MAE 546 Assignment #4

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Due April 5, 2012

1 Steady State Throttle Settings

An expression for steady-state throttle setting as a function of speed for straight driving was derived analytically be setting $\dot{x} = 0$ in the system dynamics equations.

$$\dot{x_1} = \frac{1}{m}\left(F - C_D\frac{1}{2}\rho x_1^2 S\right) = 0$$

$$\delta\left(\frac{\gamma}{V_C + x_1}\right) - \frac{C_D\rho x_1^2 S}{2} = 0$$

$$\delta(x_1) = \frac{S}{V_m^2(V_C + V_m)}(V_C + x_1)x_1^2$$

Where: $\gamma = C_D\frac{1}{2}\rho V_{max}^2 S(V_C + V_{max})$

A plot of $\delta(x_1)$ vs x_1 is shown in Figure 1 below:

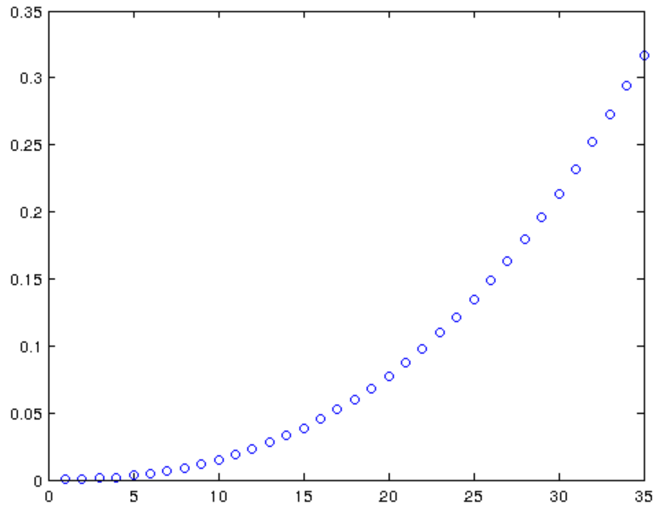

Figure 1: Steady-State Throttle Values as a Function of Speed

2 LTI Model of Dynamics and LQR Feedback

2.a Continuous LTI Model Matrices

Equations for the continuous-time LTI model matrices **F**, **G**, and **L** as a function of the steady-state operating points are shown below:

$$\mathbf{F} = \begin{bmatrix} -\left(\frac{\gamma}{V_c^2} + \frac{C_D \rho S}{m} x_1^*\right) & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ x_4^* & 0 & 0 & x_1^* \\ \frac{u_2^*}{l} & 0 & 0 & 0 \end{bmatrix}$$

$$\mathbf{G} = \begin{bmatrix} \frac{-\gamma}{V_c^2} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{x_1^*}{l} \end{bmatrix}$$

$$\mathbf{L} = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}$$

where γ is defined as in Problem 1.

2.b Continuous Linear Quadratic Regulator

The continuous-time, constant-gain LQR feedback gain matrix $\mathbf{C}$ was calculated as a function of the operating points using Matlab's *lqr* function and cost function weighting matrices

$$\mathbf{Q} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad \mathbf{R} = \begin{bmatrix} 100 & 0 \\ 0 & 100 \end{bmatrix}$$

[need to calculate and plot]

2.c Discreet-Time LTI Model Matrices

Equations for the discreet-time LTI model matrices Φ, Γ, and Λ were calculated at the steady-state operating points assuming a sampling interval $\Delta t = 0.1sec$, and are shown below:

2.d Sampled-data Linear Quadratic Regulator

3 Adaptive Cruise Control

The nonlinear system model for automobile dynamics was simulated with a Simulink model to test the performance of the sampled feedback controller developed in part 2.d.

3.a Gain-Scheduled Trajectory Following

We wish to follow a nominal straight-ahead trajectory ramping velocity from 0 to 24m/s in 10 seconds, holding that velocity for 5 seconds, and ramping down to 0m/s after another 10 seconds was provided to the system as input. Gain scheduling was applied for the control matrix $\mathbf{C}(x_1^*)$ and nominal throttle setting $u*_1(x_1^*)$, using the values of $\mathbf{C}$ determined in part 2.d for nominal speeds of 1 to 35m/s.

To define the nominal trajectory in Simulink, a signal builder block was used, shown in Figure 2 below. In order to apply gain scheduling [explain how GS applied]

Figure

3.b Non-Gain Scheduled Trajectory Following

The same nominal trajectory was used with a constant value feedback controller (no gain scheduling).

3.c Closing Distance on a School Bus

The automobile initially cruises 100m behind a school bus traveling at a constant 20 m/s. We wish to instruct the control system to close the distance to 50m in 10 seconds using feedback control, maintaining a speed of 20 m/s at the end of the period.

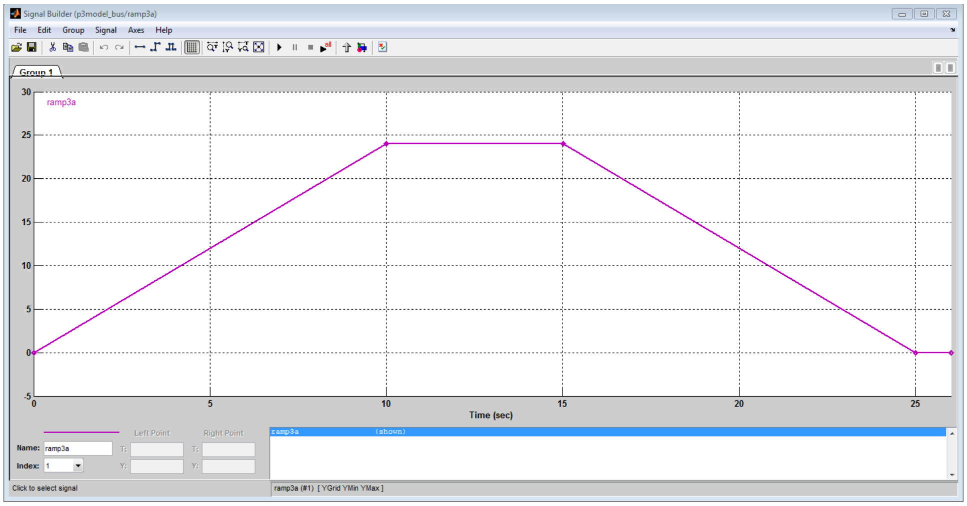

Figure 2: Nominal Trajectory in Signal Builder

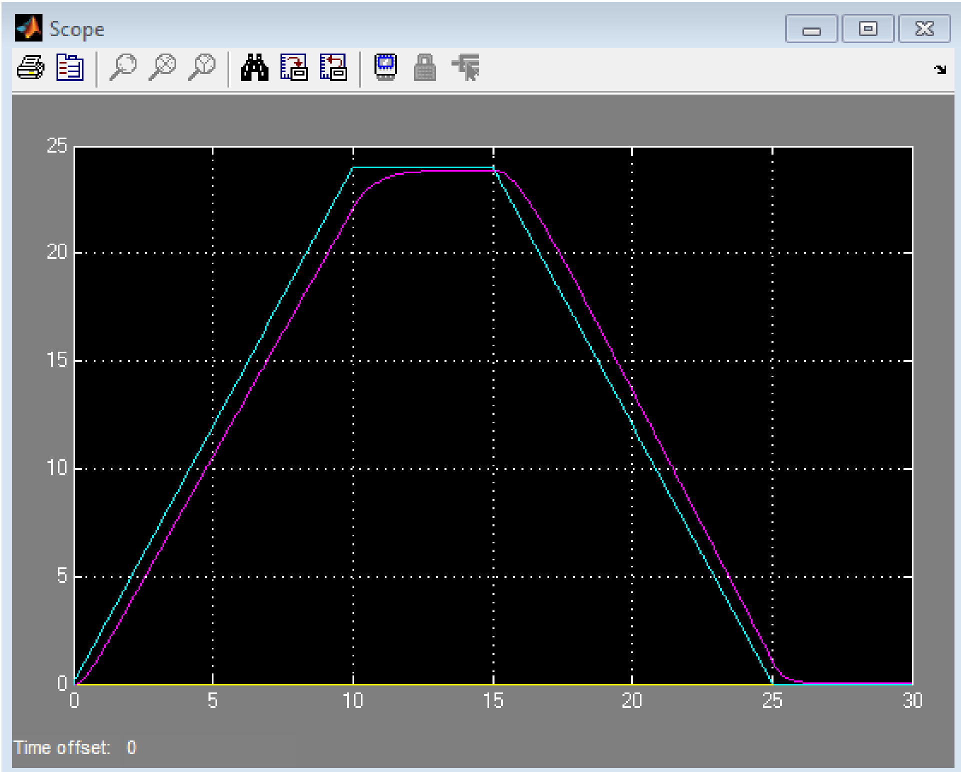

Figure 3: Ramp Trajectory Response with Gain Scheduling

To develop a simulated solution to this problem, a simple model of the school bus was built in simulink by feeding a constant velocity of 20 m/s into an integrator to produce a position output. The nominal position of the automobile was then defined relative the bus's position using a signal builder block, and fed to the control system as input.

3.d Maintaining Distance Behind a School Bus