CONTROL M LAB REPORT

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The work done in lab 1:

Calculate the transfer function of the motor system according to the physical model of the motor system. And bring this transfer function into monic form and input it into MATLAB, use MATLAB and find the zeros and poles of the transfer function P.

Using the Simulink model in MATLAB to build an open-loop model, name it model 1, adjust the parameter frequency to 1 rad/s. Read the output in the scope. Then change the frequency of sine wave into 5 rad/s, compare the corresponding image of 1 rad/s and 5 rad/s.

Secondly, set up a continuous-time function control model. To set up a close-loop system, select a suitable compensator C(s), get the transfer function D(s). Using function tf to input the function into the MATLAB. Use function bode to decide the stability of P(s), C(s) and L(s). Then, analyze the system to select a more suitable value for the gain K, use root-locus method to select controller gains (rlocus in MATLAB). Set the Controller Gain value in the model to the values found above and evaluate the responses by running the simulation for each gain value. Verify that the overshoot and damping specified from the root-locus analysis correspond with those obtained in the simulation. Use Nyquist plot to judge the stability of the closed-loop system, and use bode to judge the stability of the system under different gains(K).

Thirdly, add transport delay to the system, test the effect of different delay values in different K values.

For the digital control section, using Z-transfer method to transfer the continuous function into discrete function. Set the sampling time T=0.01s, using the MATLAB function: P_zoh = c2d(P, T, 'zoh'). Using the command Dd = tf(NUM,DEN,T), where NUM and DEN need to be set according to the poles and zeros found. Setup digital feedback system with compensator and simulated plant, adjust the initial conditions, get the output image from the scope, and compare it with the previous continuous signal. Then, change the sampling time to T=0.04 and Run the digital feedback system again.

The work done in lab 2:

Use model 1 plug servo to the system, and get the input of 1 rad/s and 5 rad/s.

Then, use model 2 and model 3 to do the following experiment, compare the output to the mathematical model. Finally, remove the disk from the servo motor and run the simulation to see if there are any effects of different physical values on the results.

At last, use model 4 to run the simulation, compare the time histories of the continuous and the digital versions of the controller. Then, change the sampling time to T=0.04 to see if there’s any difference.

Method & tools used：

MATLAB，Simulink，root-locus method, Nyquist rule, Z-transfer method, Laplace Transform, bode plot, ‘pole-zero matching’ technique.

RESULTS:

Q1.1:

$$G(s) = \frac{\theta(s)}{v_m(s)} = \frac{k_t}{J_{eq}R_m s^2 + k_t k_m s}$$

Q1.2:

$$G(s) = \frac{\theta(s)}{v_m(s)} = \frac{\frac{k_t}{J_{eq}R_m}}{s^2 + \frac{k_t k_m}{J_{eq}R_m} s}$$

Q1.3:

Number of poles: 2

Pole No.1: -10.02

Pole No.2: 0

Number of zero: 0

Q1.4:

The output amplitude at 1 rad/s is larger than the output amplitude at 5 rad/s. This means that the gain at 5rad/s is smaller than the gain at 1rad/s.

The delay of the output relative to the input at 1rad/s is larger compared to 5 rad/s. This means that the phase shift at 1rad/s is equal to the phase shift at 5rad/s.

It does correspond to what I expected.

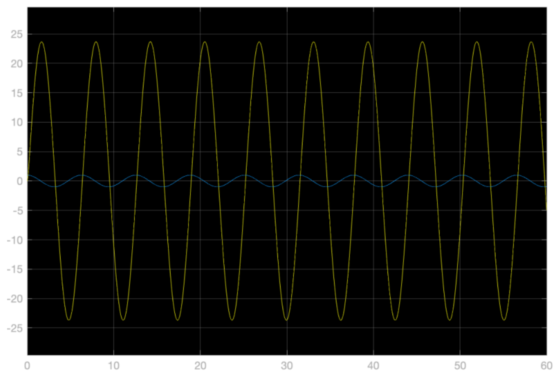

Figure 2 : 1 rad/s

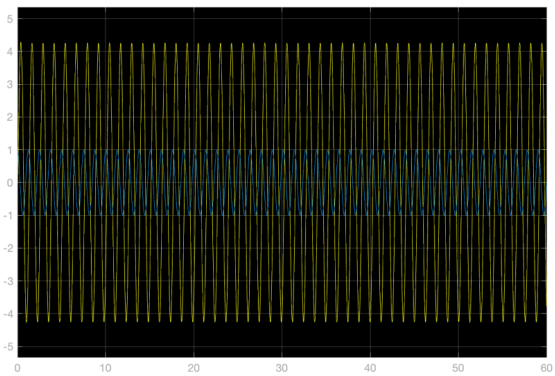

Figure 2 : 5 rad/s

Q1.5:

The magnitude of P(s) and L(s) is large at low frequencies and small at high frequencies. It has low pass characteristics.

L(s) crosses the 0dB line at a higher frequency than P(s)

The magnitude of C(s) increases at higher frequencies.

We can see from the zeros and poles from the transfer function. The gain is 238.6 for lower frequency and 0 for higher frequency.

The corner frequencies are the poles of the function, which are 0 and -10.02.

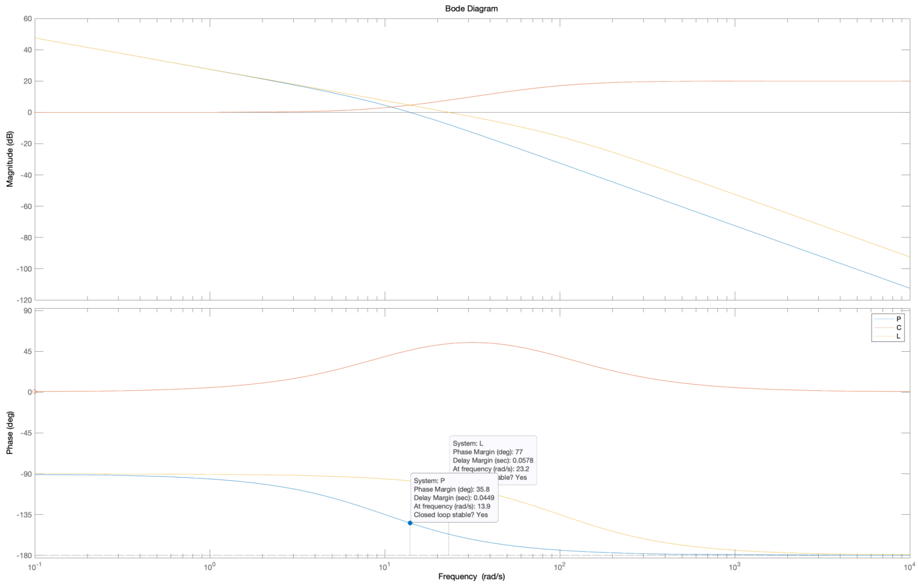

Figure 3 Bode diagram

Q1.6:

P(s): cross-over frequency (13.9 rad/s), gain (0 dB), phase (35.8 deg).

L(s): cross-over frequency (23.2 rad/s), gain (0 dB), phase (77 deg).

Q1.7:

Location of poles

	Feedback gain K	Pole1	Pole2	Pole3
A	0.2	-95	-10	-5
B	2.2	-50+j52.4	-50+j-52.5	-10

Table 1: Root locus gains and poles

Q1.8:

The response with K_A is critically damped. The response with K_B is underdamped. The response with K_A is slower than with K_B. The control signal for K_A is smaller than for K_B.

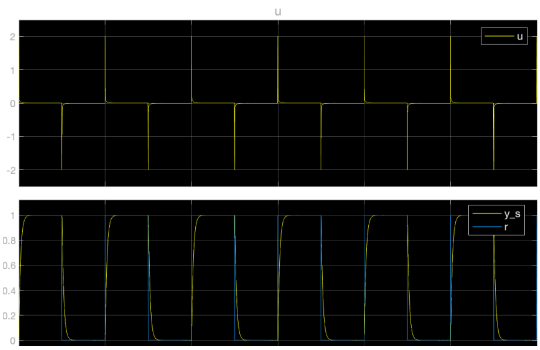

Figure 5 : K=0.2

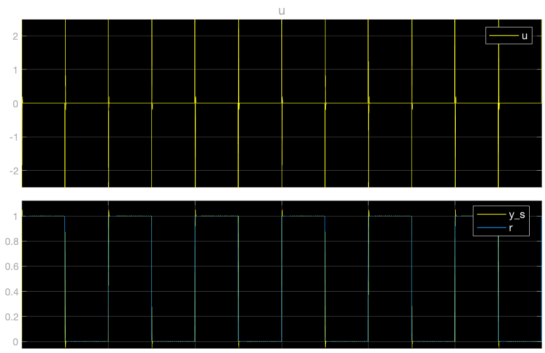

Figure 5 : K=2.2

Q1.9:

	Phase margin (deg)	Frequency (rad/s)	Delay margin (s)
A	87.3	4.76	0.32
B	64.7	47.4	0.0238

Table 2: Margins

Q1.10:

The phase margin for K_A is 87.3 deg, which is the same compared to result from Q1.9. The phase margin for K_B is 64.7 deg, which is the same compared to result from Q1.9.

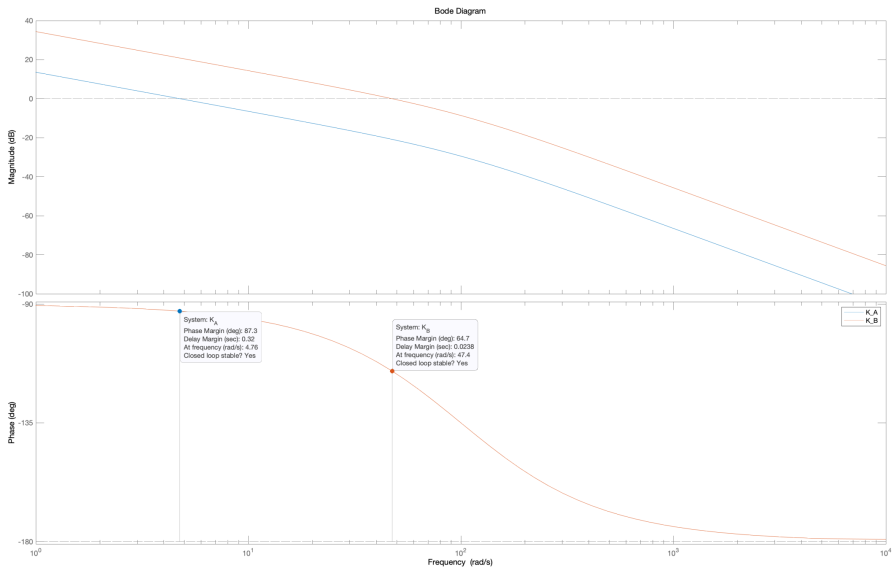

Figure 6 : Bode diagram (K_A, K_B)

Q1.11:

For a transport delay which is slightly smaller than the delay margin, the system response is underdamped.

For a transport delay which is slightly larger than the delay margin, the system response is unstable.

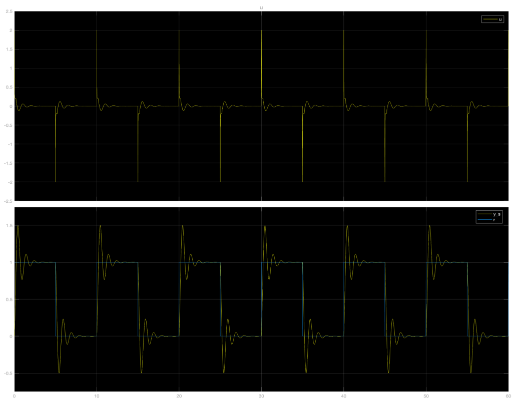

Figure 7 : K=0.2, delay (0.2)

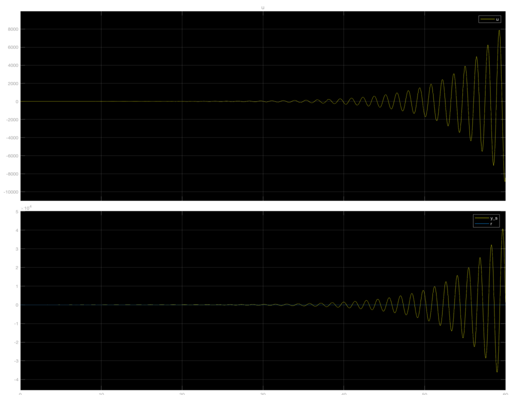

Figure 8 : K=0.2, delay (0.35)

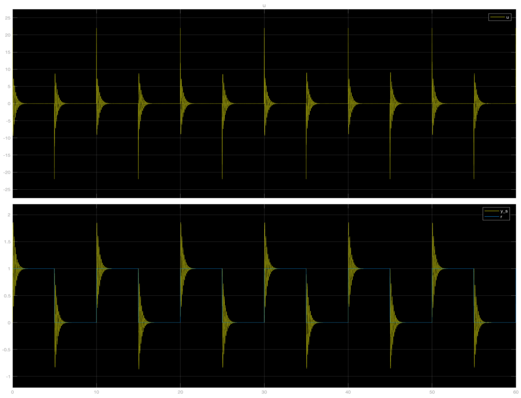

Figure 9 : K=2.2, delay (0.0208)

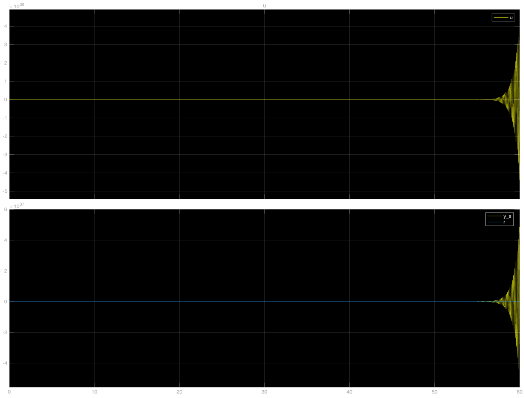

Figure 7 : K=2.2, delay (0.0268)

Q1.12:

$$a = \frac{k_t T}{J_{eq} R_m} \; ; \; b = 0 \; ; \; c = -e^{-\frac{k_t k_m T}{J_{eq} R_m}} - 1 \; ; \; d = e^{-\frac{k_t k_m T}{J_{eq} R_m}}$$

$$P_{zoh}(z) = \frac{0.01154\, z \; + \; 0.01116}{z^2 \; - \; 1.905\, z \; + \; 0.9046}$$

Q1.13:

$$K_d = 14.6136 \; ; \; D_d(z) = \frac{z - 0.9048}{z - 0.3679}$$

Q1.14:

The phase (deg) at 200 rad/s of continuous compensators is 23.8.

The phase (deg) at 200 rad/s of digital compensators is 14.7.

At low frequency, both diagrams are about the same. But at high frequency, the digital diagram drop down quicker than continuous.

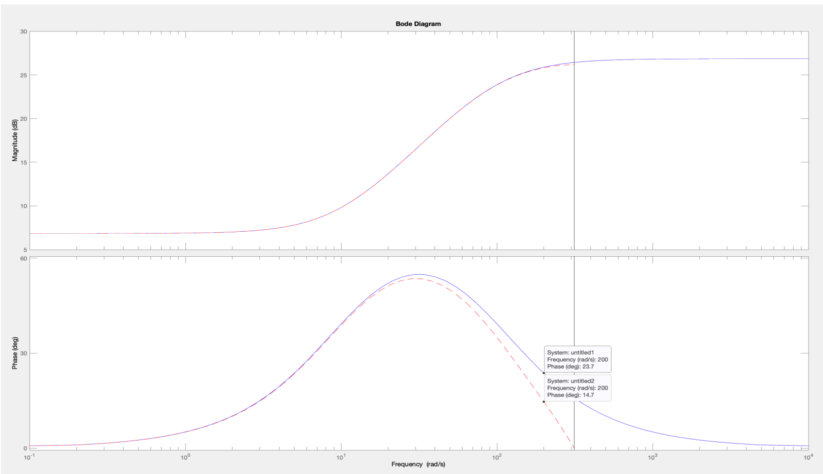

Figure 8 : Bode diagrams of the continuous and digital compensators

Q1.15:

Digital loop has a higher overshooting, while the settle time of both loops are about the same.

Figure 10 : continuous

Figure 10 : digital

Q1.16:

$$P_{zoh}(z)\_new = \frac{0.1678\, z \ + \ 0.1468}{z^2 \ - \ 1.67\, z \ + \ 0.6697}$$

$$K_d\_new = 6.5509\ ;\ D_d(z)\_new = \frac{z \ - \ 0.6703}{z \ - \ 0.01832}$$

Q1.17:

It is marginally stable.

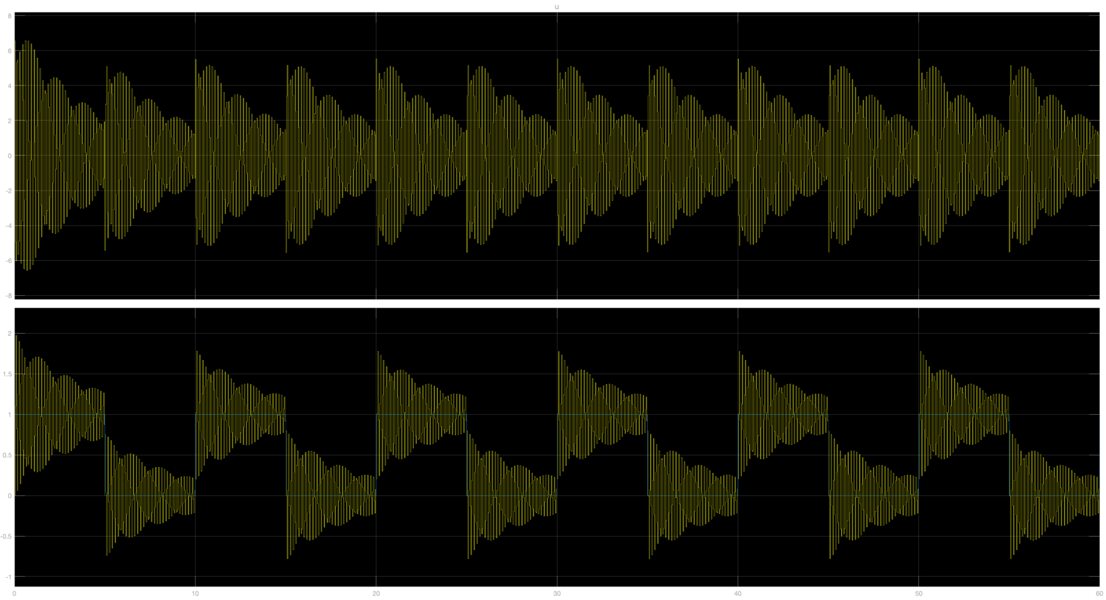

Figure 11 : The time history of y_s

Q2.1:

For 1rad/s. The basic shape of the outputs of simulated and real systems are the same. Over time the output signals of the simulated and the real system diverge a little.
For 5rad/s. The basic shape of the outputs of simulated and real systems are the same. Over time the output signals of the simulated and the real system diverge a little.
The main reason for any difference between simulated and real plant is variable motor

parameters.

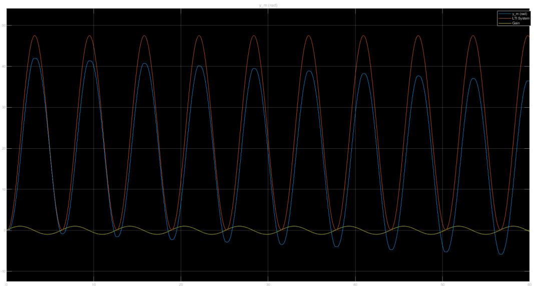

Figure 13 : 1 rad/s

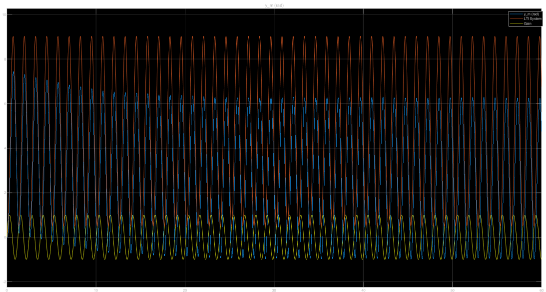

Figure 13 : 5 rad/s

Q2.2:

The real system has a small steady state offset. The overshoot is smaller than expected. The control signal does exceed the plant capacity. During steady state, the control signal is equal to zero.

The reason why there are differences between real system and the simulation is that the real system has load weight and friction and other unknow variable.

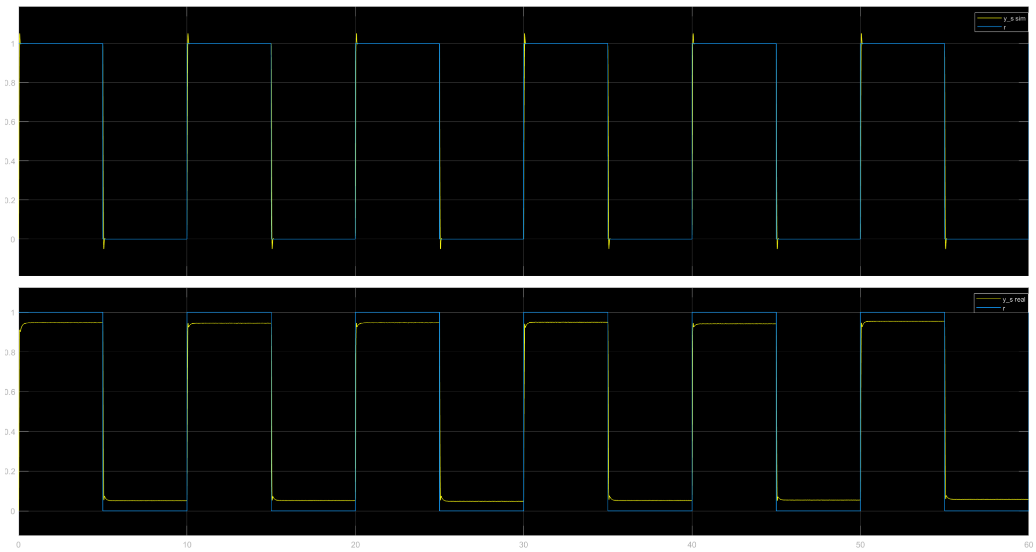

Figure 14 : real system and sim system

Q2.3:

The system eventually becomes unstable. The main reason for the differences between real plant and the mathematical model is that the real plant has limited plant capacity.

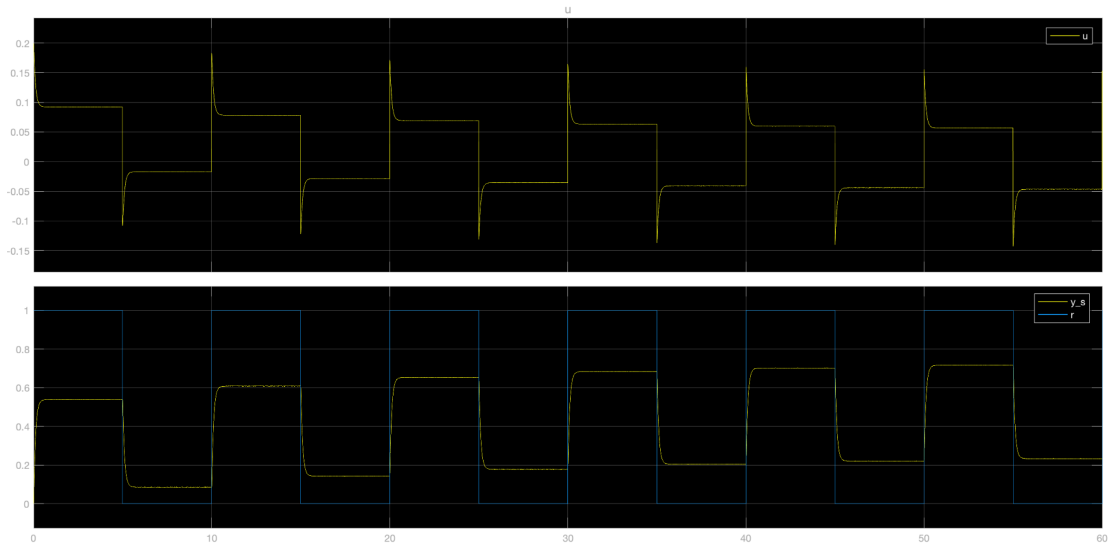

Figure 15 : delay=0

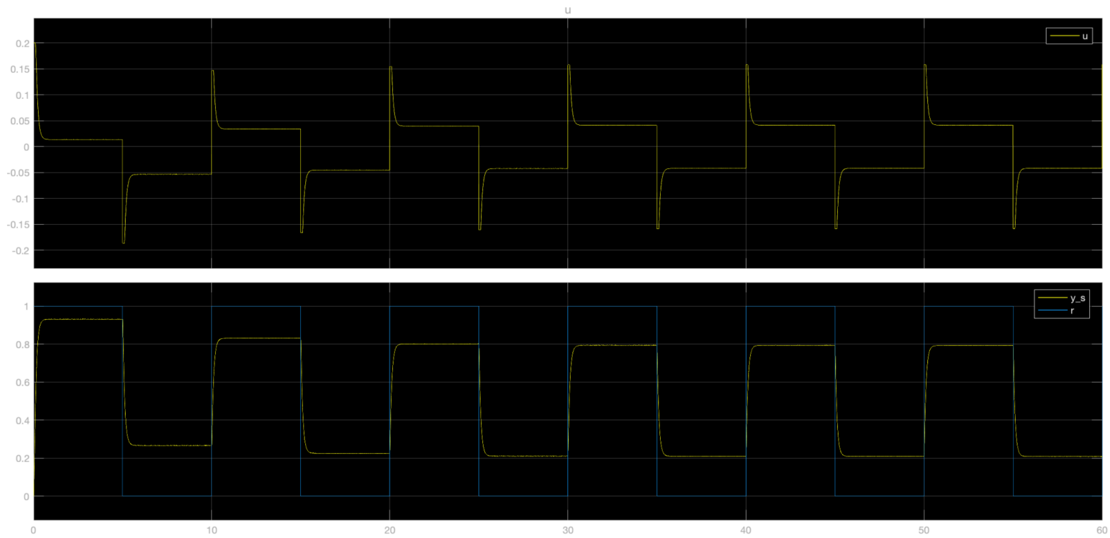

Figure 16 : delay=0.1

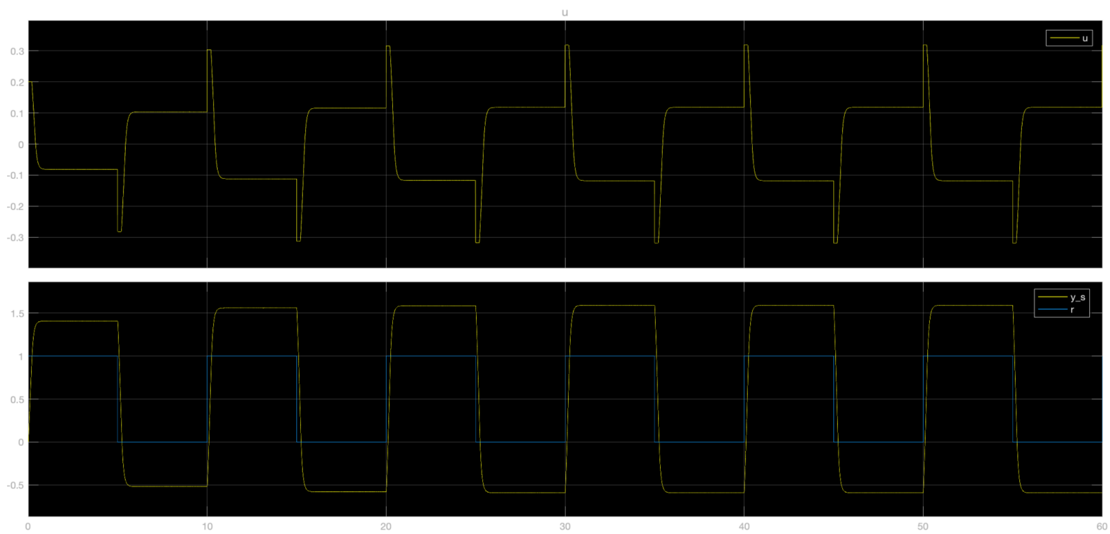

Figure 17 : delay=0.2

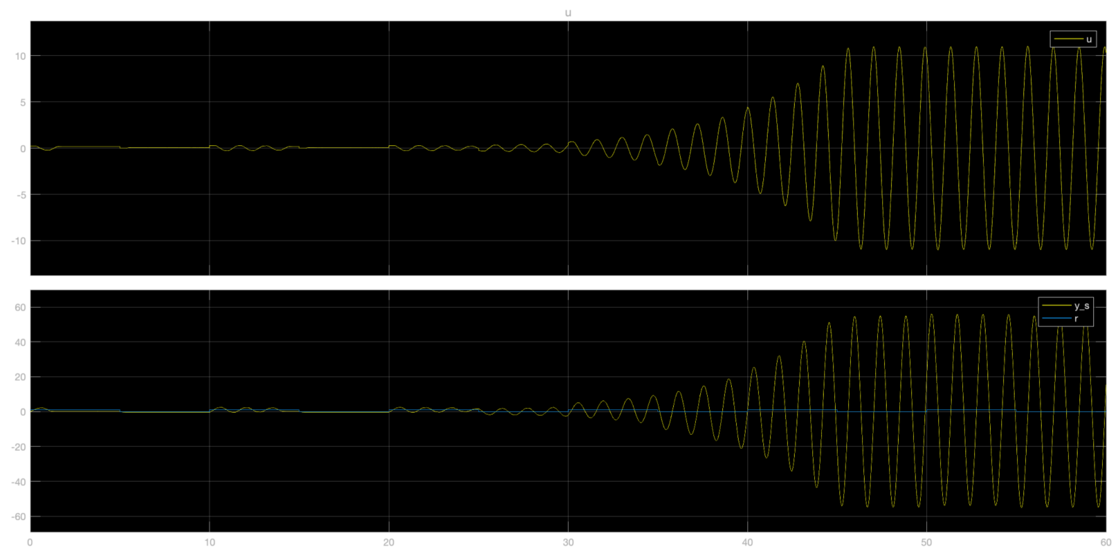

Figure 18 : delay=0.35

Q2.4:

The load moment of inertia has changed. The closed loop system is slightly changed.

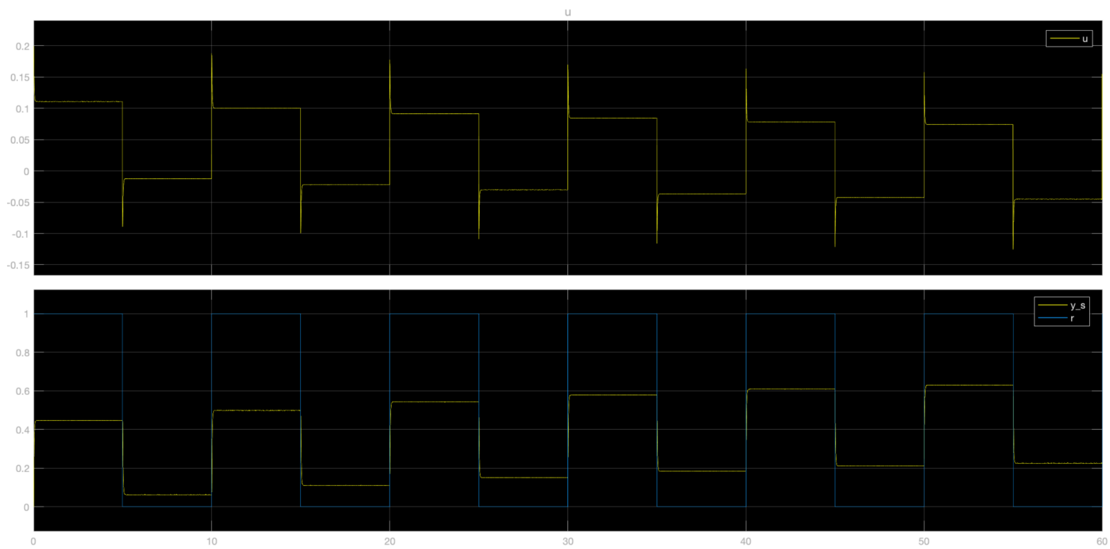

Figure 19 : no disk

Q2.5:

Digital controller has a higher overshooting.

The digital controller and the continuous controller have the same settle time.

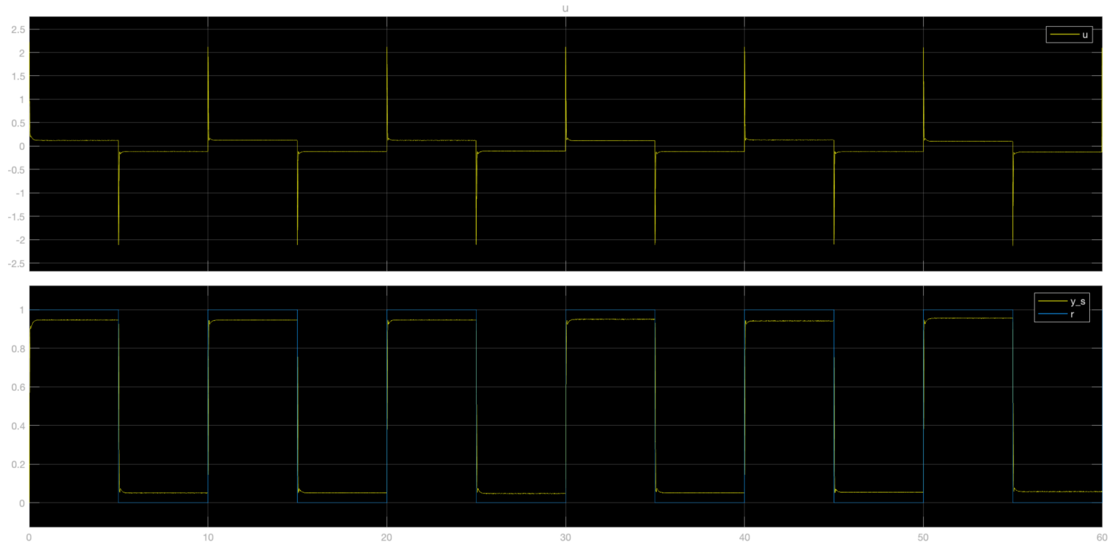

Figure 21 : continuous controller

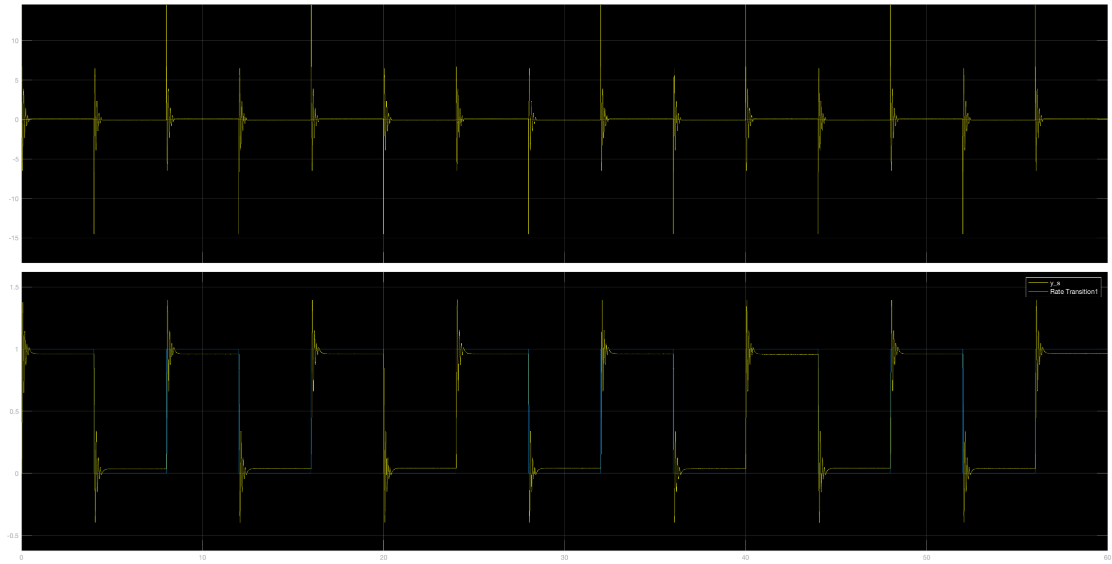

Figure 20 : digital controller

Q2.6:

The system is marginally stable

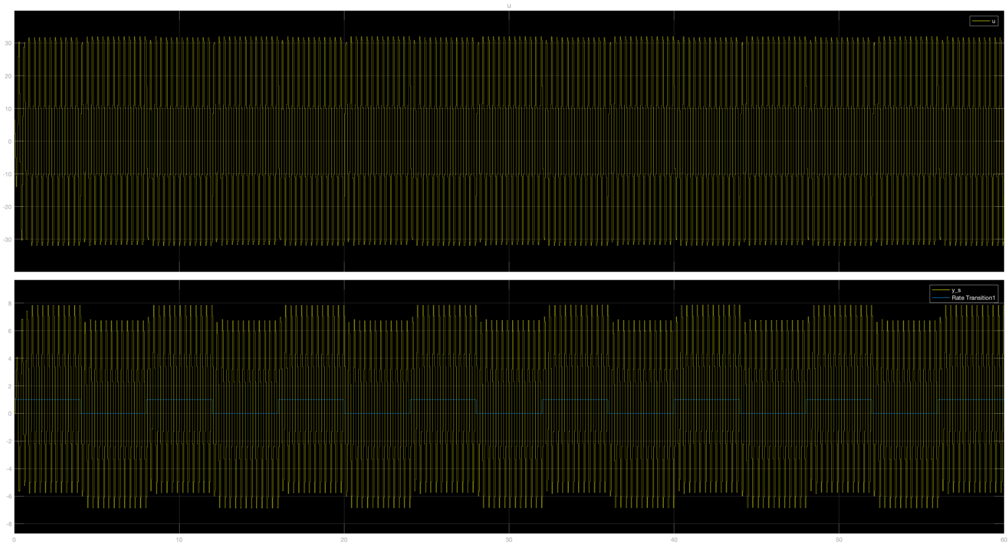

Figure 22 : T=0.04

Discussions:

Observation error will happen when choosing points from the plot, so useing MATLAB function to find the precise point would be a better solution. Rounding error is another aspect that needs to be taken care of. Since I use 'int' as data input, symbolic calculations should be used in calculations instead of intermediate numerical calculations. The influence of the physical parameters of the motor should also be noted. The number of samples are way too small, especially for in-person lab. So, it is recommended to run the same test for several round to decrease random errors.