Prelaboratory Exercise 3

Objectives

In this Prelab, you will familiarize yourself with unity feedback closed-loop systems as well as P, PI, and PID controllers.

Assignment 1

Read *Modern Control Engineering* – Ogata 5th ed. pages 24-25 and 123-129 for a basic understanding of a hydraulic servo valve's inner workings. Note: The valves themselves can have proportional and integral action. This "mechanical control system" can surprise the unwary engineer.

Assignment 2

Read this entire Prelab.

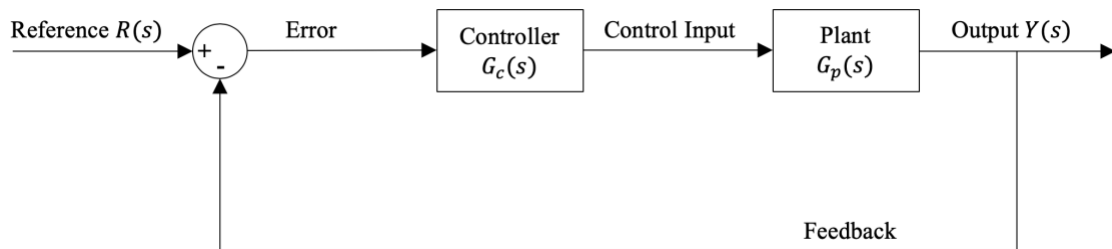### Unity Feedback Closed-Loop Systems, Theoretical Overview:

Figure 1: Theoretical Unity Feedback System

Consider the closed-loop system in Figure 1. The transfer function $H(s)$ for the system can be written using basic block diagram algebra.

$$H(s) = \frac{Y(s)}{R(s)} = \frac{G_c(s)G_p(s)}{1 + G_c(s)G_p(s)} \tag{1}$$

The mathematics of the system allow the engineer to determine the closed-loop response in terms of the controller and plant dynamics. Thus, the engineer can modify the controller such that a desirable response is achieved. These calculations are the basis for classical control. However, for an intuitive understanding of what is going of physically, one must look more closely at each block and connection.

The output $Y(s)$ of most systems will have some unit of measure. This could be position in meters, velocity in meters per second, flow rate in cm^3/s, or temperature in Celsius. The reference may vary in time. The output will likely be measured by some sensor. Typical measurement devices include variable resistors, speedometers, flow meters, and thermocouples. In Figure 1, the measurement takes place at a pick-off point – a gross oversimplification!

Controlling the system entails applying an input to direct the system output $Y(s)$ towards some desired reference $R(s)$. A controllable system must also have an actuator of some sort. For example, in a conventional oven, the actuator may be the valve that opens a gas burner to change the temperature inside. In modern control systems, these actuators typically receive electronic instructions. For example, a small voltage or current can drive a servo motor that opens the valve letting in more gas to the burner. Actuators may also receive mechanical instructions, but either way, these instructions are known as control inputs. In this lab we focus on electro-hydraulic or electro-mechanical actuators and electronic control inputs.

In a closed-loop system, the control input is based on the output error. This error is the difference between the measured output $Y(s)$ by the sensor and the desired reference $R(s)$ determined by the engineer. The error signal is typically not directly used as the control input but rather scaled by the controller's transfer function. With a properly designed controller, the system output $Y(s)$ can be made to match the reference $R(s)$. The field of control engineering is mainly concerned with designing these controllers.

Unity Feedback Closed-Loop Systems, Physical Implementation:

Implementing closed-loop control on a physical system requires careful consideration. We will specifically consider the systems in the Parker Motion and Control Lab. However, the same considerations apply to most electrically controlled feedback systems.

In Figure 2 we see a block diagram of a physical control system. The additions from Figure 1 to Figure 2 are necessary to account for the real-word signal conversions taking place in order for the system to communicate with a PC. The left half of the block diagram takes place entirely on the PC through Simulink. The D/A and A/D blocks stand for Digital to Analog Conversion and Analog to Digital Conversion. This interfaces the PC's digital signals with the real-world's analog signals. For a more detailed explanation on D/A and A/D, see *The Art of Electronics* - Horowitz and Hill, pp. 612.
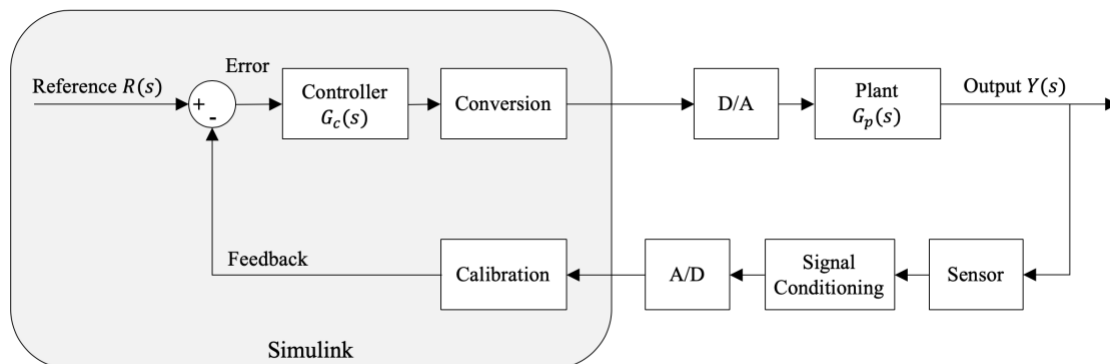

Figure 2: Physical Unity Feedback System

A sensor typically does not send an electrical signal in units of the quantity being measuring, i.e. a thermocouple does not transmit an electrical signal in units of Celsius but rather a voltage proportional to the temperature in Celsius. Similarly, for a tachometer, a digital frequency signal is transmitted which is proportional to the motor's speed. For electrical signals to be received and read by the PC (Simulink), all incoming signals must be converted to a DC voltage in the range of -5 to +5 Volts. This is the job of the signal conditioner, i.e. the big blue electrical box called the MW2000.

After a signal is conditioned into an analog voltage within range, it must further be converted to a digital signal.

Simulink can now read in the digital signal, but this is still in units of Volts. So, calibration must take place inside of Simulink to convert the voltage reading into the correct physical units the sensor originally measured. In this lab, all sensor voltage readings are linear with respect to their measurement quantity. Therefore, there is a single scaling parameter that will convert the voltage reading into the appropriate units (often provided with the sensor's datasheet). If the scaling parameter is not known, the sensor will have to be calibrated to determine the correct scaling parameter.

In the feed-forward loop after the Controller $G_c(s)$ there is another conversion to translate the physical units into a voltage quantity suitable for the actuator. The selection of this scaling parameter is heuristic and will not be discussed here. This gain may be included within the controller but not in this lab. Finally, the actuating signal generated by the controller $G_c(s)$ is converted to a real-world signal by the D/A block and sent to the actuator.

Proportional, PI, and PID Control:

Read *Modern Control Engineering* Ch. 8 for an overview of these three types of controllers. The control input of a proportional-only controller is simply the error signal multiplied by a gain. This is the simplest controller and has limited value. However, it is important to understand the effects of proportional-only control as it is used in conjunction with integral and derivative control (PI and PID).

PI control is the sum of the error signal multiplied by the proportional gain and the integrated error signal multiplied by the integral gain. The PI controller transfer function is shown below.

$$H_{c(PI)} = K_p + \frac{K_i}{s} \tag{2}$$

The effects of PI control will be discussed during lab. A PID controller's transfer function appears in (3).

$$H_{c(PID)} = K_p + \frac{K_i}{s} + K_d s \tag{3}$$

It is identical to PI control, except for the additional term – the proportional derivative. The effects of the full PID control will be discussed in lab.