CS 331 Lab/Homework #3: Control Systems & Signal Processing

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4.1: Marble Simulation

Q1a.) With increased marble mass, the position error takes much longer to stabilize.

Q1b.) The frequency of oscillation increases as Kp increases.

Q1c.) When Kd is increased by a small amount, the system stabilizes faster (i.e. stops oscillating sooner).

Q1d.) The position error remains constant at x = 4.

Q1e.) The position error never converges. It constantly oscillates between 4 and -4.

Q1f.) The position error quickly diverges and x→ ∞ (exponentially).

Q1g.) The position error quickly oscillates and diverges away from the set point.

Q2.) $0.2s^2 + (K_d)s + 2.5 = 0 \Rightarrow s = -K_d \pm \text{sqrt}((K_d)^2 - 2)$
Therefore, for oscillations to disappear, $K_{d\ (\text{theoretical})} \geq \text{sqrt}(2)$
This theoretical value is confirmed from the experimental K_d in this simulation.

Q3.) Eigenvalues: $-0.5 \pm 3.5i$
The system is stable because the real components of the eigenvalues are negative.
The eigenvalues do not depend on x_0. The eigenvalues do not depend on v_0.

Q4.) The marble settles at x = -3 when $x_0 = 4$, $v_0 = -7$, $K_p = 0$. It settles there because it starts at x = 4, but the initial velocity of -7 makes the final steady-state location become x = 4 + (-7) = -3.

Q5.) x(t) = c1 exp(s1*t) + c2 exp(s2*t) $m = 0.2$, $K_p = 0$, $K_d = 0.2$, $x_0 = 4$, $v_0 = -7$
$2s^2 + 0.2s = 0 \Rightarrow s = 0, -1$
x(t) = c1 + c2 exp(-t) x(0) = c1 + c2 = 4
v(t) = -c2 exp(-t) v(0) = -7 = -c2
➔ c2 = 7, c1 = -3 ➔ x(t) = -3 + 7exp(-t)
Therefore, as t→∞, x(t)→(-3). This agrees with Q4.

Q6.) $(x_0, v_0) = (4,50)$ is an initial condition that affects the system differently.

Q7.) In general, it is not a good idea to push an actuator to the point of saturation in the real world. This is because the device may have physical limitations, and breaking those limits may cause the device to malfunction or become damaged.

4.2: Water Seesaw Simulation

Q8.) [see printout]

Q9.) $K_p = 2.5$, $K_d = 0.9$ $K_i = 0.4$ [also see printout]

Q10.) Eigenvalues: -30.5112, -0.1693, -0.2847 ± 1.3234i
Based on these eigenvalues, the system is stable.

Q11a.) The error plot takes longer to reach the set point, and the oscillation frequency increases.

Q11b.) The error plot oscillates for a longer amount of time when K_d is increased.

Q11c.) The plot becomes closer to the set point when K_i is slightly increased.

Q11d.) When K_i is increased by a large amount, the error plot never stabilizes from oscillation.

Q12.) $K_p = 500$, $K_d = 100$, $K_i = 0.6$
This cannot be realistically achieved in lab, because the motors driving the pumping of water are probably not powerful enough to match those coefficients.

Q13.) Yes, it is possible that this system gets stuck near but not at the set point. However, integral control is not required to ensure that the modeled seesaw can balance perfectly. This is true because the modeled seesaw does not consider the static friction coefficient. It only considers the kinetic friction coefficient. The common purpose of integral control is to overcome the force of static friction, which is not included in the model.

Q14.) When kinetic friction is decreased, the system seems to stabilize quicker from oscillations. I believe this happens because as the poles of the system approach 0, less overshoot occurs and the system is able to reach steady-state faster.

4.3: Low Pass Filtering

Q15.) The minimum practical sampling rate is 3 * 24Hz = 72Hz.
[see printouts for plots of x,y,z]

Q16.)
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t = [0:1/72:2];
x = sin(2*2*pi*t) + sin(3*2*pi*t) + (7*2*pi*t);
y = sin(18*2*pi*t) + sin(22*2*pi*t) + (24*2*pi*t);
z = x + (5*y/7);
plot(t,z);
```
[see printout for plot of x and z_f]

Q17.) The frequency response is shifted to the right when the cutoff frequency is increased , and the response tends to drop off more sharply.

Q18a.) The filter's frequency response has a sharper drop at the cutoff frequency. As a result, the magnitudes tend to converge towards 1 or 0.

Q18b.) It smoothes out the plot of z_f, making it resemble the smoothness of the plot of x.

Q19.) The advantage of a high-order filter is that more of the noise can be cleanly filtered out while still preserving the desired signal. However, a disadvantage of a high-order filter is the time shift of the filtered signal. It requires longer processing time.

Q20.) In my opinion, I think 10Hz is a good cutoff frequency, and n=6 is a good order for the filter. By using the Butterworth filter equation, I found that 99.32% of the desired signal (x) remains, while only less than 3% of noise (y) remains. Plus, the time delay from using a 6th order filter is not too critical.

Q21.)
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[B,A] = butter(6,10/36);  zf = filter(B,A,z);
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[see printouts for plots of the frequency response, zf, x]