24-774 Lab 2 Report

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A - State Estimator Design

Question 1: Complementary filter for angle estimation

Link - https://youtu.be/vMNgp47LEPw

Alpha chosen for complementary filter is 0.98 such that the response is fast, but there is no significant drift in the estimate.

Question 2: Angular velocity estimation

The plot below shows the comparison between the pure gyro readings for angular velocity and the low pass filtered angular velocity (alpha = 0.6). While alpha was set this low so that the plots can be distinguished, on hardware, alpha is set to 0.8 to capture fast response.

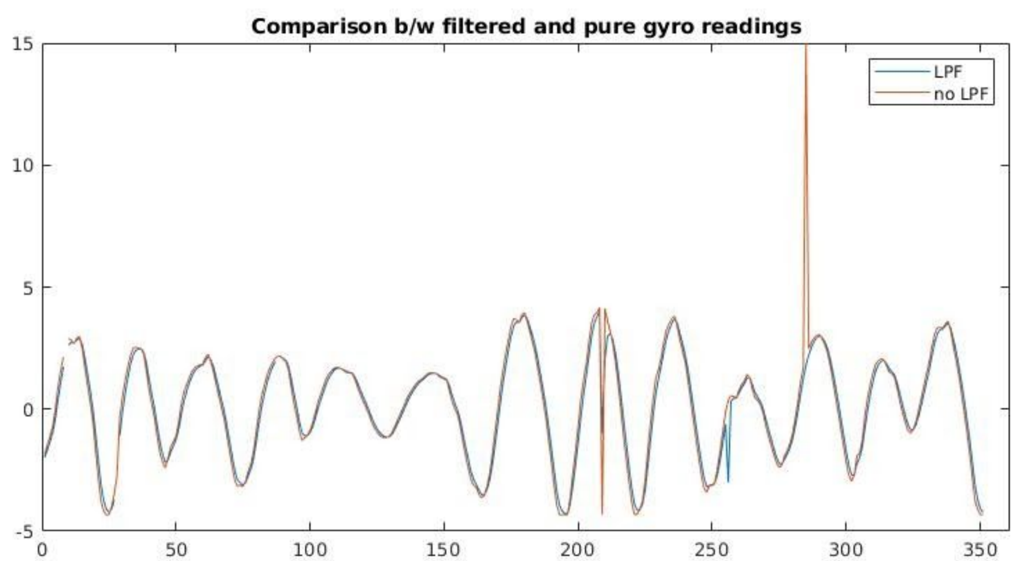

Fig: X axis = time steps with sample rate of 5 ms, Y axis = angular velocity in rad/s

Using a low pass filtered estimate can slow down the response in comparison to the pure gyro reading, but this may be worth it if the gyro reading has high frequency noise that is affecting how aggressive you can set the D gain (and thus the P gain). Additionally the LPF can also insulate against sudden spikes in the estimate due to sensing errors.

B - Control Design

Question 1: Transfer function approach

First I derived a transfer function from the state space model by setting C to output only the angle, and then using the command ss2tf(A,B,C,D). The aim behind this was to use PID tuner block in Simulink by defining a TF between voltage and output angle.

set $C = \{0, 0, 1, 0\}$, $D = 0$

Find TF using

ss2tf(A, B, C, D)

The transfer function obtained was -

```
>> tf(n,d)

ans =

    18.66 s^2 + 2.396e-19 s + 7.694e-40
  ---------------------------------------
  s^4 + 0.01683 s^3 - 224.3 s^2 - 2.787 s

Continuous-time transfer function.
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However, PID tuner failed to converge for this TF in spite of trying out various settings. So, I chose to manually tune PD gains so that the Simulink simulation gives desirable time-domain results. I settled on a set of gains for PD that worked well on both simulation and hardware: *Kp = 150, Kd = 3*

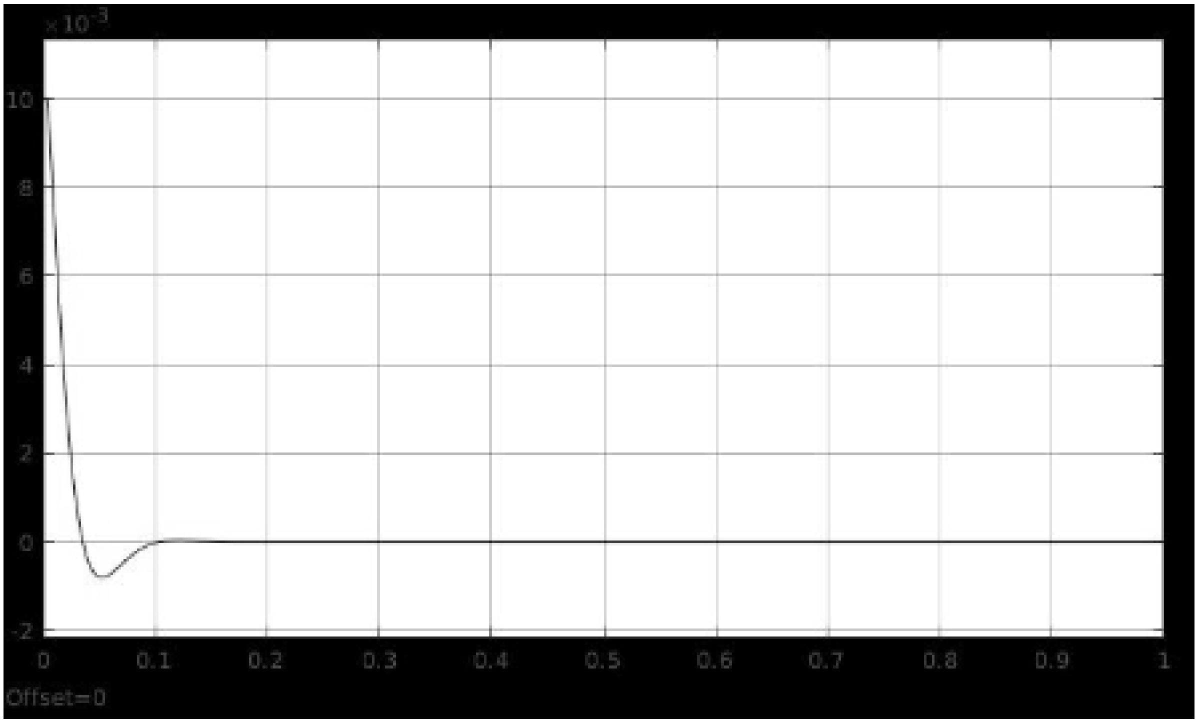
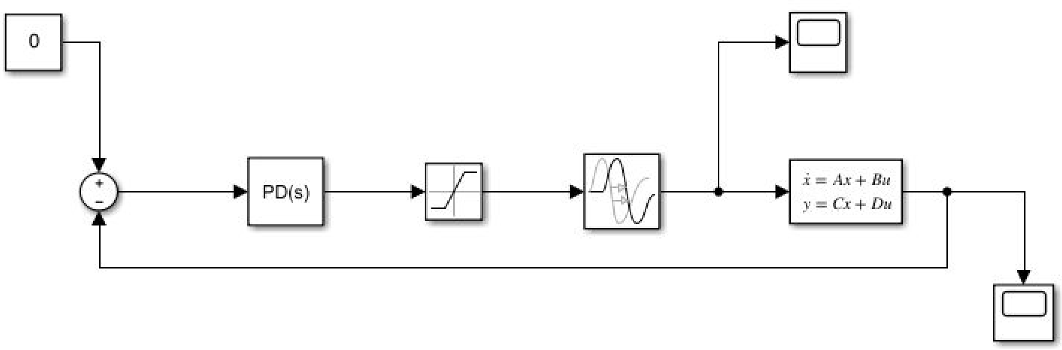


Fig: Time response for Simulink model given initial angle of 0.01 rads



Note: The output from the PD controller is in terms of voltage, which is converted to pwm by dividing by max voltage (~ 8V) and multiplying by 255.
*PWM = (PD output) * 255 / 8*

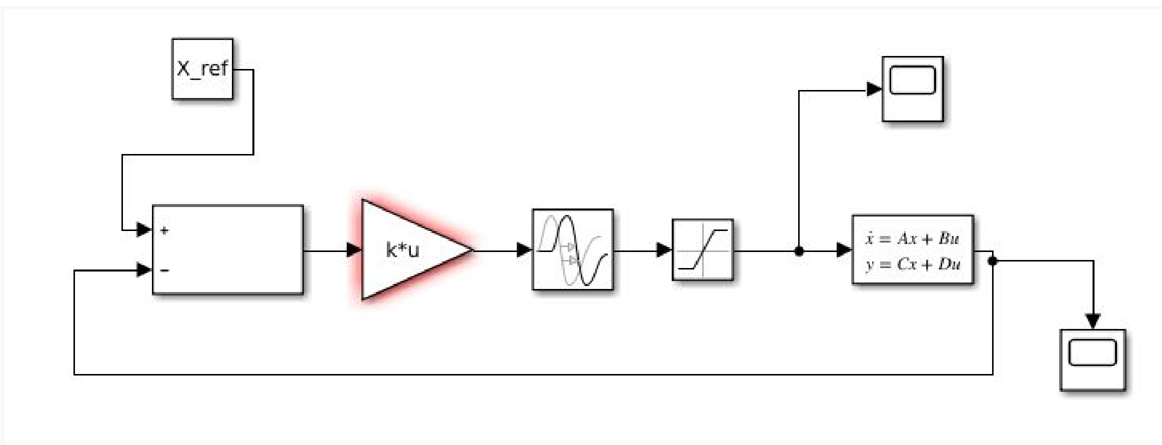
Link - https://youtu.be/RUXOv82KdJA

Question 2: CT LQR approach

The parameters chosen for LQR are -

Q = diag([0.001, 0.1, 5000, 1])
R = 0.2
K_x = 0.0707
K_xdot = 1.6866
K_theta = -171.1
K_thetadot = -4.93

For the angle complementary filter - alpha is set to 0.98; For the angular velocity LPF - alpha is set to 0.8.



Link - https://youtu.be/ZJpNiv5V1Zo

Sampling time comparison: 20 ms is the highest sampling time the controller could be reliably stable at, however there are some low-amplitude oscillations involved. It could however be coaxed to be stable up to 35 ms given the right initial conditions.

C - Conclusion

This assignment firstly was a good introduction to state estimation using rudimentary but effective filters like complementary filter and low pass filter. Complementary filters do great at filtering the low frequency noise of the gyroscope and the high frequency noise of the accelerometer to give a fast but consistent estimate.

The control design part helped familiarize me with state space design methods and how to implement a state-space controller. Other valuable lessons were learning how to do LQR tuning such that the controller can run successfully on hardware without saturating and causing jitter. Additionally, seeing how increasing the sampling time affects the response was quite interesting.