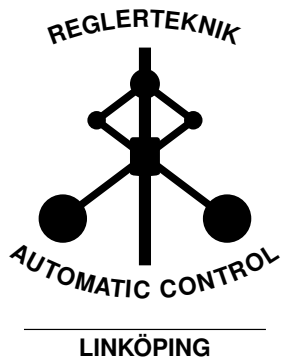
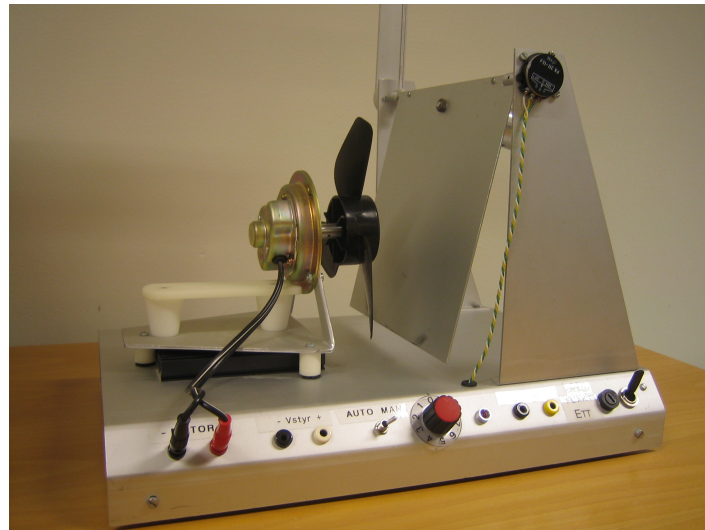


System Identification of a weather vane

This version: 2024-01-11



Name: _____

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1 Introduction

Objective of this lab

In this lab we consider a system which we refer to as the weather vane, which consists of a fan blowing air towards a plate suspended from its upper side, as seen in Fig. 1. The input to the system is a voltage that drives the fan, and the output is a voltage measurement which is proportional to the plate angle. The goal is to find a good model of this system. As help, you can use the material from the computer lessons, the course book and this lab manual. Do not forget that all MATLAB commands have built-in help texts that explains the syntax.

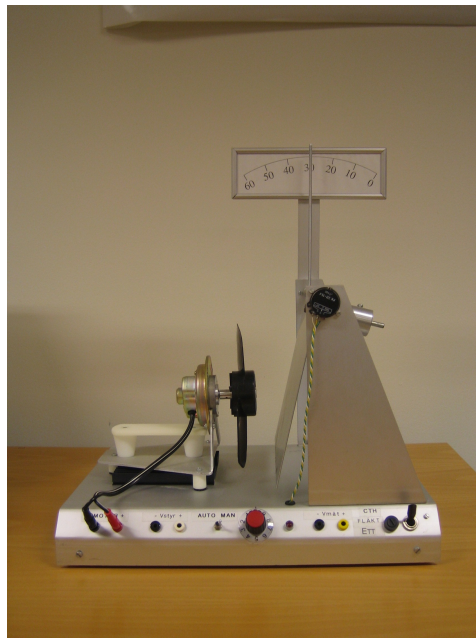


Figure 1: The weather-vane system.

Purpose of the lab

The purpose of this lab is to show how system identification can be used to find mathematical models. In particular, the lab is designed to illustrate:

1. How to collect and use data for solving an identification problem.
2. How to choose a suitable class of models.
3. How to estimate a model from collected data.
4. How to evaluate the quality of the found model.

Structure of the lab

In the lab we use MATLAB and its SYSTEM IDENTIFICATION TOOLBOX (SITB). Basic knowledge about how to use this toolbox is assumed. The lab is focused mainly on the aspects of system identification which are not investigated in detail during the computer lessons. For example the choice of the input signal, the selection of the model order, and so on.

The lab can be split into 3 parts:

1. Data collection, which is done in RT3 during a 2-hour sessions with a lab assistant. Supplementary data can be collected later but in that case without the supervision of a lab assistant.
2. Data processing, analysis, model estimation and validation as well as the writing of a report, are tasks which can be carried out in any location.
3. Peer review of another group's report, followed by revision of the report (according to comments from the peer review), and submission of the final report.

Since it is a mandatory to write a **report** with the results you obtained, it is for your own sake important that you put emphasis on the preparatory tasks. This in order to maximize the time you can dedicate to doing experiments and discussing with the lab assistant during the scheduled data collection time slot. You have access to RT3 and ISY's computer rooms throughout the course. Discussions with other classmates about practical problems are encouraged and there are also a number of opportunities for you to get in touch with a laboratory assistant.

2 System identification

2.1 Procedure

Finding a model through system identification is done in multiple steps, among other things:

1. Choice of sampling time.
2. Choice of input signal.
3. Data collection.
4. Prefiltering and other forms of data processing.
5. Spectral analysis
6. Estimation of a (parametric) model.
7. Evaluation of the model (model validation).

Normally, the last two steps must be repeated a number of times until satisfaction. It can also be the case that you have to redo your data collection due to poor selection of sampling time or input signal. In practice, the data collection part, including the choice of sampling time and the input selection, is often the most time-consuming part. With a good set of measured data, it is relatively simple to quickly develop and evaluate a large number of models using SITB in MATLAB, as you have seen in the computer lessons.

2.2 Choice of sample time

What to consider when selecting the sampling time is discussed in more detail in [1, cha. 17.2]. It is encouraged to first carry out a step response experiment in order to get an idea of the time constant, pure time delay and static gain. A rule of thumb is to choose a sampling frequency about 10 times the bandwidth of the system. However, due to the complexity of this system a sampling frequency about 20 times the bandwidth of the system is recommended for this lab, that is

$$\omega_S = 20\omega_B, \quad \text{unit rad/s}$$

The bandwidth, ω_B , is approximately equal to $1/\tau$, where τ is the time constant of the system. We then have

$$\omega_S = 20\omega_B \approx \frac{20}{\tau}$$

The time constant, τ , can be estimated from the step response as the time it takes for the output to reach 63% of its final value (disregarding the pure time delay). From this estimate the sampling time, T , can be found. Afterwards you can check if the selected sampling time corresponds to 4-8 samples during the rising phase of the step response. This can also be used as an approximate method for determining T .

Hints

- If you are uncertain about what an appropriate sampling time for the system should be, keep in mind that it is often better to sample a bit too fast than a bit too slow. Therefore, round off the sampling time towards a lower value rather than a higher one.

That's not to say it is always good to sample quickly. Too fast sampling may cause numerical problems in the sense that the estimated model gets poles very close to 1 and zeros outside the unit disk (non-minimum phase system).

2.3 Choice of input

When it comes to choosing an input signal, one should remember that the input should excite as many modes as possible in the system. Therefore, you should make sure that the energy of the input signal is spread over all the frequencies which you are interested in. A natural first choice, if you can choose freely, is to let the input signal be white noise. The spectrum for white noise is constant over all frequencies. In order to obtain white-noise signals in MATLAB the functions `rand` and `randn` can be used.

Another possible problem, which partially contradict the concept of using many frequencies, is that the input energy gets scattered over so many frequencies that the signal-to-noise ratio (SNR) becomes poor. Whether this is a problem or not depends on how much noise there is and how high magnitudes that are allowed for the input. A poor SNR affects estimation methods negatively. Therefore, it is sometimes convenient to focus the input energy on a smaller number of frequencies which are deemed most interesting. This can be done using for example sinusoidal inputs or filtered noise.

Another default choice is to use what is called a telegraph signal which randomly switches between two levels. The function `telegraf` generates such a signal and can be copied from the course library. It is noteworthy that in most practical cases one can not use arbitrary input signals. This may be due to constraints in the size of the input signal and/or of its derivatives. Other reasons may be that the system cannot cope with inputs that contain arbitrarily high frequencies. Constraints like these can be easier to deal with using a telegraph signal than pure white noise.

2.4 Model validation

As seen in the computer sessions, there are a many ways to validate a model. For instance one can compare the frequency response of a parametric model with the frequency response obtained through spectral estimation, look at pole-zero plots in order to see overfitting issues, analyze the uncertainty associated with the model parameter estimates, study the model residuals and compare the simulated model output with the measured output of the real system. To perform the latter test, you can proceed as follows:

1. Collect two independent sets of data.
2. Estimate the model using the first dataset (the estimation data)
3. Simulate the output of the estimated model using the input of the second dataset (the validation data).
4. Plot and compare the simulated output with the output of the validation data.

The process of testing a model against "new" data (ie, not the same data as used for the estimation) is called cross-validation and is natural way of determining if a model is working as intended or not. Generally, you should expose the model to as many different tests as possible to minimize the risk of accepting an incorrect (bad) model.

2.5 Preparatory tasks

1. Read Chapters 10, 12, 16 and 17 in [1].
2. Review all computer sessions about identification.
3. What is the difference between parametric and non-parametric identification?
4. Assume that a system has got a time constant equal to $\tau = 0.1$ s. What sampling frequency is it appropriate to use?
5. In which frequency region should the input signal have the most energy content?
6. Plan your data collection.
7. Read about step responses, poles, model order and more in [2].

2.6 Before you begin

When you get to the lab session, you need to do some things in order to get started.

- Copy the lab files from K: to your personal documents folder (do not store them locally on the computer).
- Start MATLAB 2016b.
- Go to the directory with the lab files you just copied.
- Open the file `fan_plate.m` and execute the first cell (key `ctrl-enter`) in order to start XPC-target Explorer.
- This item needs to be done *only the first time* that you execute the code. The following times you log in and execute the code you *must skip* this steps.
 - Right click on `TargetPC2` and choose `connect`.
 - Right click on `TargetPC1` and choose `delete`.
 - Right click on `TargetPC2` and choose `disconnect`.
 - Right click on `TargetPC2` and choose `rename`. Change the name to `TargetPC1`.
- Right click on `TargetPC1` and choose `connect`.
- Start SIMULINK and open the model called `identifying.mdl` in order to see how it works.

Now the communication between the I/O-card and MATLAB is set up.

- In order to make a data collection, you must first specify some parameters such as sampling interval and simulation time in the file `fan_plate.m`. After this you can proceed and execute the other cells of the file. Do not forget to first save the changes you made! Note that the sampling frequency must be given as an integer.
- When the collection is complete, the data is stored in the object called `tg.outputLog`. Remember to save your data! You can create an `iddata` object containing the data (`help iddata`) and then use the `save` command to save the dataset.

2.7 Identification of weather vane

Your task is now to find a model for the weather-vane system using the collected data. Start with steering the fan manually in order to better understand the system and its dynamics. Can you deem an appropriate *smallest* choice of model order just by controlling the fan by hand? Note that the input signal *must* be in the range $[0, 10]$ V, otherwise the weather vane might break down!

Hints

- It is not difficult to deduce that the weather vane has nonlinear dynamics. As a consequence, it is difficult (if not impossible) to find a linear model that describes the system well over the whole input signal interval. Therefore, let the input signal have its working point at 4V with a deviating amplitude of about 2V.

3 Verification

The lab is verified in the form of a written report which should be readable independently of this lab manual. This means that *all* of your choices should be thoroughly explained and motivated, including the choices made during the data collection. Your final models must have captured the essential behavior of the system. However, the most important thing about the lab is not that you succeed in finding the very best models, but that you can motivate the decisions made during the identification procedure. It is also important that you explain the shortcomings and merits of your models. These shortcomings and merits can be of a different nature, such as model accuracy, parameter estimate uncertainty, physical interpretation etc. Therefore, be as clear as possible in your explanations. Also, include relevant plots in your report and make sure that you write out clearly what it is relevant to see in them. Below follows a description of what the report should contain.

3.1 Report content

Description of the task

First you should describe the task at hand so that someone who has not worked on the lab can understand what the report aims to answer. Include a short description and a figure of the system.

Identification experiment

Describe how the experiment was designed. This should include a description of the experiments you use to decide a suitable sampling time and input signal. Present your data collection and preprocessing methods. Show plots in each step of the process, e.g., step responses, periodograms and the collected data.

Identification from data

Present the models you estimate from data. This should include

- Spectral analysis
- Correlation analysis
- Parametric models, **Test several structures and orders!**

The spectral and correlation analysis models should be compared to the parametric models you estimate. You may use the correlation analysis to get a rough estimate of the delay of the system, but also try different delays when estimating the parametric models. The spectral analysis can give an idea of how many poles your models at minimum should have to give reasonable results. For the correlation analysis, use `cra` in the command line, as you did in exercise session 6 (Computer exercises in S.I. part 1), and not the GUI's impulse response estimate. Use SPA and ETFE for the spectral analysis, also as in exercise session 6.

Estimating parametric models is an iterative procedure. When trying different parametric model structures and orders, use the validation methods to decide if you need to go back and change model structure or order. You should not present all models you have tried in depth (see the section below), but you should state roughly how many you have tried (which model structures and which orders).

Model validation

To validate the model you should at least use and present the following:

- Cross validation
- Residual analysis
- Pole/zero diagram

- Confidence interval for the parameters
- Strengths/weaknesses of the models
- Which model do you recommend and why?

When you have tried many models and gone through the validation steps you will have to decide which models that best describe the system. Pick a few model candidates that you think are good, and present a closer analysis of the validation. Comment on problems the models have in the validation, and if you have tried to resolve them, for instance, you may see a sign that the model order might be too high, but reducing the order gives a poor fit to validation data. Pay attention to overlaps in the pole zero diagrams, non-white residuals, and parameter confidence intervals containing zero, consult the course book [1] for details. Not all aspects of your models will be perfect - use your validation experiments and argue which of you model candidates are most suitable.

Hints:

- The frequency response can be easier to interpret by switching to linear scale for both axes, especially when determining the system bandwidth during input selection phase. This is achieved by toggling `Style->Linear frequency scale` and `Style->Linear amplitude scale` in the frequency function plot window.
- It can be helpful to collect one large sample of data, and split it into estimation and validation data after preprocessing, so that the same preprocessing steps are applied to both datasets.
- Compare the spectral analysis and correlation analysis with the parametric models
- When inspecting the frequency response and pole/zero plots of the models, it is possible to turn on confidence intervals.
- Don't forget to inspect the zeros and poles of the noise model for the relevant model structures.
- Confidence intervals for the parameters can be found by clicking the 'present'-button when viewing a model in the GUI, or typing, e.g., `present(arx331)`, in the command line if the model is exported to your workspace. Using a confidence interval wider than \pm one standard deviation might be advisable.
- Non-linear and state space models can be included in your report, but *should not* be considered as candidates for the model recommendation in this lab.

- Discuss **all** of your validation methods when recommending a model. Reports neglecting important aspects of the validation will need to be revised.

The report must be submitted electronically in **.pdf** format to facilitate administration and for being able to run it in Urkund (<http://www.arkund.se/SE/>). Deadline for the submission of the report (and for the submission of the final revised version) as well as other details can be found on the course website.

The report can be given the following grades: **pass (godkänt)**, **revise (komplettering)** or **fail (underkänt)**. If you are requested to revise the report, the revision must be done before the deadline given on the course homepage. If the grade is 'fail' you will not be able to submit a new report until the next exam session.

Instructions and deadlines for report submission can be found on the course homepage and in Lisam.

4 Peer review

The peer review is an exercise in which students learn from other course members and help each other to improve the lab reports. A few days after you have handed in your report, you will be assigned the report of another group of students in a randomized way. Read the report carefully and write a review according to the bullets below. The deadline for the submission of your review can be found on the course website.

In your peer review, you should answer and discuss the following questions:

1. Is the description of data collection clear? Are the methods used for data collection described in sufficient detail so that the experiments can be performed by someone else?
2. Are there clear descriptions of the solutions to all tasks? Discuss all the items in Section 3 separately.
3. Do you agree with the presented conclusions? What would you like to change in the conclusions based on the data, the experiments and the results?
4. What is the greatest strength of the report? Discuss the content, not the format.

5. What suggestions do you have for improving the quality of the report?
Discuss clarity, readability and technical accuracy.

The questions should be answered as a discussion, presenting arguments for your positions and proposing alternative methods and improvements.

Specific tips:

- Use constructive criticism.
- Use a positive tone and accommodating language.
- Describe the things that can be clearly improved.
- Avoid comments that may be perceived as insulting or inappropriate.

Many people ignore feedback that they find negative, vague, or confusing. Therefore, try to have positive tone and be specific in your comments. This will make your feedback more useful to those who wrote the report. The review report should be 1-2 pages and submitted according to the information on the course website.

References

- [1] L. Ljung, T. Glad and A. Hansson. *Modeling and identification of Dynamic Systems*. Studentlitteratur, 2021.
- [2] T. Glad och L. Ljung. *Reglerteknik - Grundläggande teori* Studentlitteratur, 2007.