G

Laboratory Sessions

In this appendix we propose several laboratory sessions in order to help the reader to become familiar with the techniques presented in this book. The sessions described in this Appendix can be worked out with the help of the MATLAB® and Scilab control design and identification functions and toolboxes available from the book website (*hhtp://landau-bookic.lag.ensieg.inpg.fr*). Additional laboratory sessions can be developed by the reader from the examples and applications presented in Chapters 3, 4, 7, 8 and 9. Other laboratory sessions are described on the book website.

G.1 Sampled-data Systems

Objective
To become familiar with the discrete-time representation of a physical system.

Functions to be used: cont2disc.m (cont2disc.sci) and standard MATLAB®/Scilab functions.

Sequence of operations

1. Study the step response of the first-order discrete-time model corresponding to the ZOH discretization of a first-order continuous-time model $G/(1+\tau s)$:

$$H(z^{-1}) = \frac{b_1 z^{-1}}{1 + a_1 z^{-1}}$$

for a_1 = *-0.2 ; -0.5 ; -0.7 ; -0.9* by choosing b_1 such that the static gain $b_1 / (1 + a_1) = 1$ for all models. Superimpose the curves obtained on the same plot for an easy comparison.

2. Find for all models the equivalent time constant (normalized with respect to the sampling period).

Reminder: the time constant is equal to the time necessary to reach the 63% of the final value.

3. Question: Does $a_1 = -0.2$ correspond to a fast sampling of a continuous time first order system, or to a slow one ?
   Same question for $a_1 = -0.9$.
4. What are the approximated values for a_1 if the sampling periods $T_s = T / 4$ and $T_s = T$ (T = time constant) are chosen?
5. Study the response in time domain for $a_1 = 0.5$ and 0.7. Give an interpretation of the results.
6. Study the effect caused by the sampling period and the fractional delay on the discrete time model obtained by discretizing with a ZOH the following system:

$$H(s) = \frac{G.e^{-sL}}{1 + sT}$$

for $G = 1$, $T = 10s$; $L = 0$; $0.5s$; $1s$; $2s$; $3s$ and $T_s = 5s$ and $10s$.

Analyze the properties of poles and zeros of the pulse transfer function for all models.

G.2 Digital PID Controller

Objective

To become familiar with the digital PID and to emphasize the importance of using a three-branched digital controller (RST).

Functions to be used: cont2disc.m (cont2disc.sci), bezoutd.m (bezoutd.sci) and standard MATLAB®/Scilab functions.

Sequence of operations

1. Find the discrete-time model from the ZOH discretization of

$$H(s) = \frac{G.e^{-sL}}{1 + sT} \quad \textit{for } G = 1, T = 10s, L = 3s \textit{ and } T_s = 5s$$

2. Find the digital PID1[1] controller with a continuous-time equivalent which provides the best performances, corresponding to a second order system with a damping equal to 0.8.
3. Once the PID is computed, perform a simulation of the closed loop in the time domain. Use a rectangular wave as reference.
   Is it possible to obtain a closed loop response faster than the open loop response for this ratio of time delay/time constant equal to 0.3?
4. Find the digital PID1 with no continuous time equivalent that provides a closed loop rise time approximately equal to half of the open loop one.
5. Perform a simulation in the time domain. Explain the possible overshoot from the values of $R(q^{-1})$.
6. In the same conditions as the point 4, compare the digital PID controllers type 1 and 2.

G.3 System Identification

Objectives
Session G.3-1: to become familiar with the recursive parameter identification methods and the model validation procedures.

Session G.3-2: to identify two real systems (a distillation column and a flexible robot arm) directly from I/O data.

Functions to be used: rls.m, rels.m, oloe.m, afoloe.m, foloe.m, estorderiv.m, vimaux.m, xoloe.m, olvalid.m (or the corresponding Scilab functions) and standard MATLAB®/Scilab functions.

Session G.3-1

Data files
The files to be used are TØ, T1 and XQ, each one containing 256 I/O samples[2]. The files should be centered.

The input signal is a PRBS generated by a shift register with $N = 8$ cells. The file TØ has been obtained by simulating the following model:

$$A(q^{-1})\, y(t) = q^{-d} B(q^{-1})\, u(t)\ ; \qquad u \text{ - input, } y \text{ - output}$$

$$A(q^{-1}) = 1 - 1.5\, q^{-1} + 0.7\, q^{-2}\ ;\ B(q^{-1}) = 1\, q^{-1} + 0.5\, q^{-2}\ ;\ \ d = 1$$

[1] Digital PID 1 and 2 controllers are presented in Chapter 3, Section 3.2.
[2] Files available on the website: *http//:landau-bookic.lag.ensieg.inpg.fr.*

The file T1 has been generated with the same polynomials *A* and *B*, but a stochastic disturbance has been added to the model output.

The file XQ is given with no *a priori* information (degree of $A \leq 5$).

Sequence of operations

1. Use structure 1 and the RLS (Recursive Least Squares) method with a decreasing adaptation gain to identify the model corresponding to TØ (with $n_A = 2$, $n_B = 2$, $d = 1$).
2. Try with degrees $B = 4$ and $d = 0$ on the same file TØ using the same algorithm previously used, to see how a pure time delay can be found out (the first coefficient of *B* is much smaller than the second one).
3. Identify the model corresponding to the file T1 using structure 1 and the recursive least squares method with a decreasing adaptation gain (as for TØ). Note the bias of the identified parameters. Try to validate the model identified.
4. Try other structures and methods to improve the results (S3 then S2).
5. When a satisfactory validation is obtained, compute and plot the step response.
6. Perform a complexity estimation (values of n_A, n_B, d) with the different methods described in Chapters 6 and 7.
7. Identify the model corresponding to XQ.

Session G.3-2

Data files: QXD, ROB2

QXD: this file contains 256 I/O samples that describe the interaction between the heating power on the bottom of a binary distillation column and the concentration of product on the top. The input signal is a PRBS generated by a shift register with eight cells. The sampling period is 10 s. *A priori* knowledge: for the distillation columns the degree of polynomial A is generally not greater than 3. The file has to be centered.

Sequence of operations

Identify the model(s) corresponding to the I/O data set, validate the models identified, and plot the step response(s).

Question 1: what is the value of the plant rise time?

Question 2: has the PRBS been correctly chosen with respect to the rise time?

ROB2**:** 256 I/O samples corresponding to a very flexible robot arm. Input: motor torque. Output: robot arm end position. The input signal is a PRBS. The sampling frequency is 5 Hz. Any vibration mode over 2.5 Hz has been eliminated by an anti-aliasing filter. *A priori* knowledge: in the frequency region from 0 to 2.5 Hz, there are two vibration modes. The file has to be centered.

Sequence of operations
Identify the model(s) corresponding to the I/O data set, validate the models identified, and plot the frequency responses (≥ 200 points).

Question 1: at what frequencies are the vibration modes? What are the corresponding damping factors?

Question 2: what are the differences between the frequency responses of a validated model and of a model which does not pass the validation test?

G.4 Digital Control (Distillation Column Control Design)

Objective
The purpose of this session is to apply the control algorithms presented in Chapter 3 to the distillation column case study (file QXD), and to evaluate the performances in simulation.

We consider two different models for the distillation column, corresponding to a time delay $d = 1$, and $d = 2$ respectively (the sampling period is 10 s). Digital controllers will be computed for both models, and the controllers robustness will be tested by carrying on crossed simulations (Model 1 with controller 2 and Model 2 with controller 1). The models are the following:

M1:
$$d = 1$$
$$A(q^{-1}) = 1 - 0.5065\, q^{-1} - 0.1595\, q^{-2}$$
$$B(q^{-1}) = 0.0908\, q^{-1} + 0.1612\, q^{-2} + 0.0776\, q^{-3}$$

M2:
$$d = 2$$
$$A(q^{-1}) = 1 - 0.589\, q^{-1} - 0.098\, q^{-2}$$
$$B(q^{-1}) = 0.202\, q^{-1} + 0.0807\, q^{-2}$$

Functions to be used: bezoutd.m, cont2disc.m, omega_dmp.m, fd2pol.m (or the corresponding Scilab functions) and standard MATLAB®/Scilab functions.

Sequence of operations

1. Design a digital controller (with integrator) for the model M1 (then for the model M2) of the distillation column.
   This operation can be carried on by using a deterministic control algorithm well suited to the model used (depending on the zeros position with respect to the unit circle).
   The desired closed loop dynamics (regulation) is specified by a second-order system, with damping factor equal to *0.9*, such that the closed loop rise time be 20% shorter than the open loop rise time. The dynamics specified for the tracking performances is the same as for the regulation.
2. Compute the controller that guarantees the performances specified above and the robustness margins $\Delta M \geq 0.5$, $\Delta\tau \geq 10s = T_s$.

3. Perform cross-simulation tests with both controllers and both models. Give an interpretation of the results.
4. Repeat the sequence of operations to design a controller assuring an acceleration (reduction) of 50% of the closed loop rise time compared to the open loop system, an overshoot less than 5% (both tracking and regulation), and satisfying the robustness margins ($\Delta M \geq 0.5$, $\Delta \tau \geq 10s$). If both performance and robustness cannot be simultaneously satisfied, select the desired closed loop dynamics such that the resulting robustness margins match the specifications. *Question:* is it possible to assure the robustness requirements with this specification for the regulation dynamics (acceleration of 50%)?
5. Perform cross-simulation tests with both controllers and both models. Give an interpretation of the results. Do a comparison with the previous case.

G.5 Closed Loop Identification

Objective

To introduce the closed loop identification algorithms. This is carried on with a simulated closed loop system.

Functions to be used: functions contained in the CLID® toolbox.

Data files: the file simubf.mat contains the external excitation r, the input u and the output y of the plant. The external excitation is a PRBS applied on the reference. The file simubf_rst.mat contains the parameters of the RST controller. The simulated plant model to be identified is characterized by: $n_A = 2, n_B = 2, d = 0$.

Sequence of operations

1. Identify and validate a model with open loop identification techniques (from *u* to *y*) ignoring the feedback.
2. Identify plant models with different closed loop identification algorithms and the given digital controller. Validate the model. Compare the various models on the basis of validation results.
3. Compare the models obtained with an open loop identification technique with the models obtained with the closed loop identification algorithms. Check the closed loop poles proximity (between the identified closed loop poles and the computed ones using both open loop and closed loop identified models).
4. Plot the step responses and the frequency responses for the identified models.

G.6 Controller Reduction

Objective
To focus attention on controllers' complexity, and to present an effective solution to the controller implementation in the case of strict constraints imposed by the available resources. The flexible transmission example will be studied and a reduced order controller will be estimated.

Functions to be used: functions contained in the REDUC® toolbox.

Data files: the file flex_prbs.mat contains the external excitation ; the file BF_RST.mat contains the parameters of the RST controller ($n_R = n_S = 5, T = R(1)$); the file BF_mod.mat contains the discrete-time model of the plant.

Sequence of operations

1. Compute the simulated control signal on the basis of the given closed loop system (will be used in the estimation algorithms). Use the appropriate sensitivity function with respect to the reduction algorithm to be used (Closed Input Matching (S_{up}) and Closed Loop Output Matching (S_{yr}).
2. Find a reduced order RST controller with $n_R = n_S = 3, T = R(1)$ starting from the given one. Validate the resulting controller.
3. Impose $n_R = n_S = 2, T = R(1)$ in order to get a digital controller corresponding to a digital PID 2 controller.
4. Compare the results obtained with the two methods (CLIM and CLOM). Give an interpretation.
5. Plot the response for a step reference change and a step disturbance on the output for the closed loop system with the nominal controller and the reduced controllers.