University of Tehran
Faculty of Engineering
School of Electrical Engineering

Modern Control Systems

Project Report

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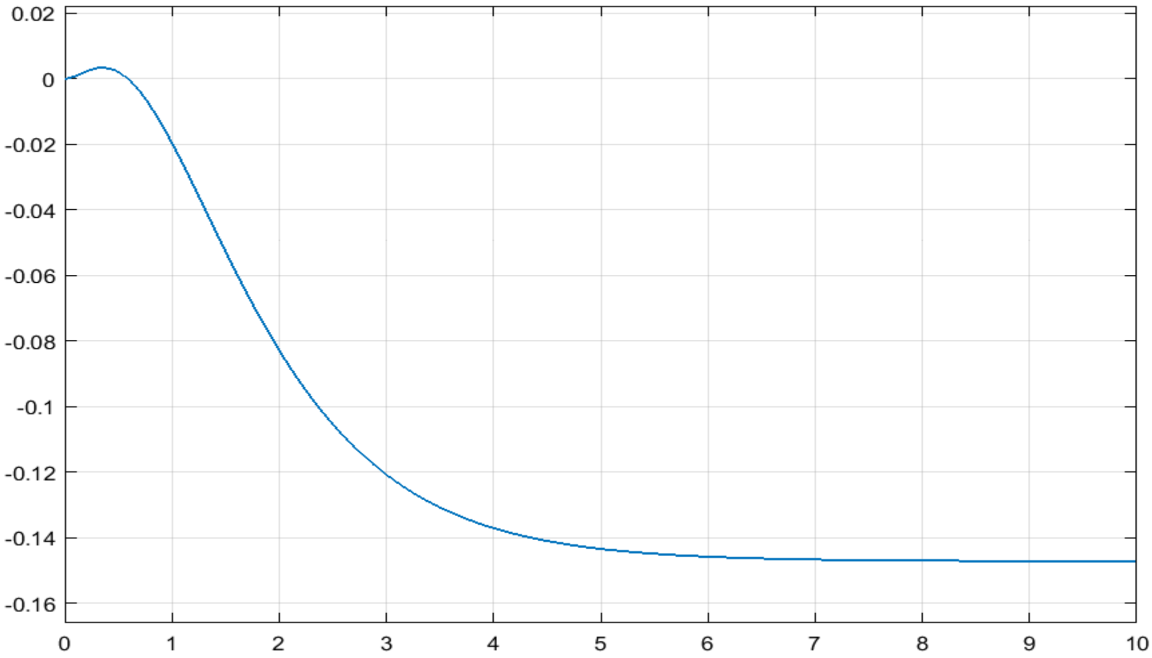
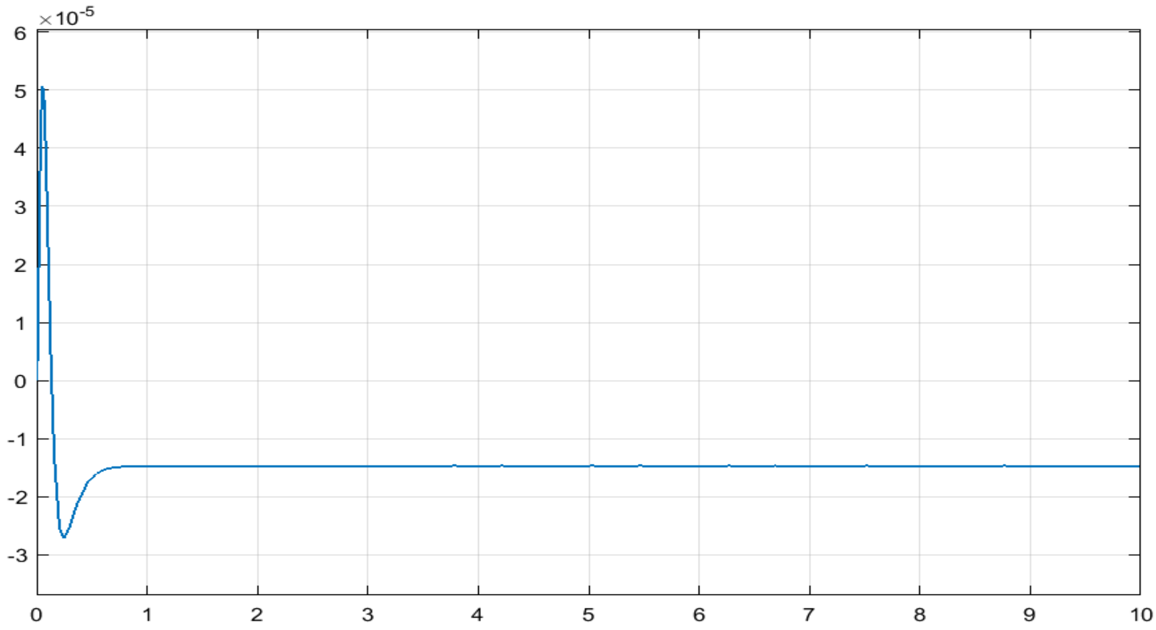
Part 1

Q1

Pendulum location output with slow poles at (-1, -2, -3, -4)



Pendulum location output with slow poles at (-10, -20, -30, -40)



```
Gains for slow poles

K_slow =

   -6.7912  -41.6377 -272.4845  -65.6047

Gains for fast poles

K_fast =

   1.0e+04 *

   -6.7912   -2.1897   -9.7607   -1.9698
```

By comparing the above two output responses, we realize that the system response is faster in exchange for increasing the overshoot and increasing the K gains.

Q2

Matrices $\bar{A}, \bar{B}$ are calculated as follows

$$\bar{A} = \begin{pmatrix} A & 0 \\ -C & 0 \end{pmatrix}, \quad \bar{B} = \begin{pmatrix} B \\ 0 \end{pmatrix}$$

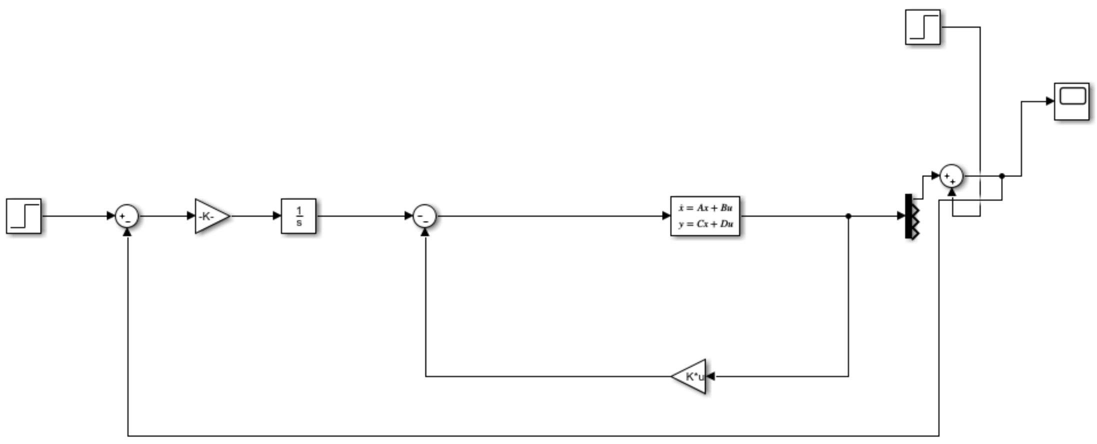
Determining the controllability of $\bar{A}, \bar{B}$

$$C = [\bar{B}\ \overline{AB}\ \bar{A}^2\bar{B}\ \bar{A}^3\bar{B}\ \bar{A}^4\bar{B}] =$$

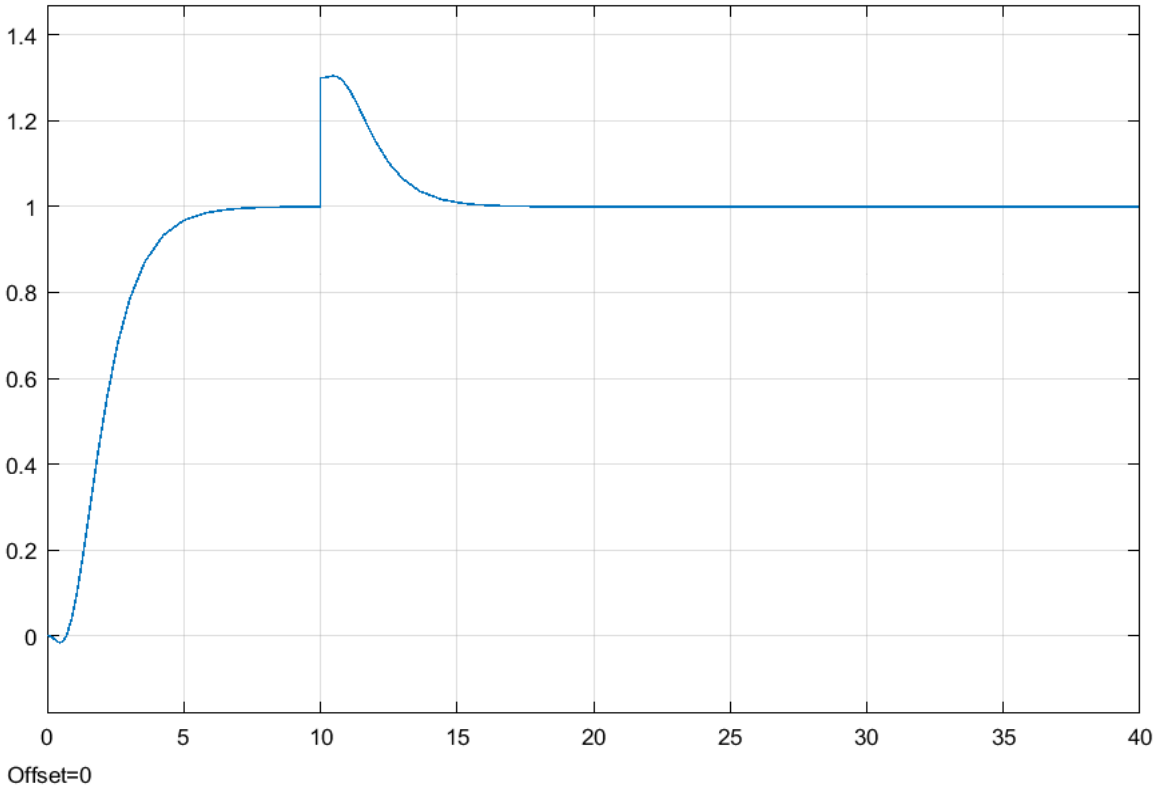
```
        0    0.2263   -0.5141    1.2722   -3.2832
   0.2263   -0.5141    1.2722   -3.2832   10.0765
        0   -0.2565    0.8920   -6.2501   20.9432
  -0.2565    0.8920   -6.2501   20.9432 -119.0770
        0         0   -0.2263    0.5141   -1.2722
```

The above matrix has rank 5, so it is an integral controllable system.

Block diagram used in question 2 with integral mode feedback



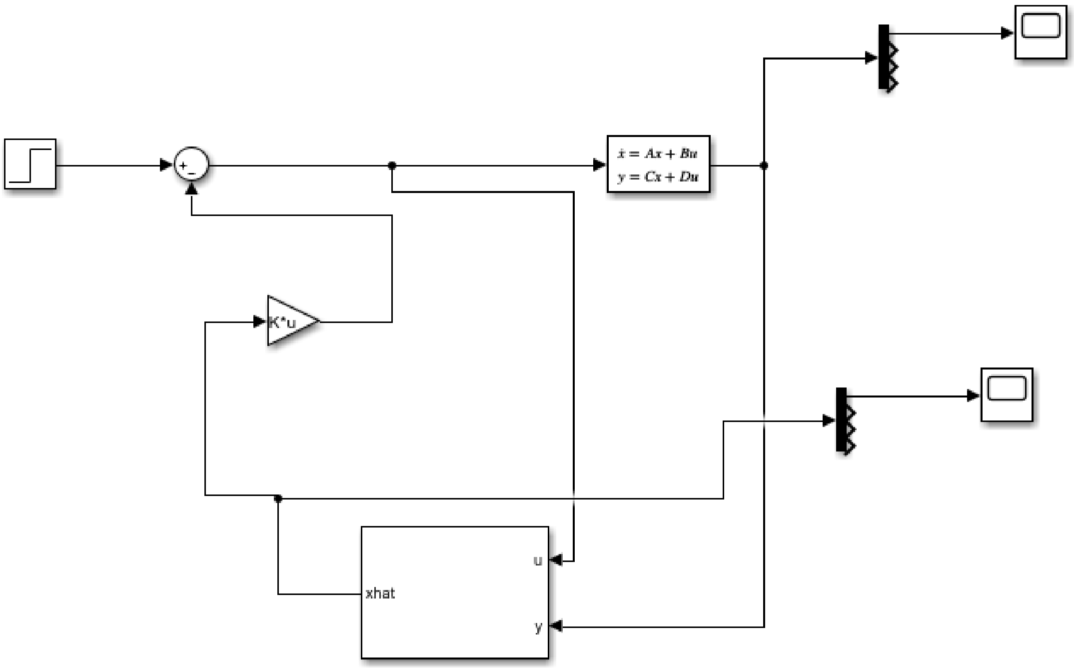
The location response of the pendulum block diagram above along with the input disturbance at time t = 10



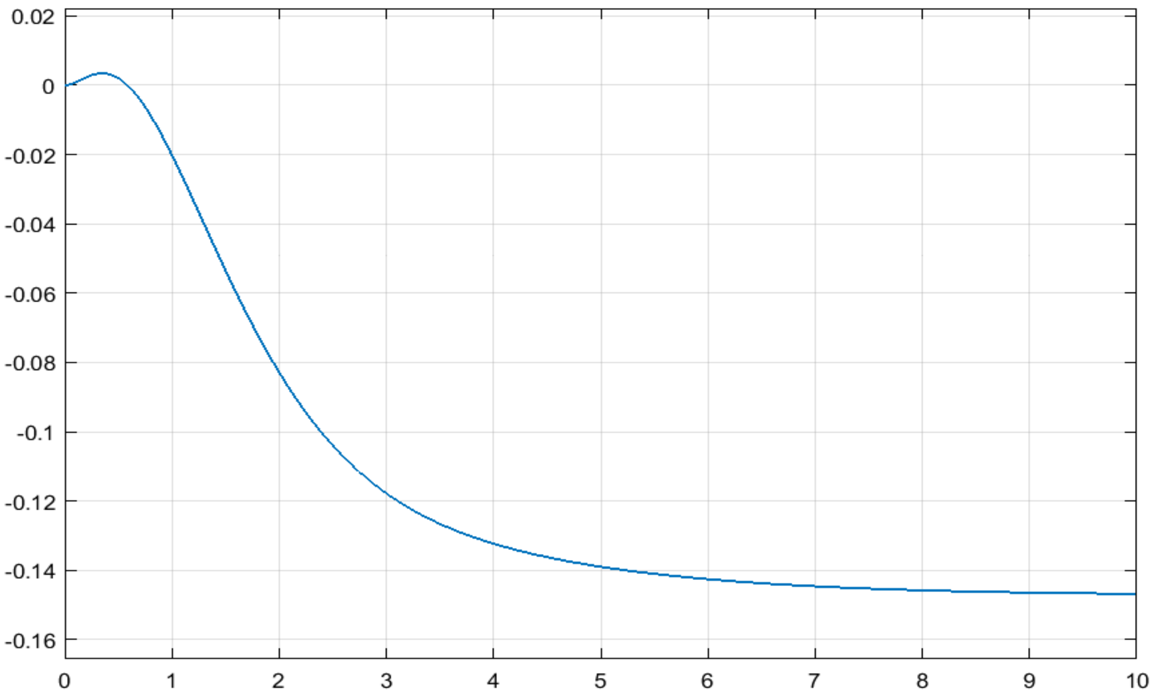
According to the figure above, we can see that the system with integral mode feedback repels the disturbance well.

سوال 3

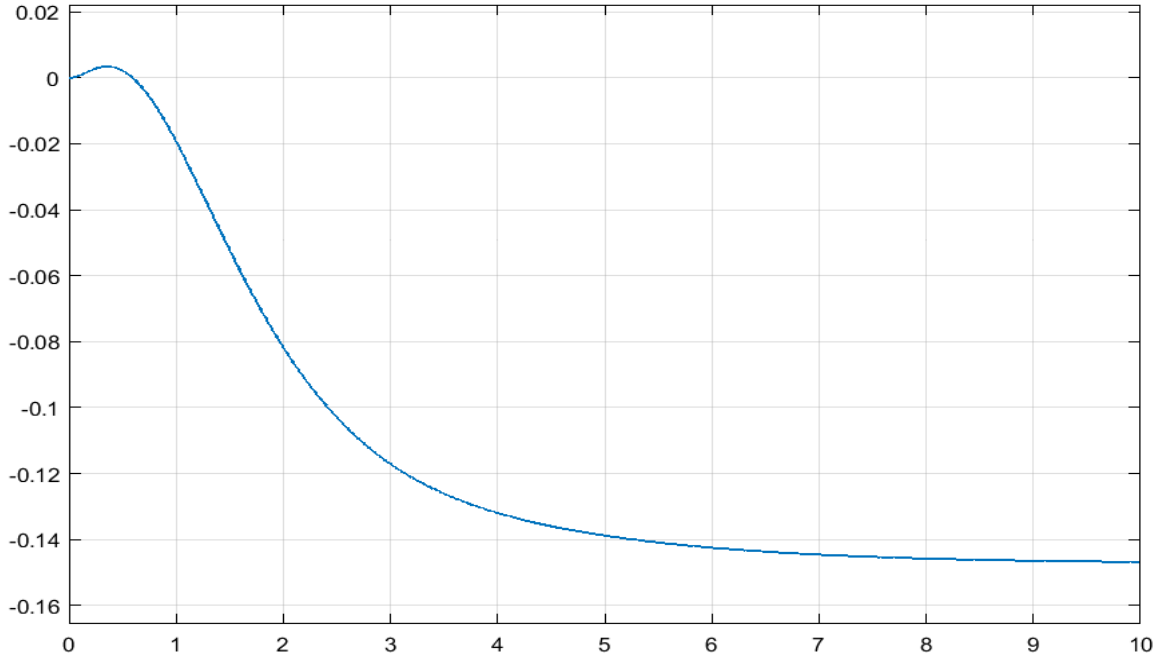
Block diagram of system with Leonberger estimator



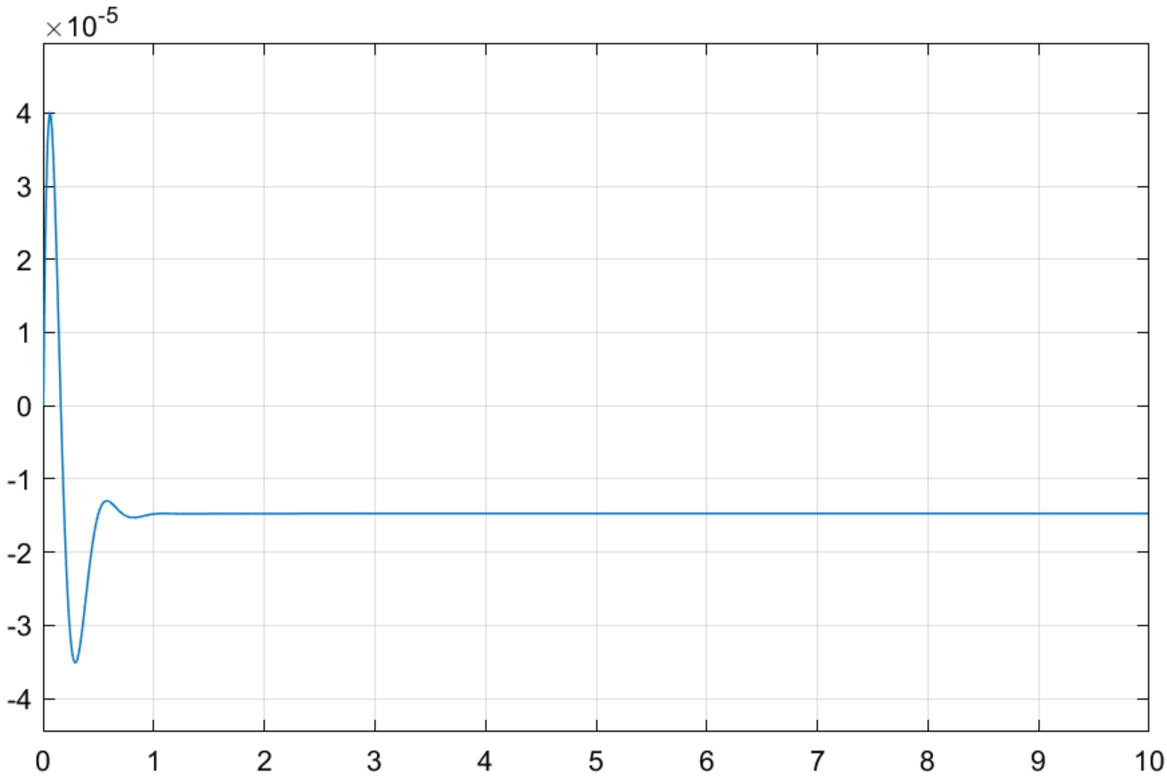
Main system pendulum location output per slow poles



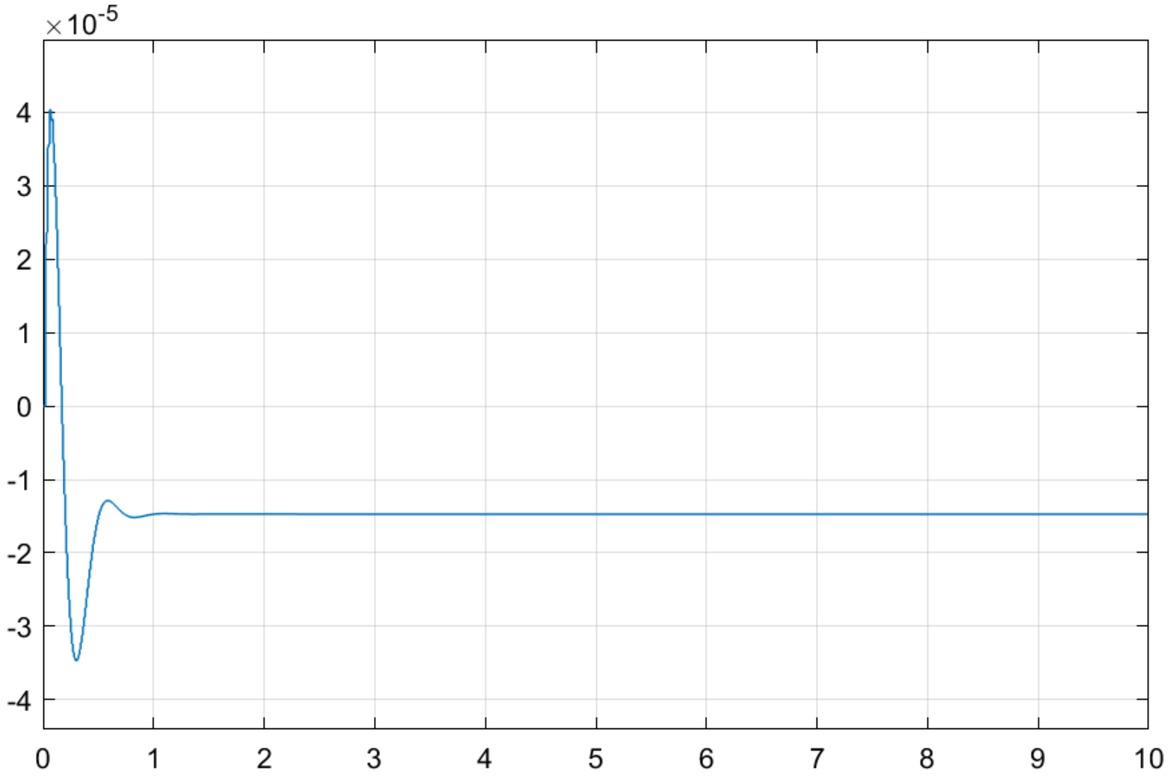
Output the estimated pendulum location per slow poles



Main system pendulum location output per fast poles

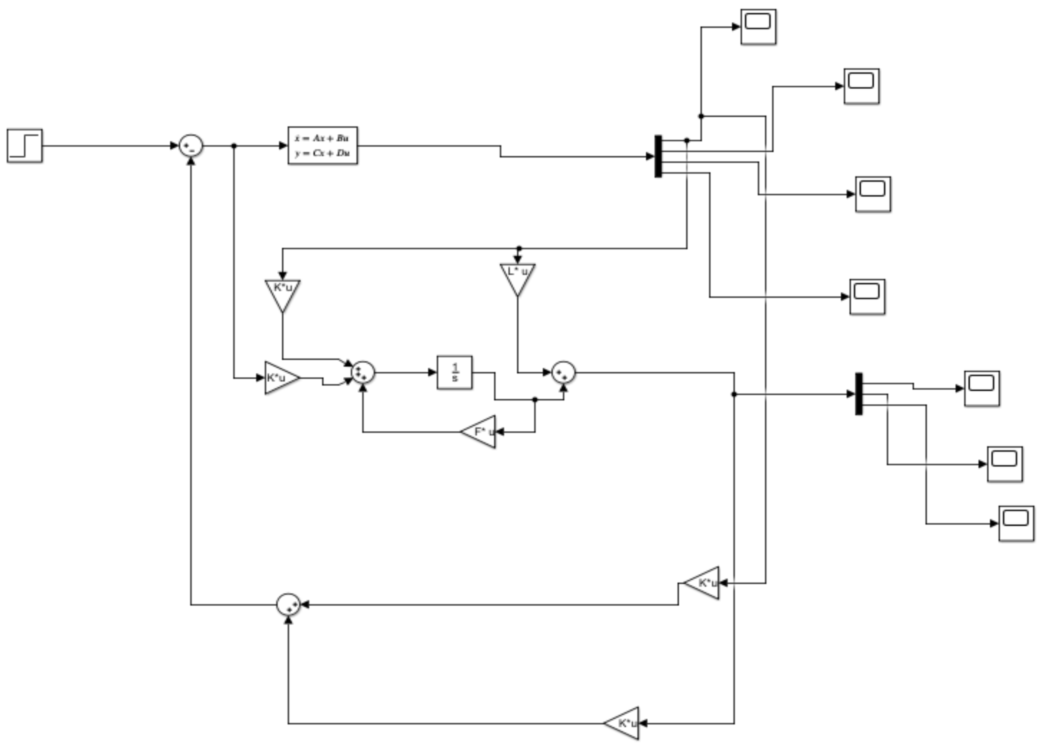


Output the estimated pendulum location per fast poles

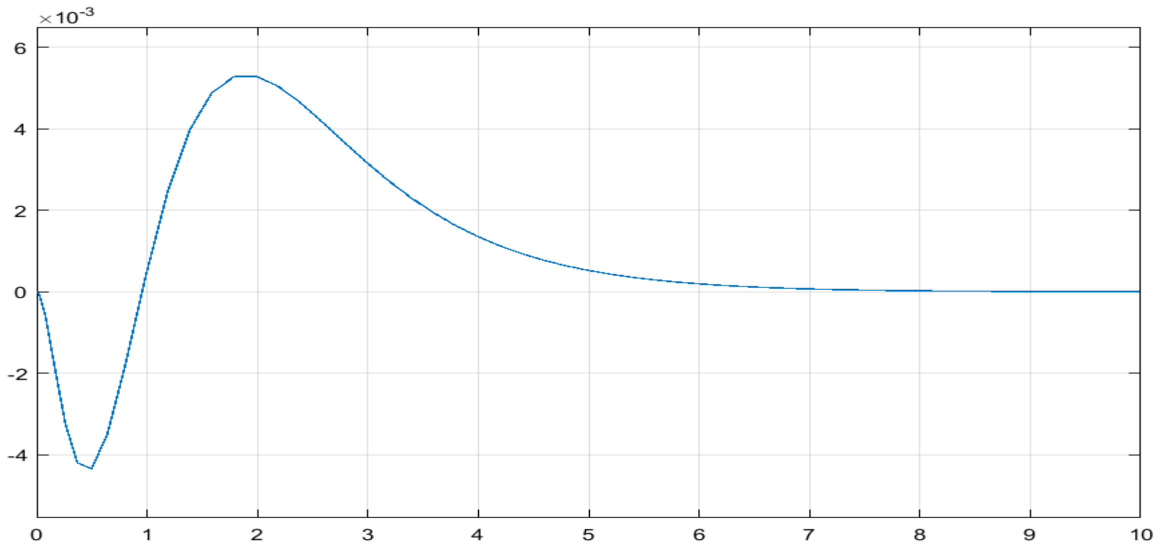


Q4

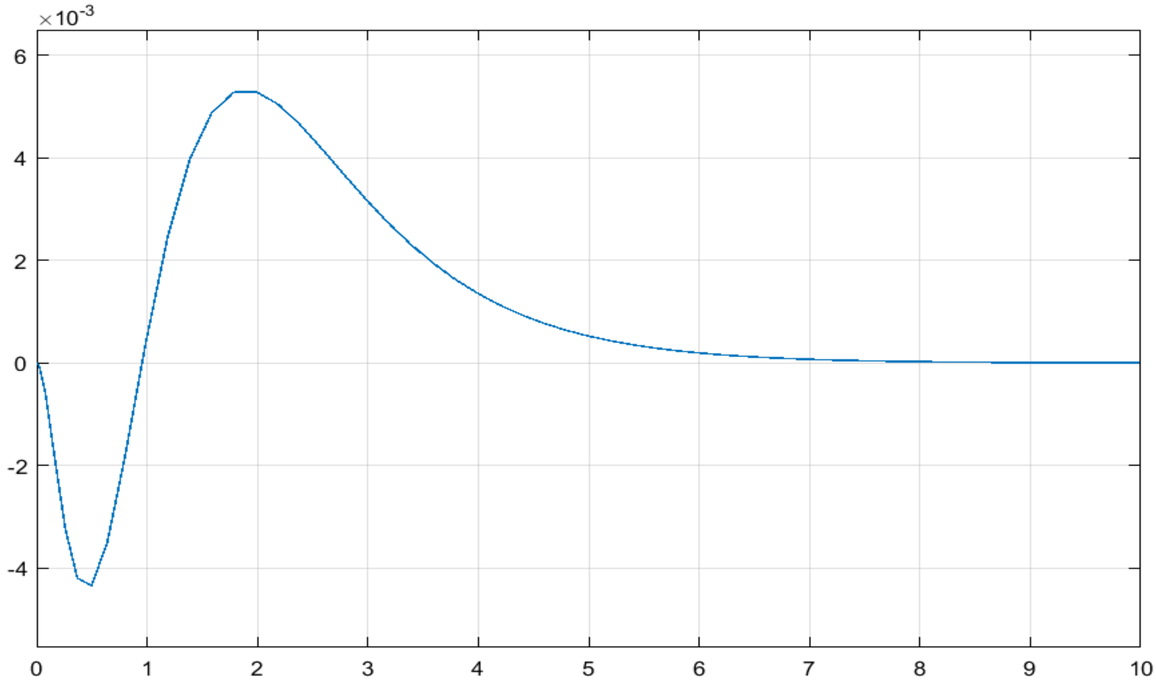
In the block diagram of the figure below, the first state is obtained directly from the original system, and the other 3 states are obtained using the reduced-order estimator.



The third mode output from the main system



The output of the third state of the estimated system is reduced in order



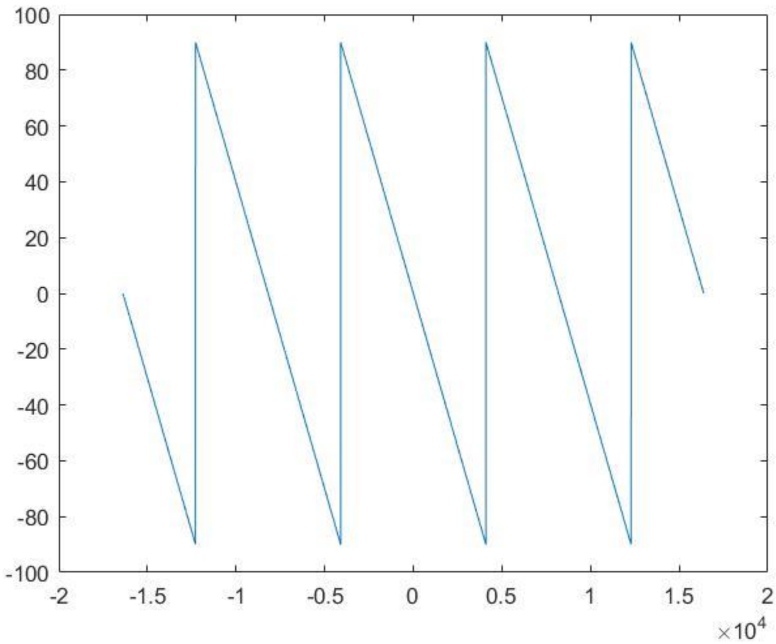
According to the above results, we can see that the reduced order estimator works correctly

Part 2

Q1

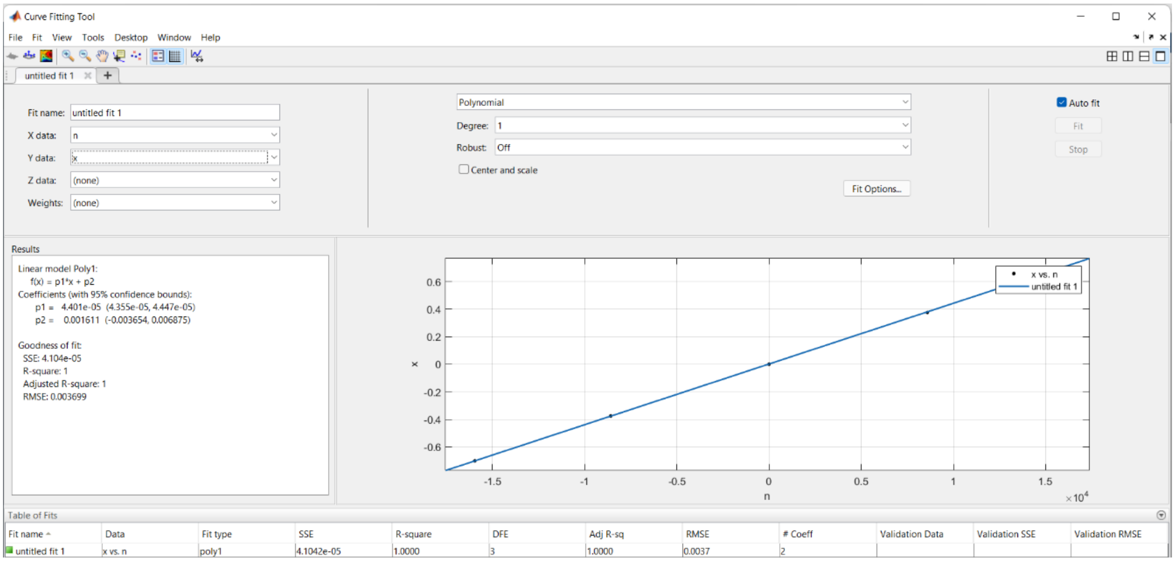
In this question, we are asked to convert the angle to a standard value, explaining step by step the changes in the corresponding function that is located after the output of the encoder. It should be noted that in this question, 4096 x 4096 pulses are created in each revolution, which means that 0 to 4096 x 4096 is mapped between 0 and 2π. Also, in the form of the system, the positive angle is rounded clockwise, but the encoder is the opposite, that is, the clockwise direction is negative. It is counted. As a result, after converting the input number to an angle, we multiply it by negative 1 until the clockwise direction becomes positive, then it may have rotated more than 1 revolution, so we get the remainder of the angle by 360 and continue. In this part, we have to map the angle between -180 and +180, the formula and the desired solution are shown in the code, and then according to the explanation of the question guide video, to move the area 3 and 4 to 1 and 2, we act as follows: If the angle was greater than +90, it means that it is in area 4. By subtracting 180 from this angle, it is transferred to area 2. And for area 3, if the angle is smaller than -90, it must be added to 180 to be placed in the first area. . In the figure below, as you can see, the points are only in the first and second areas.

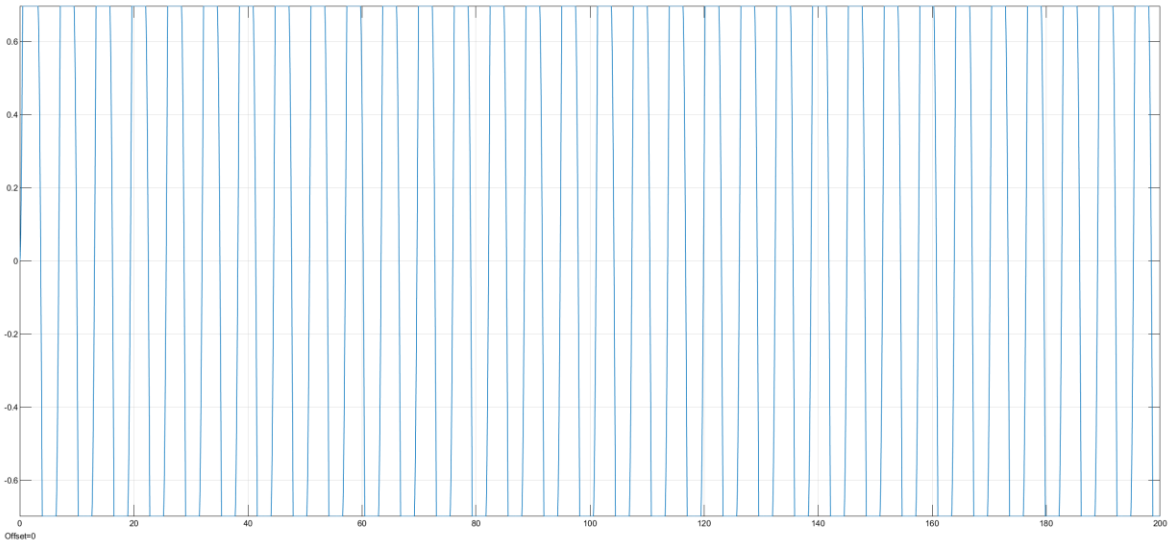
Regarding the reason for moving to quadrants 1 and 2, it can be said that in order for the pendulum to be balanced at the defined origin ($\pi/2$ trigonometric circle), if the pendulum is in the 1 and 2 areas, with a left or right movement of the cart, the pendulum can be moved to the desired balance point, but if we are in the lower half of the circle, i.e. in areas 3 and 4, depending on the direction of movement of the cart and whether the pendulum is in area 3 or 4, with a left or right movement or to the middle of areas 1 and 2, the pendulum can be moved Or at all, the pendulum can be taken to the starting point (π). So if we are in these areas, we need a back and forth movement to move the pendulum to the desired point, so we have to move area 3 to area 1 and area 4 to area 2.



Q2

In this question, with the help of the data provided to us as well as the cftool tool, we get the regression line related to the data and replace the obtained parameters in the output related to the location, as you can see in the figure below. Points between -0.7 and +0.7 are mapped.



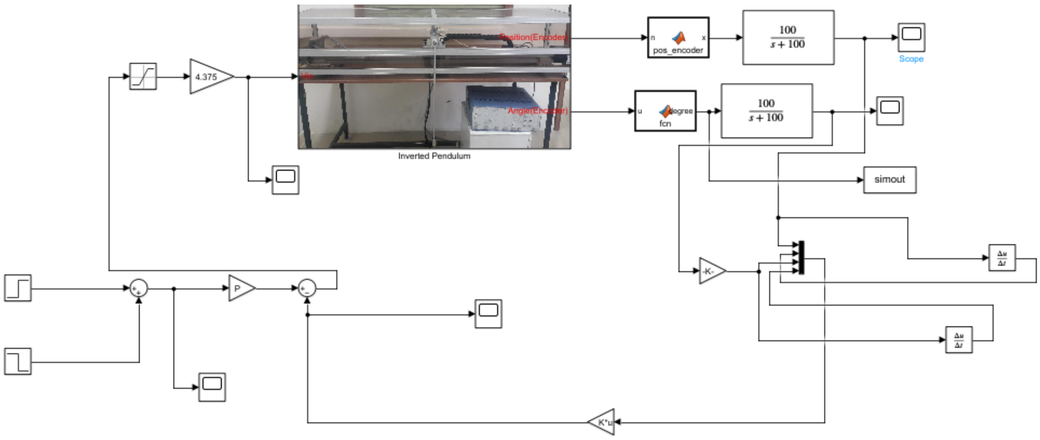


Part 3

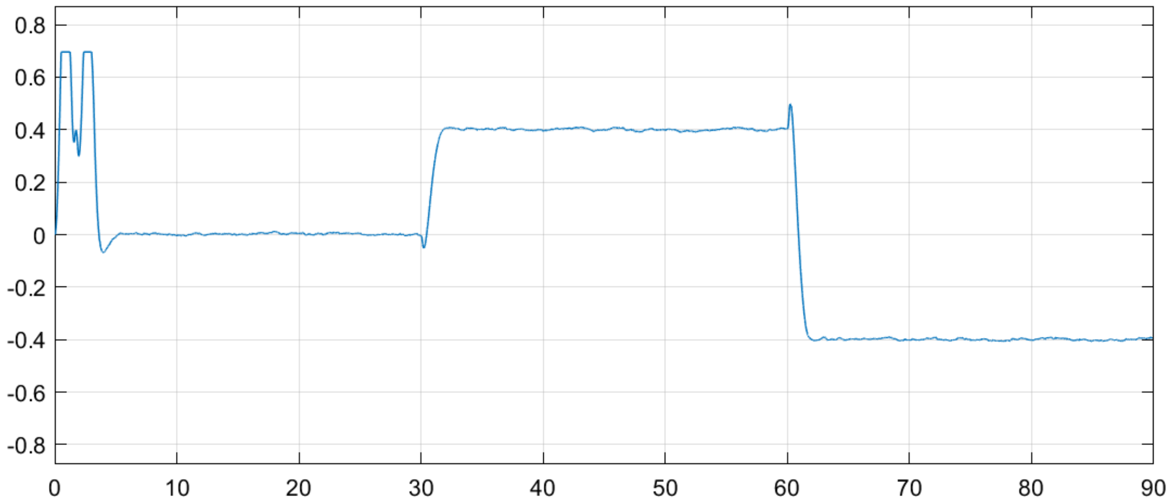
To reduce the noise of the sensors, we need low-pass filters in the output of the sensors to reduce the noise on the signal. The use of filters in real-time systems may cause time delays and thus lead to instability.

Q1

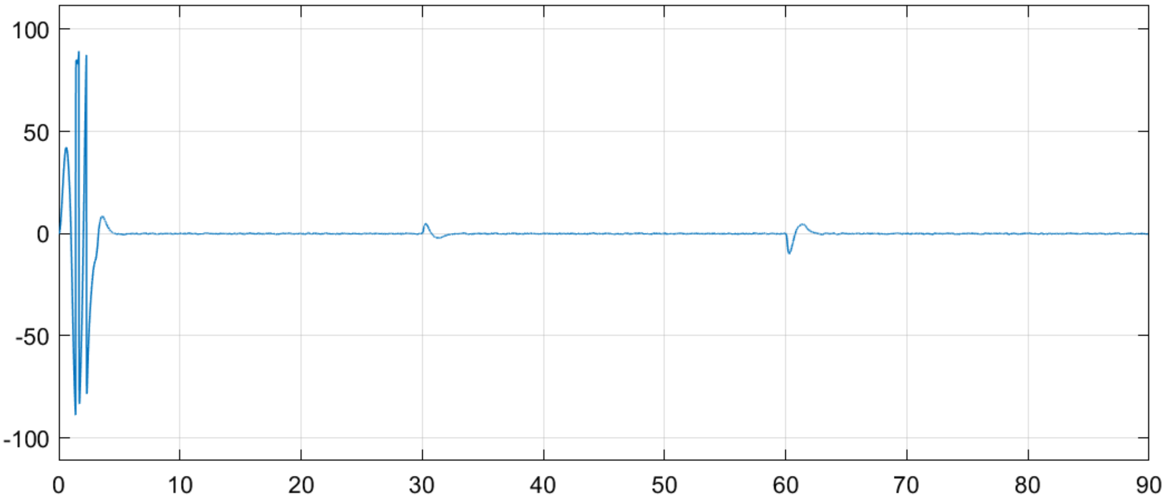
Closed control circuit with observer and considerations



Pendulum location output in non-linear system with tracker

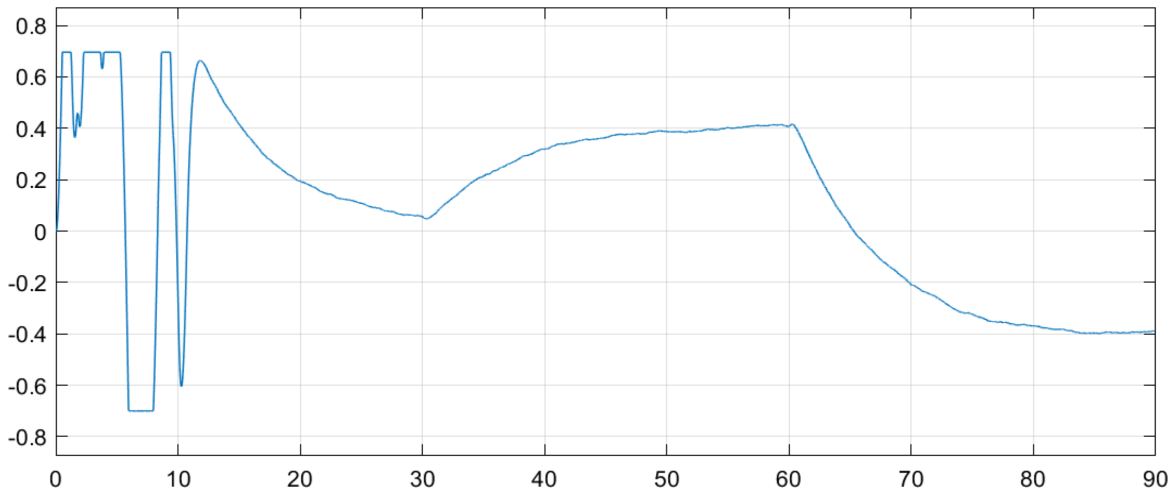


Pendulum angle output in degrees in non-linear system with observer

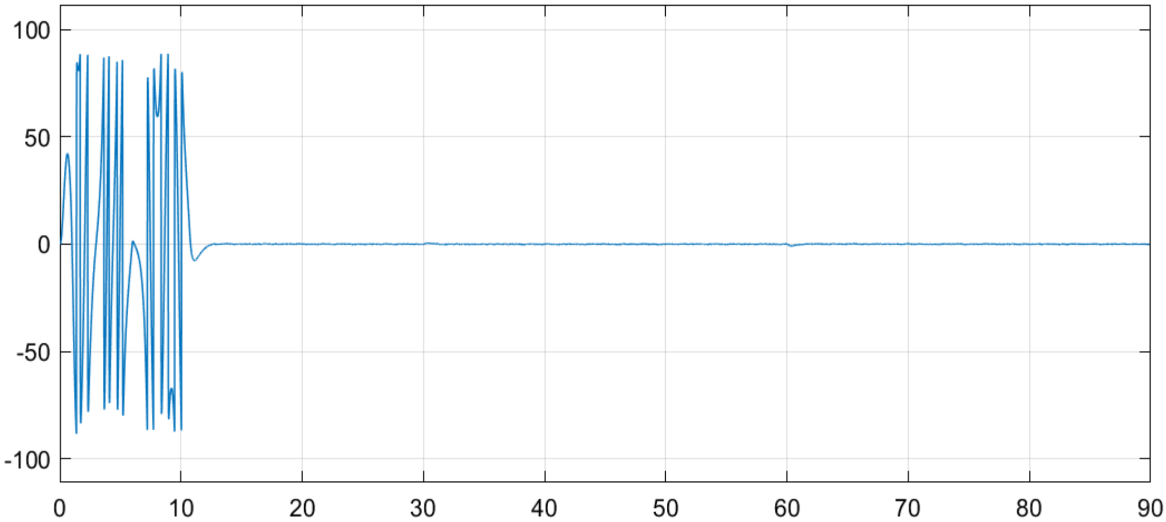


Q2

In question 1, we chose arbitrary poles in [-3-3-3-3-3]. Now we consider the slow poles first Output diagram of pendulum location with desired poles [-1-1-2-2]



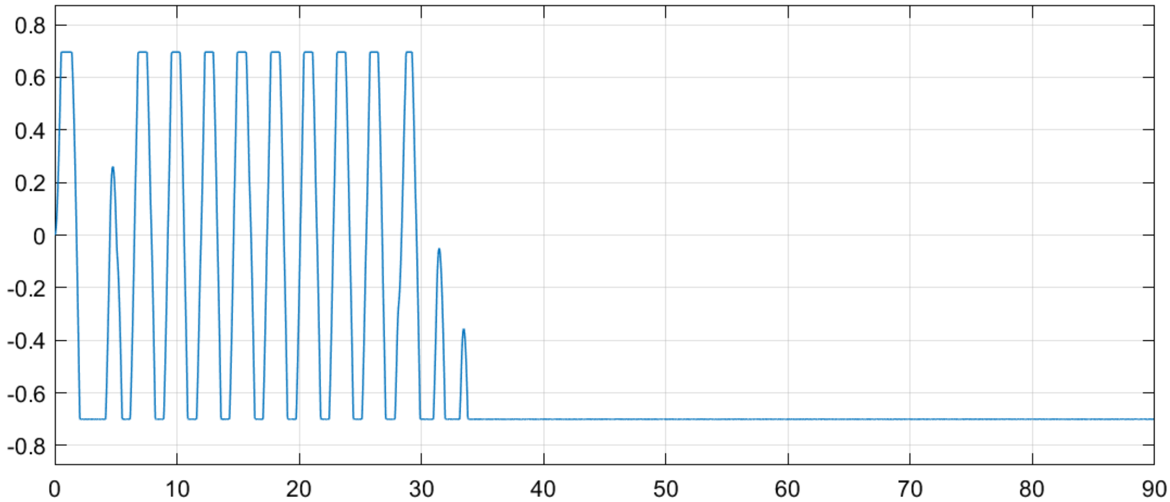
Output diagram of pendulum angle with desired poles [-1-2-1-2]



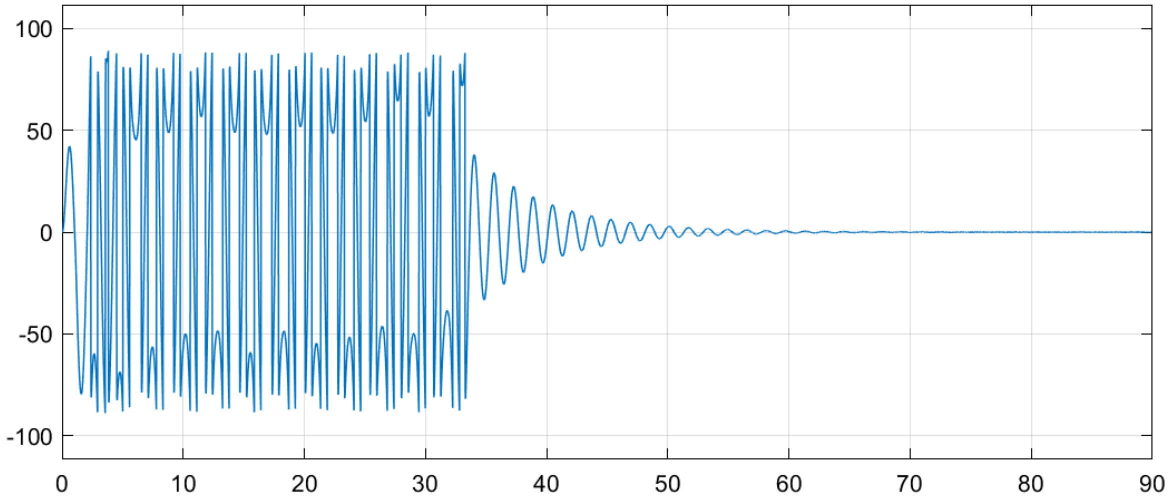
We see that with slow poles the system is not able to follow the output as well as in question 1 and the tracking is slow.

Now we consider the fast poles [-11-12-13-14].

Output diagram of pendulum location with desired poles [-11-12-13-14]



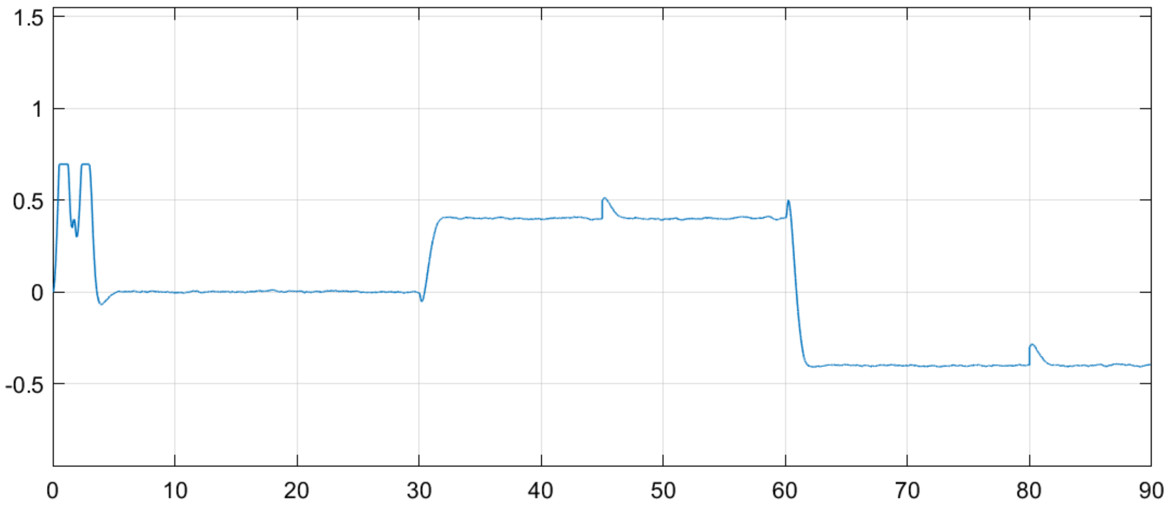
Output diagram of the pendulum angle with desired poles [-11-12-13-14]



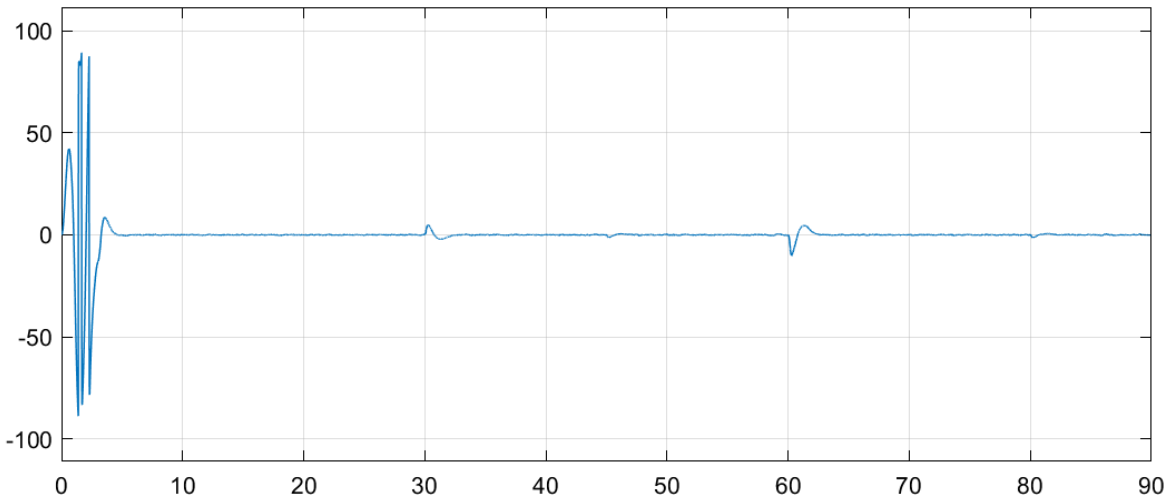
We can see that by selecting the fast poles, the system does not follow the desired input correctly at all, the reason can be the saturation block, which goes to saturation because the control signal for the fast poles is large, and as a result, the system is not well controlled. Therefore, by choosing any arbitrary pole, we cannot reach the desired solution. The reason is that we linearized the nonlinear system around the unstable equilibrium point, and we do not have complete information about the behavior of the nonlinear system, which may lead to uncontrollability with inappropriate poles. . Also, in the non-linear system, due to the limitation of the size of the control signal (saturation), it can cause the system to not be controlled correctly.

Q3

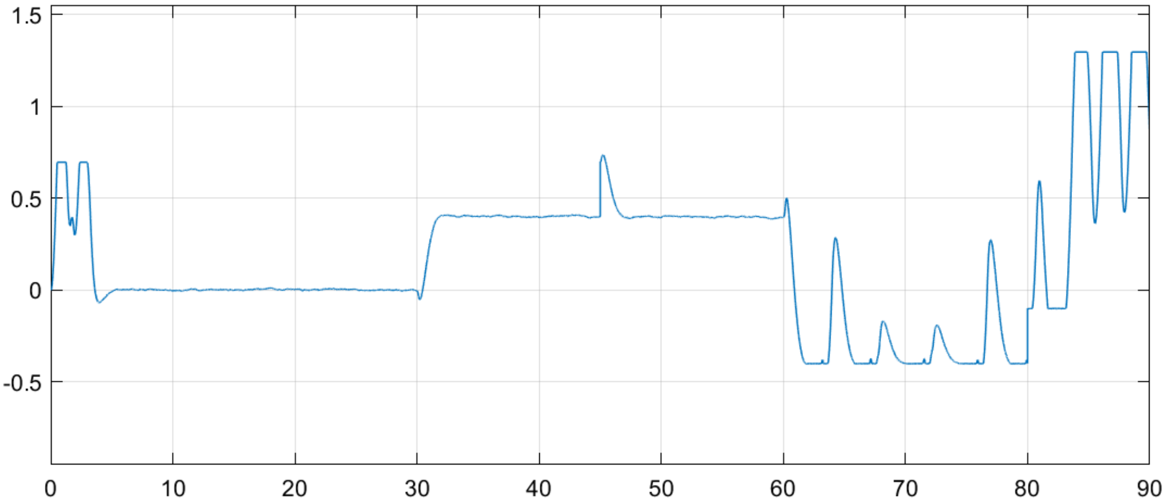
Output of pendulum location with 0.1 perturbation at moments t = 45 and t = 80



Pendulum angle output with perturbation 0.1 at moments t = 45 and t = 80



Output of pendulum location with 0.3 perturbation at moments t = 45 and t = 80



According to the above results, we can see that the system is well able to repel the disturbance, but if the amplitude of the disturbance is large, the system will not work properly.

Q4

According to the above results, we can see that in addition to the location of the pendulum, the output angle also becomes zero correctly. We know that the states of this system are dependent on each other and the system is linearized around the equilibrium point where the states are zero and the pendulum angle is equal to π, i.e. upwards. The modes of this system are also visible and controllable. Also, the characteristic equation of all modes is equal, as a result, by arbitrary determination of the poles for one mode, the characteristic equation of other modes will also change in the same way and will be stable around the working point, and thus the pendulum angle and the rest of the modes around the linearization point. remains