EXAM IN MODELING AND SIMULATION (TSRT62)

SAL: ISY:s datorsalar

TID: Tuesday 24th October 2017, kl. 14.00–18.00

KURS: TSRT62 Modeling and Simulation

PROVKOD: DAT1

INSTITUTION: ISY

ANTAL UPPGIFTER: 5

ANTAL BLAD (inkl försättsblad): 10

ANSVARIG LÄRARE: Claudio Altafini, 013-281373, 073-9931092

BESÖKER SALEN: cirka kl. 15 och kl. 16

KURSADMINISTRATÖR: Ninna Stensgård 013-282225, ninna.stensgard@liu.se

TILLÅTNA HJÄLPMEDEL:

1. *L. Ljung & T. Glad* ”Modellbygge och Simulering”
   (English title ”Modeling and Identification of Dynamical Systems”)
2. *T. Glad & L. Ljung*: ”Reglerteknik. Grundläggande teori”
3. Tabeller (t ex *L. Råde & B. Westergren*: ”Mathematics handbook”,
   C. Nordling & J. Österman: ”Physics handbook”,
   S. Söderkvist: ”Formler & tabeller”)
4. Miniräknare

Normala inläsningsanteckningar i läroböckerna är tillåtet. Notera att kommunikation med andra personer och informationshämtning via nätverket eller Internet *inte* är tillåtet under tentamen.

LANGUAGE: you can write your exam in both English (preferred) or Swedish

LÖSNINGSFÖRSLAG: Finns på kursens websida efter skrivningens slut.

VISNING av tentan äger rum 2017-11-08 kl 12.30-13:00 i Ljungeln, B-huset, ingång 25, A-korridoren, room 2A:514.

PRELIMINÄRA BETYGSGRÄNSER:	betyg 3	23 poäng
	betyg 4	33 poäng
	betyg 5	43 poäng

OBS! Lösningar till samtliga uppgifter ska presenteras så att alla steg (utom triviala beräkningar) kan följas. Bristande motiveringar ger poängavdrag.

Lycka till!

COMPUTER TIPS:

- To open Matlab:
  - open a terminal (right-click on the background and choose `open terminal`)
  - type

    ```
    module add prog/matlab
    matlab &
    ```

- Print out the model description and the plots requested
- Remember to write your AID number on each printed page you include
- In the identification exercise using the System Identification toolbox:
  - To print the model description: Right-click on the icon of the model you have computed and then click `Present`. The model description appears then on the matlab main window. Copy it into a file and print it.
  - the SysId plots cannot be directly printed. You have to choose `File` → `Copy figure`, which gives an ordinary matlab plot you can print.
- Printing in Linux:
  - A file called `file.pdf` can be printed out for instance typing in a terminal

    ```
    lp -d printername file.pdf
    ```

    (replace `printername` with the name of the printer in the room you sit in).
  - It is possible to print using `File` → `Print` in a matlab plot, but one must select the printer name writing `-Pprintername` in the `Device option` (again `printername` is the name of your printer).

1. (a) Transform

$$(\dddot{y})^3 + y = u$$

into state space form. [2p]

(b) Given the transfer function

$$G(s) = \frac{\alpha}{s+\beta}$$

how do you evaluate the parameters α and β using a step response experiment? [2p]

(c) Consider the circuit of Fig. 1, where the source is a voltage source.

- Show that the bond graph has a causality conflict.
- Show that the causality conflict can be eliminated by adding a resistance in an appropriate place. Draw the resulting circuit and its bond graph.

[3p]

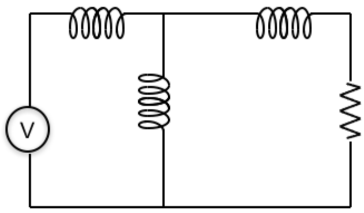


Figure 1: Circuit of Ex. 1(c)

(d) Consider the system

$$y(t) + y(t-1) = u(t) + 0.2u(t-1)$$

where $u(t)$ is a white noise of variance 1. Compute the spectrum of y. [3p]

2. Assume some data are produced by the true system

$$y(t) = u(t) + 2u(t-1) + e(t)$$

where $u(t)$ and $e(t)$ are uncorrelated white noises (of zero mean and variance λ_u and λ_e).

(a) You are asked to use one of the three following model structures

$$\begin{aligned} \text{FIR:} \quad & y(t) = b_1 u(t) + v(t) \\ \text{OE:} \quad & y(t) = \frac{b_1 + b_2 q^{-1}}{1 + f_3 q^{-3}} u(t) + v(t) \\ \text{ARX:} \quad & (1 + a_1 q^{-1}) y(t) = b_1 u(t) + v(t) \end{aligned}$$

to fit a model to the data. In all 3 cases $v(t)$ is a white noise (of zero mean and variance λ_v), uncorrelated with $e(t)$ and $u(t)$. Which one would you use and why? [3p]

(b) For the model structure you have chosen, is the estimation problem biased or unbiased? [1p]

(c) For the model structure you have chosen, compute the predictor and use the prediction error minimization method to compute the value of the parameters when $N \to \infty$. [5p]

(d) Is the model structure that you have chosen identifiable? [1p]

3. The data for this exercise are in a file called `sysid_data_20171024.mat` located in the directory `/site/edu/rt/tsrt62/exam/`. To load it into your Matlab workspace use any of the following:

   - type in the Matlab window

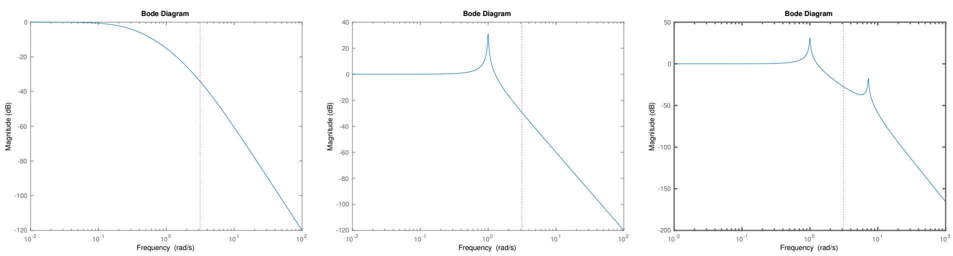
     `load /site/edu/rt/tsrt62/exam/sysid_data_20171024.mat`

   - copy the file to your current directory and then load it into your Matlab workspace (typing `load sysid_data_20171024.mat` at the Matlab prompt).

   Inside `sysid_data_20171024.mat` you will find the sampled signals u and y (the sample time is $T_s = 1$).

   (a) Estimate the frequency function using ETFE and/or SPA. [2p]

   (b) Which of the 3 continuous-time transfer functions shown in Fig. 2 can have generated the data you are studying? Motivate your answer. [2p]



(a) No resonant peak (b) Res. peak: $\omega_1 = 1\,\mathrm{rad/s}$ (c) Res. peaks: $\omega_1 = 1\,\mathrm{rad/s}$, and $\omega_2 = 7.28\,\mathrm{rad/s}$

Figure 2: Exercise 3. The dotted line corresponds to the Nyquist frequency $\omega_N = \pi$.

   (c) Construct one or more appropriate black-box models. *[Hint: It is enough to consider the OE (Output Error) class of models.]* For one or more of these models report

   - plot of the fitted model vs. validation data
   - parameter values and uncertainty
   - residual plot
   - Bode plots
   - poles and zeros placement

   Discuss and comment your choices and results. [6p]

4. The moving cart of Fig. 3 is equipped with a mechanical accelerometer, which returns the elongation y shown in the Figure. The mass of the cart is m_1, and the accelerometer is composed of a spring (of spring constant k), a mass m_2, and a damper of damping constant b. A constant force F acts on the vehicle.

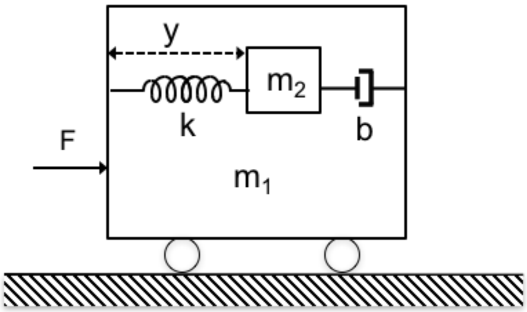


Figure 3: Exercise 4

(a) Set up a bond graph of the system and mark its causality. [5p]

(b) Translate the bond graph into state space equations, taking the elongation y of the spring as output of the system. [5p]

5. Given the system

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

assume we are interested in the inverse dynamics, i.e., we want to deduce u and x as a function of y. It is natural then to write this system in the form

$$\begin{bmatrix} I & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{u} \end{bmatrix} + \begin{bmatrix} -A & -B \\ C & D \end{bmatrix} \begin{bmatrix} x \\ u \end{bmatrix} = \begin{bmatrix} 0 \\ I \end{bmatrix} y$$

where y is the new "input", given as a function of time. In this exercise both u and y are scalar, and we take

$$A = \begin{bmatrix} -1 & 0 \\ 2 & -3 \end{bmatrix}, \quad B = \begin{bmatrix} 1 \\ -1 \end{bmatrix}, \quad C = \begin{bmatrix} -1 & 0 \end{bmatrix}$$

(a) Assuming that $D = 1$, compute the differentiability index. [3p]

(b) Assuming that $D = 0$, compute the differentiability index. [3p]

(c) If the transfer function is

$$G(s) = C(sI - A)^{-1}B + D = \frac{b_0 s^m + b_1 s^{m-1} + \dots}{s^n + a_1 s^{n-1} + \dots},$$

what is the relationship between n, m and the differentiability index in the two cases (a) and (b) above? [4p]