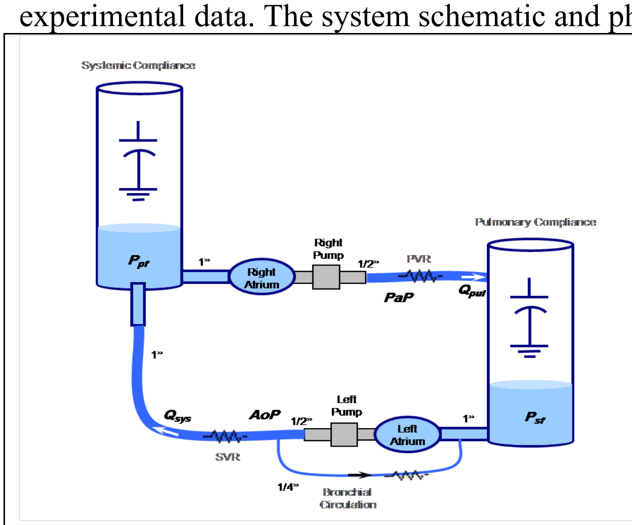
Robust Multivariable Control
MECE 7362/5397
Final Project

Out: November 22, 2018
Due: December 6, 2018 at NOON

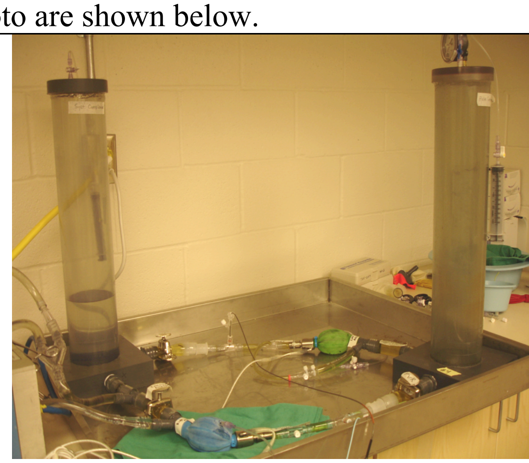
General Instructions: Please review the syllabus concerning the details associated with project format, expectations and submission. Project assignments are to be an individual effort. ***Submit all m-files in electronic form to the TAs.*** Due to grading deadlines, no late assignments will be accepted unless you have experienced a significant event. You must seek my permission prior to December 5th and official documentation will be needed.

IMPORTANT: Once you have completed Problems 1 and 2, present your results in a technical document/format having the quality worthy of submission to a technical journal. You must submit the document in Word form and *NOT* as a pdf. Cite the journal or conference proceeding that you used to format your report. Your report must have a project title, author, abstract, problem description, main results (screen captures, how you designed your controllers, crossover frequencies, transient closed loop responses, and any other additional information you care to provide for both Problems 1 and 2), discussion (comparison between of the results Problem 1 and 2) and conclusions.

System Description:
Your project is the robust multivariable control of a continuous flow (CF) total artificial heart (CFTAH) embedded within a mock circulatory system (MCS). This is a real system that led to preclinical studies at the Texas Heart Institute. The control objective is to emulate the native heart by robustly regulating blood flow in the presence physiological changes due to vascular dynamics, blood property changes and CF pump degradation. The model structures (the number of poles and zeros in each element of the plant transfer function matrix) were identified via physics and the coefficients were estimated from experimental data. The system schematic and photo are shown below.



Schematic of the Mock Loop



Picture of the Actual Mock Loop

The left axial pump supplies oxygenated blood to the *systemic* circulatory system through the aorta and the right pump takes the deoxygenated blood to the lungs (*pulmonary* system). The *diagonally-dominate* linearized model for the system is

$$\begin{bmatrix} \delta Q_{sys} \\ \delta Q_{pul} \end{bmatrix}(s) = \begin{bmatrix} 0.76\dfrac{\left(\dfrac{s}{0.31}+1\right)}{\left(\dfrac{s}{0.42}+1\right)\left(\dfrac{s}{3.23}+1\right)} & 0.53\dfrac{1}{\left(\dfrac{s}{0.42}+1\right)\left(\dfrac{s}{2.64}+1\right)} \\ 0.66\dfrac{1}{\left(\dfrac{s}{0.42}+1\right)\left(\dfrac{s}{2.93}+1\right)} & 0.66\dfrac{\left(\dfrac{s}{0.20}+1\right)}{\left(\dfrac{s}{0.42}+1\right)\left(\dfrac{s}{3.19}+1\right)} \end{bmatrix} \begin{bmatrix} \delta V_L(s) \\ \delta V_R(s) \end{bmatrix}$$

where the outputs, perturbations in flow ($\delta Q_{sys}(s)$ and $\delta Q_{pul}(s)$), have units of liters/minute and the inputs, perturbation in pump input motor voltages ($\delta V_L(s)$ and $\delta V_R(s)$), have units of volts.

Problem 1: (500 pts)
Design a diagonal integral multivariable controller by treating the MIMO system as TWO independent SISO systems by ignoring the loop interactions. That is, let

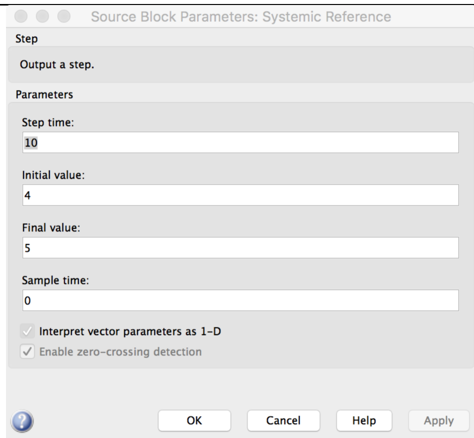
$$L_1(s) = g_{11}(s)P_{11}(s) = g_{11}(s)*0.76\frac{\left(\dfrac{s}{0.31}+1\right)}{\left(\dfrac{s}{0.42}+1\right)\left(\dfrac{s}{3.23}+1\right)},$$

$$L_2(s) = g_{22}(s)P_{22}(s) = g_{22}(s)*0.66\frac{\left(\dfrac{s}{0.2}+1\right)}{\left(\dfrac{s}{0.42}+1\right)\left(\dfrac{s}{3.19}+1\right)},$$

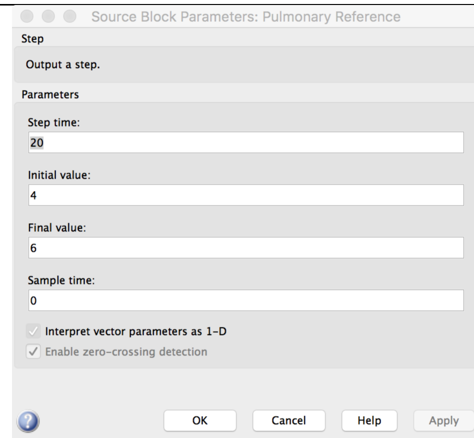
where the feedback controller is

$$G(s) = \begin{bmatrix} \dfrac{K_1}{s} & 0 \\ 0 & \dfrac{K_2}{s} \end{bmatrix}$$

Design your controllers using the Nichols chart to achieve a crossover frequency around 2 rad/sec. Be very detailed as to how you got your design including screen captures. Implement your controller within the Simulink environment (included screen captures) using the following step inputs (see next page). **Compare the transient responses of the two loops.**



Systemic Loop



Pulmonary Loop

<u>Problem 2:</u> (800 pts)

Design a diagonal multivariable controller ***in-series*** with a static decoupling controller for the same system. Identify your decoupling controller using the DC gain of the MIMO plant model. Give the details on the precompensator calculation and the final precompensator matrix. Design your controllers using the Nichols chart to achieve a crossover frequency around 2 rad/sec. Be very complete as to how you got your two designs including screen captures. Implement your controller within the Simulink environment (included screen captures) and perform the same simulations as required in Problem 1. Compare the transient response of the two loops.

<u>Problem 3:</u> (800 pts)

Design a diagonal multivariable controller ***in-series*** with a dynamically decoupling controller for the same system. Identify your decoupling controller for the MIMO plant model. Give the details on the precompensator calculation and the final precompensator matrix. Design your controllers using the Nichols chart to achieve a crossover frequency around 2 rad/sec. Be very complete as to how you got your two designs including screen captures. Implement your controller within the Simulink environment (included screen captures) and perform the same simulations as required in Problem 1. Compare the transient response of the two loops.

<u>Reference:</u> Here are my transient closed loop responses.