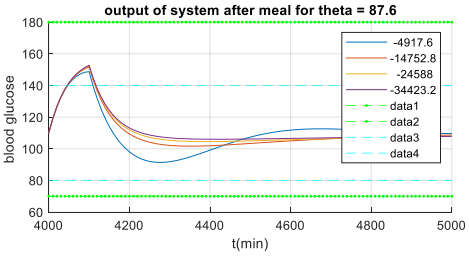

output of system after meal for theta = 73
blood glucose
t(min)
-12294
-36882
-61470
-86058
data1
data2
data3
data4

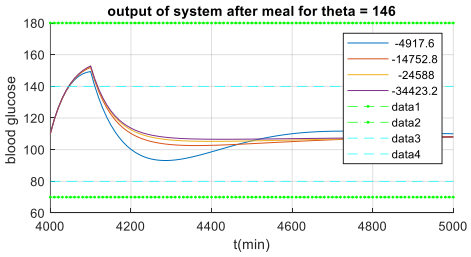

output of system after meal for theta = 219
blood glucose
t(min)
-12294
-36882
-61470
-86058
data1
data2
data3
data4

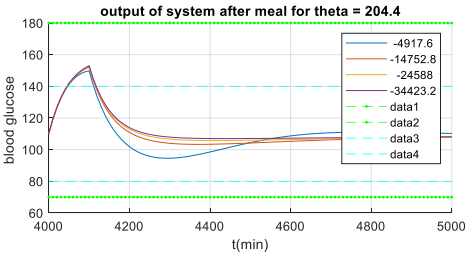

output of system after meal for theta = 365
blood glucose
t(min)
-12294
-36882
-61470
-86058
data1
data2
data3
data4


output of system after meal for theta = 511
blood glucose
t(min)
-12294
-36882
-61470
-86058
data1
data2
data3
data4









In exchange for different values of theta and k, we run the system and get the results.