School of Electrical and Information Engineering
University of the Witwatersrand, Johannesburg
ELEN3016 Control I

Control Laboratory

System Identification and Controller Design

Contents

1 Preamble

This laboratory is computer-based and is to be conducted in groups of two in your own time. On the official timetable laboratory time is allocated for the sake of allocating time to consult the laboratory assistants if advice or direction is required. The persons who are assigned to Control I to act as assistants/demonstrators are listed on the last page of this document. Lab assistants may be contacted when assistance is needed.

Any of the software Matlab, Scilab, Octave or FreeMat may be used for conducting numerical experiments.

A closing date for submitting a report on your results and findings will be announced in class. One report per group has to be submitted. Reports must comply with School for Electrical and Information Engineering’s guidelines. After submission of these reports it is up to the discretion of the laboratory assistants and the course lecturer to decide whether, in addition to marking these reports, specific individuals or groups need to be interviewed about the laboratory experiment or not.

2 Purpose

The purpose of this laboratory experiment is to introduce the concept of system identification. System identification refers to the process of deriving an analytical system model from input-output measurements of the unknown system. Once system identification has been completed successfully the inferred analytical model can then be used to design a controller for the system so that the closed-loop system satisfies the required closed-loop performance criteria. The system which has to be controlled is often referred to as the plant.

3 Objectives

On completion the student should be able to:

- Understand what system identification is.
- Use any method of system identification for deriving an analytical model for an unknown plant.
- Derive the model for the given plant or system.
- Design a controller using the derived analytical model of the unknown system.
- Determine the overall transfer function of the closed-loop system, including both the controller and the system to be controlled.
- Generate and plot poles and zeros of the transfer function.

4 References

4.1 Review topics

- Transfer functions of continuous-time feedback systems
- Continuous-time response of first-order and second-order systems
- Poles, zeros, and characteristic roots

4.2 Exploratory topics

- Feedback control concepts
- Classical continuous-time and digital controllers and design

5 Overview

Various systems require the use of feedback controls based on the concept of measuring certain variables of the plant and then adjusting the actuator to bring about a desired state in the plant. In industry a typical apparatus that requires control is an electrical motor which is usually used as an actuator. The setup for this lab concerns an X ray scanner (Figure 1) which, from a modeling point of view, is very complex and effectively unknown. Even if a model would be available, the parameters from one X ray scanner to the next will differ significantly due to component tolerances thereby rendering the available model useless. In such cases system identification is the only way to obtain a representative model for the system being considered. With an analytical model obtained by means of system identification one can now proceed to develop a controller using this model as the target as opposed to the actual system. Once a controller is designed the controller is then used to control the actual system. It might be necessary to adjust the controller slightly to obtain the best results for the actual system and controller in closed-loop configuration.

6 Background

6.1 X ray scanner

The setup for this lab concerns an X ray scanner (Figure 1). A voltage controlled high-tension power supply unit drives the X ray generator.

The X rays power control set-point (ranging between 0.5 V and 5.5 V) coming from the controlling computer is converted from digital to analogue after which it is amplified by the high-tension power supply unit to a high voltage (ranging between 600 V and 1 050 V) which then drives the X ray generator. The rotating scintillator produces pulses which are converted to a voltage pulse train by the photo-multiplying tube. The amplitude of each voltage pulse is proportional to the X ray power radiated at those time instants. To remove spurious noise this voltage pulse train is low-pass filtered, converted from analogue to digital after which a peak detector algorithm (in the computer) estimates the peak value of each pulse.

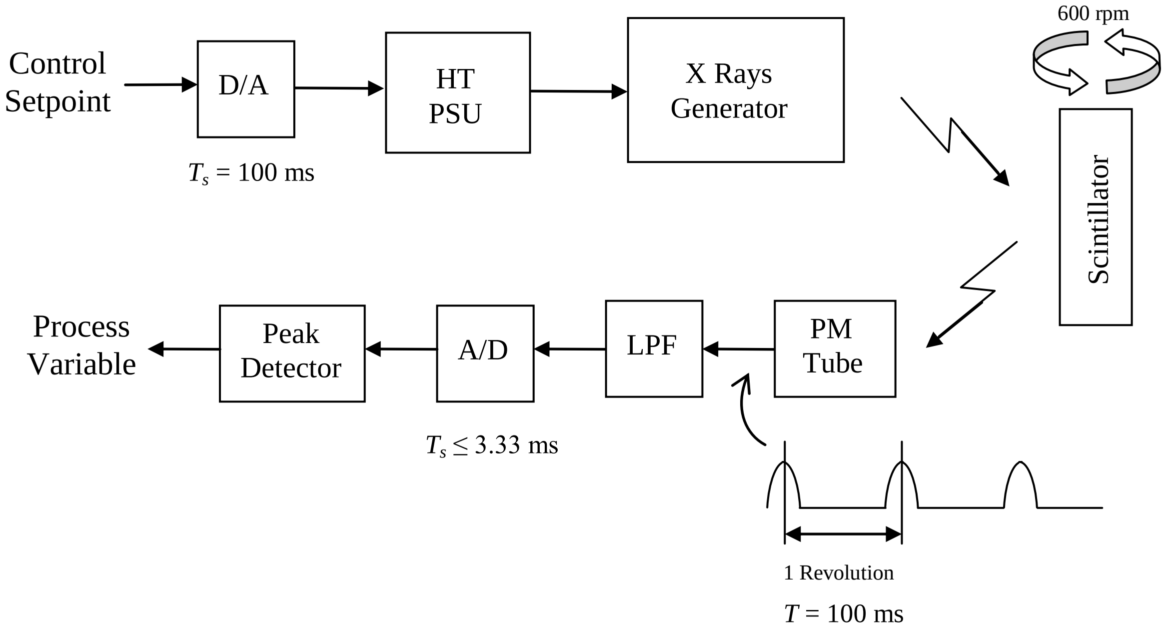

Figure 1. X ray scanner system block diagram.

The output of the peak detector is assumed to be calibrated such that the process variable equals the control set-point (Figure 2). Note that the sample rates of the A/D and D/A differ.

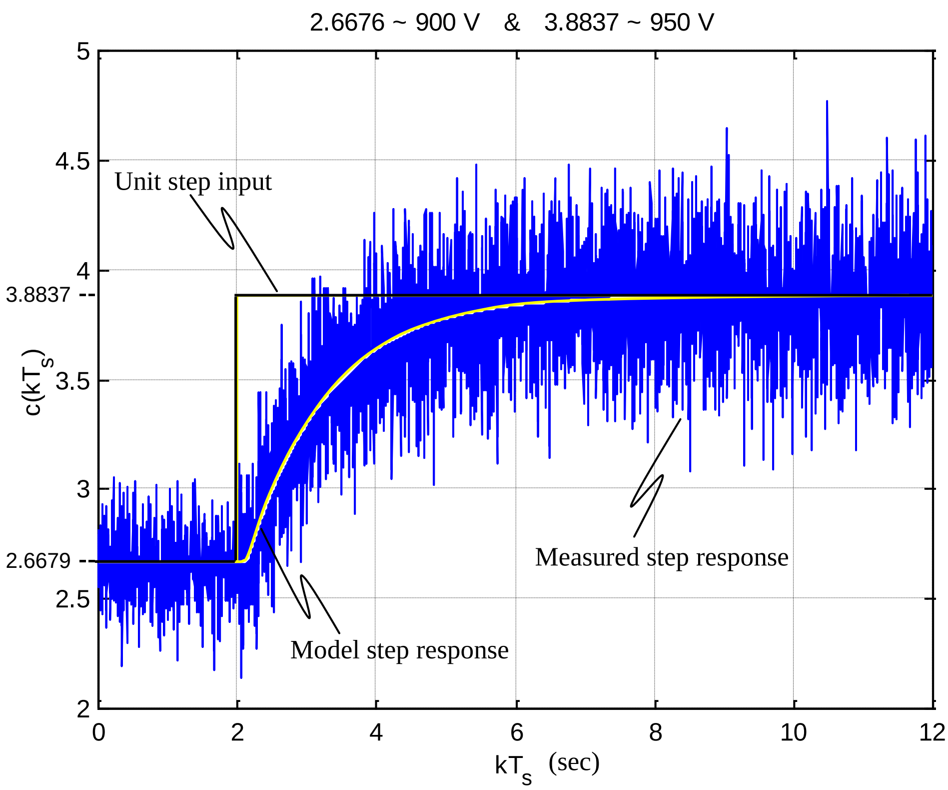

Figure 2. Measured system step response.

6.2 System identification

All system identification schemes use time domain or frequency domain input-output measurements acquired from the actual system. We shall restrict our attention to time domain measurements.

Consider the situation as shown in Figure 3 where a known signal $x(t)$ is applied to the input of the actual (but unknown) system and $y(t)$ is the resulting system response. Assume we have the input-output sample set, $\{x(t_i), y(t_i)\}_{i=1}^{N}$ where $\{t_i\}_{i=1}^{N}$ is a sequence of time instants. Often the samples are taken uniformly over time in which case $t_i = (i-1)T_s$ and T_s is the sampling period of interest here.

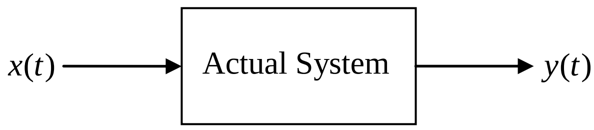

Figure 3. System setup for acquiring input-output measurements.

The simplest approach to model identification is to use a simple input function $x(t)$ typically to be an impulse, a step or a sinusoidal function and then to choose the parameterized output function, $\hat{y}(t)$, based on the evidence produced by the measurements using $x(t)$ as the input excitation. Often a first-order or second-order model will suffice. If the least-squares criterion is used, then the "best" solution to the model identification problem, is obtained by finding the values of the parameters, parameterizing $\hat{y}(t)$, which minimize the quantity

$$J = \sum_{i=1}^{N} \left(y(t_i) - \hat{y}(t_i) \right)^2$$

In optimization terminology, J is referred to as the cost function or objective function of the optimization problem. The best least-squares model describing the output $y(t)$ uses the parameter values that minimize the objective function J and will be denoted by $\hat{y}_{LS}(t)$. Figure 2 shows an example of a model step response fitted to the measured output data.

It should be stressed that the success of this approach depends on how accurately the chosen parameterized model $\hat{y}(t)$ models the actual system's output response. It is therefore of the utmost important to choose the parameterized model $\hat{y}(t)$ to model all relevant dynamical properties in the measured output response.

Using the Laplace transform properties the transfer function associated with the best least-squares fitted model is then given by

$$\hat{G}_{LS}(s) = \frac{\mathscr{L}\{\hat{y}_{LS}(t)\}}{\mathscr{L}\{x(t)\}}.$$

6.3 Control system design

Given the approximate transfer function $\hat{G}_{LS}(s)$ for the actual system the usual controller design methodologies can be used to design a controller to satisfy the user's specifications.

The following very simple specification is assumed to be given: The client requires the controller to be implemented on the controlling computer and that the closed-loop system has a short rise time and minimal overshoot. A good design should also maximize the closed-loop system's ability to reject unwanted noise and disturbances.

6.4 Closed-loop system

Figure 4 shows the block diagram of the closed-loop system for the derived transfer function as well as for the actual model in which case the actual system replaces the approximating model. The process variable is fed back and subtracted from the control set-point. This difference (or error) is then fed to the controller which transforms the error into a compensated input to the model/system.

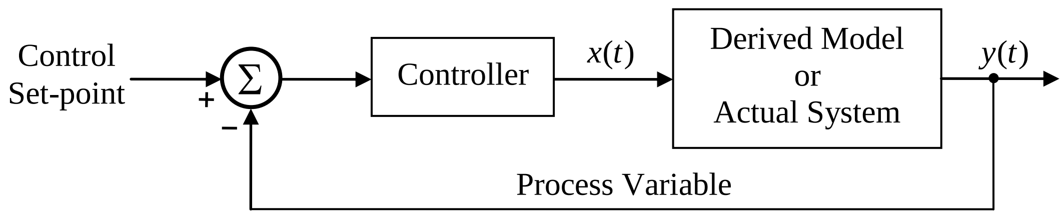

Figure 4. Simplified block diagram of the closed-loop system.

7 Laboratory Experiment

7.1 Experiments

Question 1

Choose an appropriate continuous-time signal model for the output of the actual system and derive its optimal parameters using the data file `student.dat` and Matlab's `fminsearch` command. The file `student.dat` contains the variables `t` (time vector), `r` (input signal vector) and `cn` (output response signal vector). These variables are related as follows: for index `i` the corresponding time, input and output values are `t(i)`, `r(i)` and `cn(i)` respectively.

Question 2

Assuming the process variable to be time-continuous design a classical continuous-time controller. Discuss the closed-loop system's performance.

Question 3

Assuming the process variable to be time-discrete design a classical discrete-time (i.e. digital) controller. Discuss the closed-loop system's performance.

Question 4

Determine the overall transfer function for the closed-loop system shown in Figure 4.

7.2 Simulation software

You need to write your own Matlab/Scilab/Octave code to simulate the system. You are not allowed to use Simulink for this lab project.

7.3 Different controllers (optional for bonus marks!!)

If time allows design another controller different from the one already implemented and compare the performances of the two controllers and interpret your results.

Laboratory assistants:

Please consult the Head Lab Assistant, Tinashe Chingozha, 416805@students.wits.ac.za, to obtain the complete list of lab assistants.