Ryerson University

Department of Electrical, Computer and Biomedical Engineering

BME639: CONTROL SYSTEMS BIOROBOTICS

Lab Project 1

Introduction to Simulink, Closed-Loop Control vs. Open-Loop Control, Transient Response and Stability

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Introduction and Objectives

There are three Labs in this class and each Lab has to be completed in pair. Make sure to find a Lab partner and inform your Lab instructor about it at the beginning of this Lab. Also, make sure to check the Lab due date based on your group.

Each lab requires four weeks and the tasks for Part one (two weeks) and Part two (two weeks) are provided explicitly. The Lab project is required to provide complete answer to the questions. Note that formatting has 10% of the Lab grades and, 15% of each of your Lab grades is on your summary of the Lab which has to be provided individually. Your summary has to explain clearly what you have learned in the Lab.

Before submitting the report the TA asks questions about your report. If there is no consistency between your oral answer and the report, you will lose %50 of your total mark.

In the first part of this project, you will start working with Simulink in MATLAB and use it to represent LTI systems and explore step responses of a first order systems. You will also study the closed-loop and open-loop control methods and compare them in terms of accuracy and robustness.

In the second part, you compare the step response of first order systems with higher order systems. You will also study the proportional control of the second order and third order systems and compare the time domain specifications and stability of the systems.

Part One (two weeks)

A. Introduction to Simulink

A.1:[**1 Mark**] Type `simulink` in the MATLAB command and open a new model file. Use the Simulink library (`Sources`) to generate a sine wave with frequency of 0.2Hz. Use the Simulink library (`Continuous`) to generate derivative and integral of the sine wave. Use the multiplexer (`Mux`) block to form a vector signal so that the scope block displays the signal and its integral simultaneously. Provide a print of your Simulink model.

A.2:[**1 Mark**] Run the simulation for 20 seconds. Save the sine wave, its integral and derivative in the MATLAB workspace by using `simout` block in Simulink library (Sinks). The `simout` is used after a multiplexer. The output in `simout` has to be saved with an `array` format. The saved data is a matrix with three columns. Plot the columns separately using `subplot` in MATLAB and explain your results. Provide a print of your Simulink model.

A.3:[**1 Mark**] Repeat part A.1 and A.2 with a pulse signal instead of the sine wave with the same frequency of 0.2Hz and pulse width of %50. Provide a print of your Simulink model.

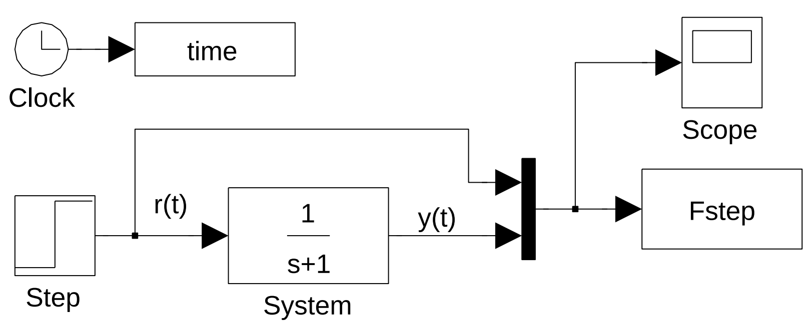
A.4:[**3 Marks**] In Simulink, use the `Transfer Function` block to generate the following four systems:

$$\frac{0.5}{s+0.5}, \quad \frac{s+1}{0.1s+1}, \quad \frac{s+3}{s+0.3}, \quad \frac{1}{s-1}$$

Plot input and output of all these systems to the unit step by using `subplot` in MATLAB (Run the simulation for 20 seconds). Find the poles and zeros of the each system. Compare the outputs with each other and with the input. Which one is an unstable system? Explain your response. Provide a print of your Simulink model.

B. Time Response of First-Order Systems

B.1:[**5 Marks**] Generate the following first order system in Simulink. Plot input and the unit step response of the system. Find DC gain (k) and time constant (τ) of the system using step response (Run the simulation for 10 seconds). Compare the results with theoretical values. Provide a print of your Simulink model.



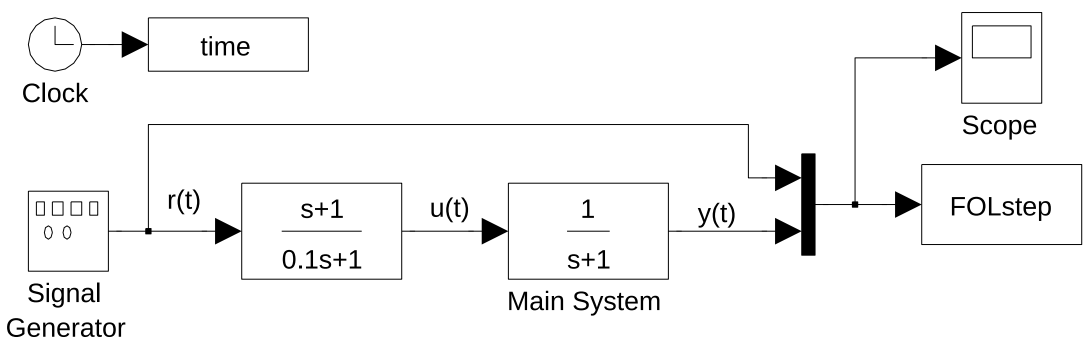
B.2:[**3 Marks**] Obtain mathematical expression for output of a typical first order system to unit step as a function of time,

$$\frac{k}{\tau s + 1}$$

Explain if by changing the pole location on the real axis could you see any oscillations in the unit step output.

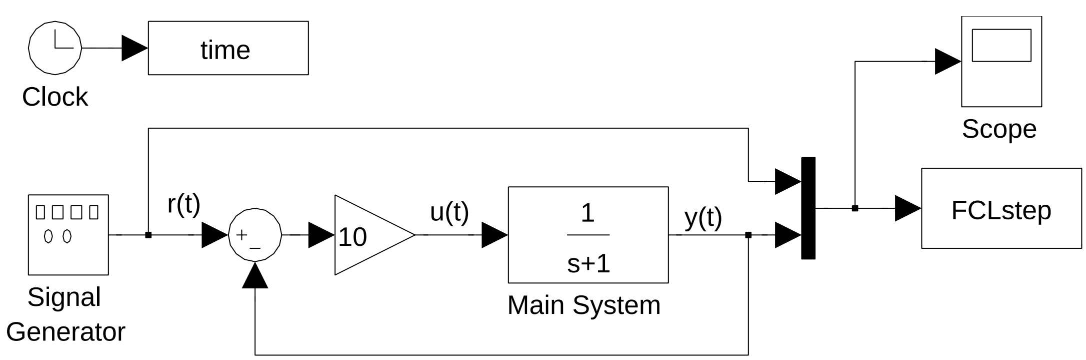
C. Closed-Loop Control vs. Open-Loop Control

C.1:[**2.5 Marks**] Consider the system in Part B.1. We can use the following structure in order to increase the speed of the system 10 times faster than the original system. We call it *Open-loop approach*. Generate the system in Simulink,



Generate a square wave signal with amplitude one and frequency 0.5Hz. Plot reference input and output of the system (Run the simulation for 3 seconds). Find the transfer function $\frac{Y(s)}{R(s)}$ of the system, then calculate the time constant (τ) and steady-state error (e_{ss}). Provide a print of your Simulink model.

C.2:[**2.5 Marks**] Another method to increase speed of the system is using gain and feedback that is called *Closed-loop approach*. Generate the following system in the same Simulink model file in Part C.1,



Generate a square wave signal with amplitude one and frequency 0.5Hz. Plot reference input and the square wave response of the system (Run the simulation for 3 seconds). Find the transfer function $\frac{Y(s)}{R(s)}$ of the system, then calculate the time constant (τ) and steady-state error (e_{ss}). Provide a print of your Simulink model.

C.3:[1 Mark] Compare the results of open-loop approach in Part C.1 with the closed-loop approach in Part C.2.

	Time constant (τ)	Steady-state error (e_{ss})
Open-loop Approach		
Closed-loop Approach		

Which method could increase the speed exactly 10 times? Explain which method is more accurate in terms of steady-state error?

C.4:[3 Marks] Plot the control signal $u(t)$ for both approaches using `subplot` in MATLAB and compare them.

C.5:[10 Marks] In order to test the sensitivity of the both approaches to variation of parameters of the system, change the main system first to $\frac{1}{s+0.5}$, then to $\frac{0.5}{s+1}$ in the both approaches. Plot reference input and output of the square wave response for each systems. Compare the results with the response of the original system in Part C.1 and C.2. Provide a print of your Simulink model. (Hint: You may require to re-tune the input signal frequency to plot the complete response of the system.)

Find the transfer function of $\frac{Y(s)}{R(s)}$ for each system, then calculate and compare the time constant (τ) and steady-state error (e_{ss}).

Main System $\frac{1}{s+0.5}$	$\frac{Y(s)}{R(s)}$	Time constant (τ)	Steady-state error (e_{ss})
Open-loop Approach			
Closed-loop Approach			

Main System $\frac{0.5}{s+1}$	$\frac{Y(s)}{R(s)}$	Time constant (τ)	Steady-state error (e_{ss})
Open-loop Approach			
Closed-loop Approach			

C.6:[**2 Marks**] Which method is more robust to the variation of pole, closed-loop approach or open-loop approach? Which one is more robust to the variation of gain, closed-loop approach or open-loop approach? Why? Explain your answer.

Part Two (two weeks)

A. Introduction to High-Order Systems

A.1:[**2 Marks**] In Simulink, generate the following three systems,

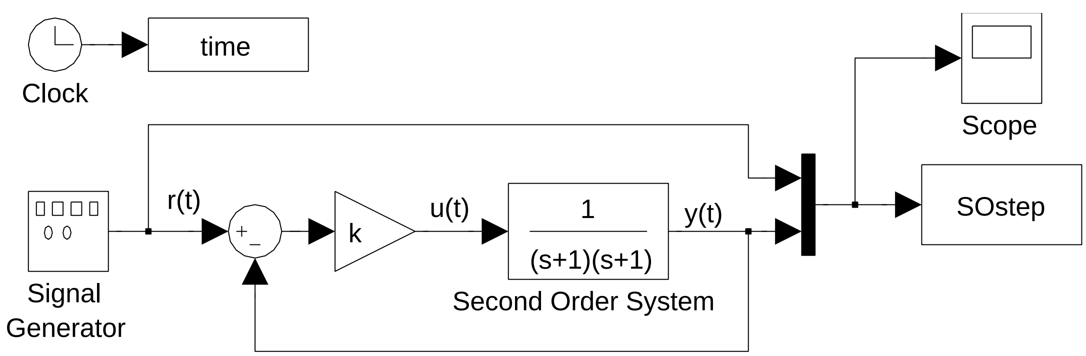
$$\frac{1}{s+1}, \quad \frac{1}{(s+1)^2}, \quad \frac{1}{(s+1)^3}$$

Generate a square wave with amplitude one and frequency 0.05Hz. Plot the input and output of all these open-loop systems to the square wave in a same scope (Run the simulation for 30 seconds). Provide a print of your Simulink Model.

A.2:[**2 Marks**] Compare the outputs with each other and with the input. Explain what is the main difference between step response of a first order system and higher order systems.

B. Time Response of Second-Order Systems

B.1:[**3.5 Marks**] Generate the following closed-loop system in Simulink,



Generate a square wave with amplitude one and frequency 0.05Hz. Plot reference input and output of the system to square wave signal for $k = 2, 5, 10$, separately (Run the simulation for 50 seconds). Provide a print of your Simulink model.

B.2:[**4 Marks**] Find closed-loop transfer function for each three systems, $\frac{Y(s)}{R(s)}$, and their poles and zeros by using MATLAB function `roots`.

B.3:[**7.5 Marks**] Find the natural frequency (ω_n) and damping factor (ζ) for each closed-loop system. Calculate the time domain specifications of the output, rise time (t_r), percentage of maximum overshoot ($\%O.S.$), settling time (t_s) and steady-state error (e_{ss}).

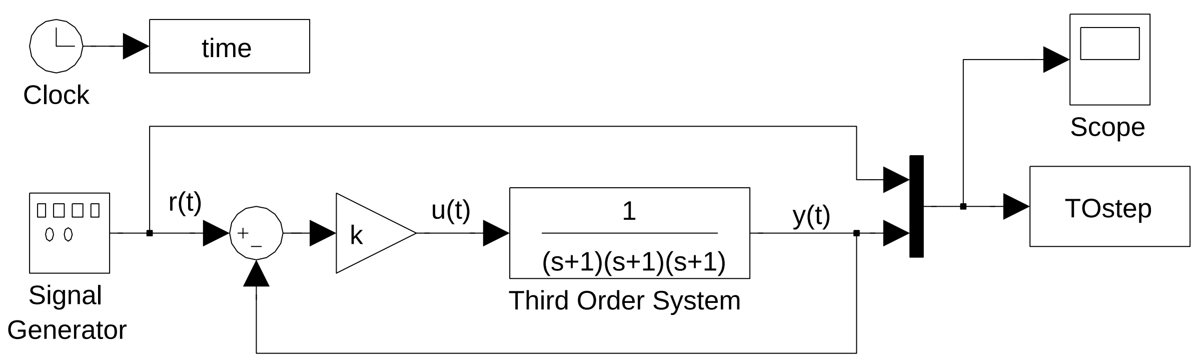
	Natural frequency (ω_n)	Damping factor (ζ)	Rise time (t_r)	% Max. overshoot ($\%O.S.$)	Settling time (t_s)	Steady-state error (e_{ss})
K = 2						
K = 5						
K = 10						

B.4:[**2 Marks**] Explain the relation between the variation of proportional gain k and the time domain specifications.

B.5:[**2 Mark**] Explain if there is a limitation for increasing the gain k in terms of stability.

C. Time Response of Third-Order Systems

C.1:[**3.5 Marks**] Generate the following closed-loop system in Simulink,



Generate a square wave with amplitude one and frequency 0.01Hz. Plot reference input and output of the system to square wave signal for $k = 2, 5, 10$, separately (Run the simulation for 150 seconds). Provide a print of your Simulink model.

C.2:[**5 Marks**] Find closed-loop transfer function for each three systems, $\frac{Y(s)}{R(s)}$, and their poles and zeros by using MATLAB function `roots`.

C.3:[**5.5 Marks**] Find the time domain specifications of the output, rise time (t_r), percentage of maximum overshoot ($\%O.S.$), settling time (t_s), steady state error (e_{ss})) using the the `tf` and `stepplot` functions in MATLAB.

	Rise time (t_r)	% Max. overshoot ($\%O.S.$)	Settling time (t_s)	Steady-state error (e_{ss})
K = 2				
K = 5				
K = 10				

C.4:[3 Marks] Explain if there is a limitation for increasing the gain k in terms of stability. Find marginal stability gain (k_{crt}), by using Routh-Hurwitz approach. Plot the reference input and output of the closed-loop system for $k = k_{crt}$.