System Identification

Laboratory Exercise 3
EL1820, Modelling of Dynamical Systems
August 2010

Ragnar Wallin, Per Bodin, Oscar Flärdh, and Björn Johansson
Automatic Control/School of Electrical Engineering/KTH

Goal: The goal is to gain experience and insight in system identification techniques. We will use system identification tools to construct a linear model of the so called Fan & Plate process.

Contents

1 Introduction

System identification is an experimental method to construct models from input and output data. In this laboratory exercise, you will collect appropriate input and output data to construct a linear model of the so called Fan & Plate process. The model should be able to describe the behavior of the process around a working point. The model will be constructed with the help of the System Identification Toolbox in MATLAB® . The goal of this exercise is to give you practical experience in how to use system identification to devise models. The exercise intends to illustrate:

1. How to acquire and process data to be used for system identification.

2. How to choose an appropriate class of models.

3. How to construct models from acquired data.

4. How to validate and assess the quality of the constructed models.

2 Preparation Tasks

2.1 Identification from Given Data

The first task is to identify a model from given data. You may download the file "lab3_prep.mat" from the course home page. Load the mat file into MATLAB® using the command `load lab3_prep.mat`. You will now have the variables u (input) and y (output) in your workspace. They consist of 1200 samples from a process sampled with 1 s. Use the first 600 samples for estimation and the rest for validation. You should be able to find a model that fulfills:

- Both residuals within the 99% confidence interval.

- At least 85% fit on simulated output.

- At most seven parameters in the model.

Note: Neither the data nor the requirements from this preparation task has anything to do with the fan that should be modelled in this lab.

2.2 Physical Modelling of the Fan

You should now find a physical model of the fan and plate system. The voltage to the fan is the input, and the plate angle is the output. Make the following assumptions:

- The transfer function from fan voltage to rotational speed of the fan is a first order linear system.

- The speed of the air at the fan is proportional to the rotational speed of the fan.

- The distance between the fan and the base of the plate is L.

- The pressure from the air on the plate is proportional to the square of the speed of the air. The turbulence can be neglected.
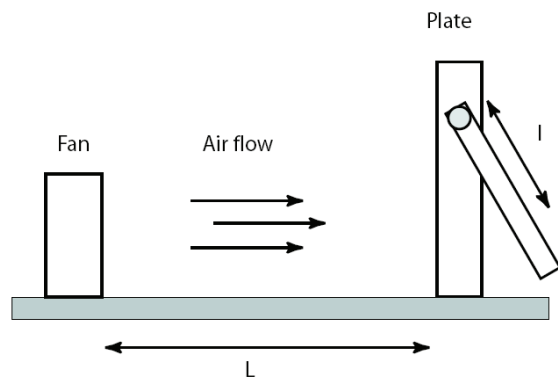
Figure 1: Illustration of the fan and plate process, with definition of L and l.

- The dynamics of the plate is modelled with torque balance. The inertia of the plate is J. There is no friction in the link, but the damping due to air resistance is proportional the the rotational speed of the plate. The plate can be viewed as a point mass at distance l_g from the link. The air affects the plate an an area A, centered at distance l from the point of rotation of the plate (see Figure 1).

The model is nonlinear. Suggest a suitable model order for a linear model that is valid for small deviations from a working point.

3   The Report

The data acquisition will be done by the students without supervision in the automatic control laboratory. The results will be written up in a report. The report will be written in English or Swedish, and there is a report template available on the course homepage. Then the report will be reviewed, and depending on the quality of the report, you will either pass or fail.

Please collaborate in pairs. It is ok to work alone, but it is not ok to be more than two people.

Note that the following is required to pass:

- The report including plots should be rather short (around 4-5 pages).
- Staple the grading template (first page) and the report together. The grading template can be found on the last page.
- One or two authors per report.
- See the grading template for further criteria.
- A paper copy of the report should be handed in to STEX before the date specified on the homepage. Do not use email etc. You may use regular mail.

We will put a note on the homepage when the reports have been graded. Pick up the report at STEX. If the report got the grade fail, then you have to revise it and hand it in once more, see the course homepage for deadline. The revised report will either get the grade pass or fail. If you fail this time, you have to redo the exercise next year.

The report must include the following:

- Motivate the choice of the working region, where the process can be approximated with linear dynamics.

- Motivate the choice of sampling time.

- Describe in detail how the input signal was chosen and how you acquired the output signal. Specify the amount of data you have acquired for identification and validation.

- Use more than one model structure and compare the results using the validation data.

- Present the result with plots of Bode diagrams, poles and zeros, and validation performed with simulation (`compare`) and correlation analysis (`resid`). Comment on the model order choice you made.

- Solutions to the two preparation tasks.

4   Process Description

The process consists of a fan that blows air on a suspended plate. The input is the motor's driving voltage and the output is a gauge voltage which is proportional to the angle of the plate. The process is shown in Figure 2. Do not forget to turn on (and off when you are done) the power
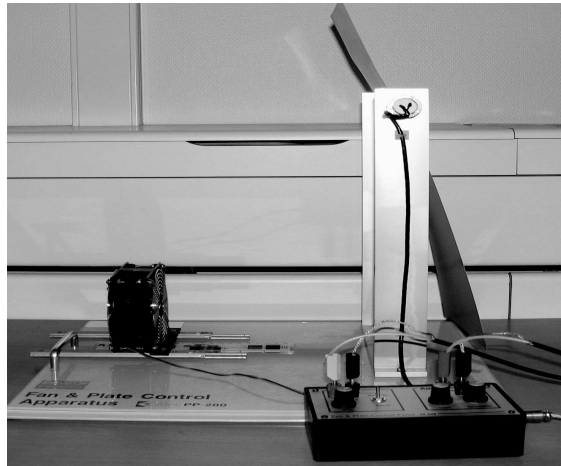

Figure 2: The Fan & Plate process.

supply, which is a white box with a green button.

5   Procedure

In this exercise, you will construct a linear model for the relationship between the input and output signal. The model should be valid for small deviations around a working point: If the input to the fan is a constant voltage, then the plate will settle at a constant angle, this constant angle and the constant input voltage form the working point of the process.

The system identification experiments should be made by making small deviations from the working point. However, the deviations has to be large enough, such that the disturbances do not dominate in the output signal. The disturbances originate, among other things, from the turbulence in the air.

You need to choose and perform:

1. Find a working region where the dynamics is linear.

2. Sampling time.

3. Type of input signal.

4. Data acquisition.

5. Prefiltering and other data processing.

6. Spectral analysis.

7. Estimate a parametric model.

8. Model validation.

System identification is an iterative process, where especially the two last steps have to be repeated until an acceptable model has been found.

5.1 Computer Login and Software

Log in with the username **mods**, the password is "lab3". On the desktop there is a folder named "Modeling of Dynamical Systems". Open this folder and double click on the file "Application.exe". Then a LabVIEW graphical user interface (GUI) for data acquisition is shown. The GUI is shown in Figure 3.
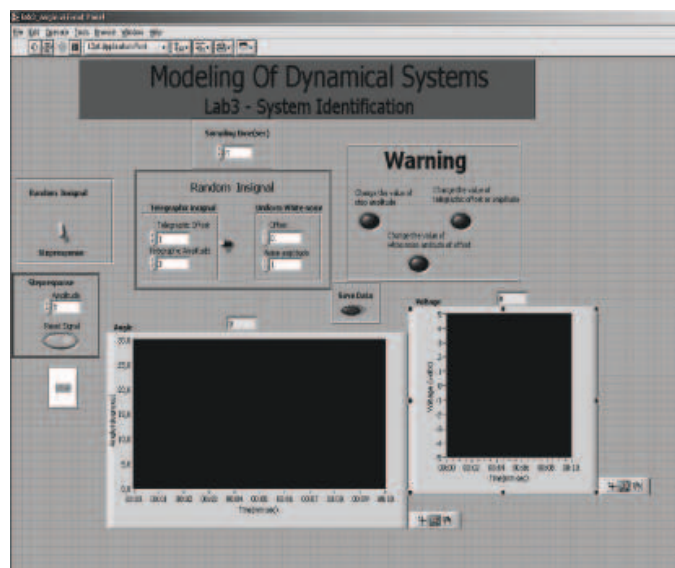

Figure 3: Main window.

The buttons and windows in the GUI have the following functions

Sample Time Specifies the sampling time in seconds.

Random input - Step response Switch that switches between random input and step input.

Step Response Specifies the amplitude of the step.

Random input The random input varies between two values, and it can also have an offset. In this field, the amplitude and offset are specified. It is recommended to keep amplitude+offset ≥ 0 to be in the correct operating range. The input can be chosen to be either a telegraph signal or white noise by the switch in the middle.

Scopes One graph shows the input voltage (V) to the fan. One graph shows the angle (degrees) between the stand and the plate.

Warning If the input signal is out of range, then this warning indicator is lit. Note that this only warns if the signal is out of the working range of the fan motor. The range for the system to be approximately linear might be significantly smaller.

Save data Saves data from the experiment. When you click this button, you are asked to choose a name and location for the data file. When you click OK, the data collection starts. Stop the data collection by again clicking on "Save data".

Stop Aborts the experiment.

5.2 Working Point

To conduct a system identification experiment, a working point is selected in the operating range of the process. In this exercise, the working point is prespecified to be in an area where the process is rather linear. Turn the `Bias`, `Gain`, and `Zero Offset` dials (on the process) to the positions marked by dashes. Do not touch these dials for the remainder of the laboratory exercise.

5.3 Region with Linear Dynamics

When estimating a linear model from a nonlinear system, it is important that the process is kept sufficiently close to the working point. This can done by selecting a small enough range of the input for a linear approximation to be valid. One way to test this is to perform several step response experiments with different amplitudes. If the system is linear, the output should approximately be scaled with the amplitude of the step (this is one of the properties of a linear system). Start with a small amplitude for the first step, A_1, and then increase the amplitude a little for each step. Then plot the normalized step responses $\frac{y_i(t)}{A_i}$ and find the input amplitude when the system starts to show nonlinear behavior. Make sure that the input never exceed this value during the rest of the experiment.

5.4 Sampling Time

The sampling time is often chosen by first performing a step response experiment with short sampling time. Then the sampling time is set to give around ten samples per rise time (the rise time is the time it takes for the signal to go from 10% of the change to 90% of the change). From this initial step response experiment, it is also possible to get an estimation of the time delay of the process.

Set the sampling time to 0.05 s and choose an appropriate amplitude, where the system is approximately linear. Use the switch to make sure that the input is a step. Find the rise time and choose an appropriate sampling time. Enter the chosen sampling time.

Tip: The step response can be very noisy and it can be hard to find the rise time. One way to attenuate the noise is to perform several (e.g, 10) step response experiments and then plot the average of these experiments.

5.5 Data Acquisition

To acquire the data, use a random input signal. Choose either the telegraph signal or white noise, and choose amplitude and offset. Start the experiment and adjust the amplitude or offset if necessary. When you have found good settings and have acquired enough data, save the data and finish the experiment. Remember to have enough data for both model estimation **and** validation. Locate the folder where you saved your data and move it to your USB memory stick. The computer is *not* connected to the internet and it is not possible to transmit the file via email etc. Then remove your data file and exit LabVIEW. Shutdown the computer and the process' power supply. You will complete the remainder of the exercise in the computer rooms or on your own computer.

5.6 Model Structure

To find a good model structure, always start with something simple, for example, ARX. If this is not good enough, try something a bit more complicated, for example, ARMAX. If this is still not good enough, increase the flexibility in the model even more, for example, BJ. Start with a low model order and increase gradually. The theory on how to do this is given in the computer exercises.

Data is loaded in to MATLAB® with the command `load filename.lvm`. The input signal is in the first column and the output is in the second column. To get the input signal to be in the variable u and the output signal to be in the variable y, we can use the following commands.

```
>> matlab_data = load filename.lvm;
>> u = matlab_data(:,1);
>> y = matlab_data(:,2);
```

6 Software

If you want to perform the MATLAB® parts on your own computer, you need to have MATLAB® and the System Identification Toolbox installed.

Grading template for laboratory exercise 3
EL1820, Modelling of Dynamical Systems
August 2010

Fill out this box only.

Title ....

Author 1 ....

Personal identity number ....

Author 2 ....

Personal identity number ....

	Pass		**Fail**	
	$\leq$ 2st		> 2	
Number of Authors	☐		☐	
	yes		no	
Author names and title filled out?	☐		☐	
	yes	often	sometimes	no
The report is well structured? The language is understandable?	☐	☐	☐	☐
	yes	often	sometimes	no
The figures are clear?	☐	☐	☐	☐
		yes	no	
The preparation tasks are solved and well motivated?		☐	☐	
		yes	no	
The data acquisition is well described?		☐	☐	
		yes	no	
The choices of model structure and model order are well motivated?		☐	☐	
		yes	no	
The model is validated using new data?		☐	☐	
		yes	no	
The authors have reflected on their results?		☐	☐	

	Pass	**Fail**	
First review	☐	☐	Sign:

....

	Pass	**Fail**	
Second review (if failed in the first review)	☐	☐	Sign:

Pass

Signature: