EXAM IN MODELING AND SIMULATION (TSRT62)

SAL: ISY:s datorsalar

TID: Monday 29th October 2018, 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 2018-11-16 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) What is a model validation and why is it so important? [2p]

(b) Consider the model

$$y(t) + ay(t - 1) = bu(t - 1) + e(t)$$

with the feedback law $u(t) = -ky(t)$ (k is known). Show that the system is not identifiable. Modify the feedback law so that the system becomes identifiable. [2p]

(c) Given the true system

$$y(t) = \frac{N(q)}{D(q)}u(t) + \frac{1}{R(q)}e(t)$$

where $N(q)$, $D(q)$ and $R(q)$ are polynomials and $e(t)$ is a white noise, which classes of black-box models can give an unbiased predictor? [2p]

(d) Check for the presence of causality conflicts in the bond graphs of Fig. 1. Show that if a causality conflict is present, it can be solved by adding a single R-type element to the graph. [4p]
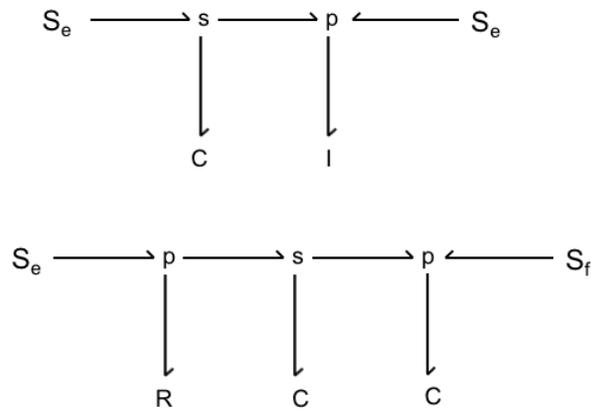

Figure 1: Exercise 1

2. Consider the following "true" system

$$y(t) + 0.4y(t-1) = 0.2u(t) + v(t)$$

where $v(t)$ is a zero-mean white noise of variance 2. We aim at fitting ARX models

$$y(t) + a_1 y(t-1) + \ldots + a_{n_a} y(t-n_a) = b_1 u(t) + \ldots + b_{n_b} u(t-n_b+1) + e(t)$$

of different order n_a and n_b using the prediction error minimization method on the function

$$V_N(\theta) = \frac{1}{N} \sum_{t=1}^{N} (y(t) - \hat{y}(t|\theta))^2$$

The input u is a white noise of zero mean and variance 1 and uncorrelated with v.

(a) Assume that $n_a = n_b = 1$. To what values are the estimates of a_1 and b_1 converging when $N \to \infty$? What is the variance of these estimates as a function of N? [4p]

(b) Assume instead that $n_a = 2$ and $n_b = 1$. To what values are the estimates of a_1, a_2 and b_1 converging when $N \to \infty$? What is the variance of these estimates as a function of N? [4p]

(c) What can you say in general for the estimated values of the parameters and for the variance of these estimates when we vary $n_a \geq 1$, $n_b \geq 1$ for this system? [2p]

3. The data for this exercise are in a file called `sysid_data_20181029.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_20181029.mat`

- copy the file to your current directory and then load it into your Matlab workspace (typing `load sysid_data_20181029.mat` at the Matlab prompt).

Inside `sysid_data_20181029.mat` you will find the sampled signals u and y (the sample time is $T_s = 0.5$).

(a) Construct one or more appropriate black-box models fitting the data, with the constraints that the total number of parameters is ≤ 8 and that the fit to validation data is at least 90%. Report:

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

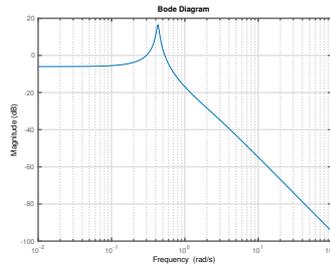Discuss and comment your choices and results. [8p]

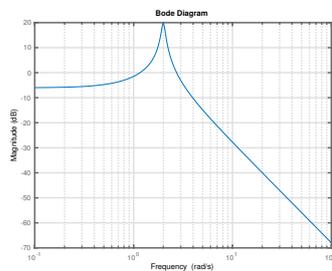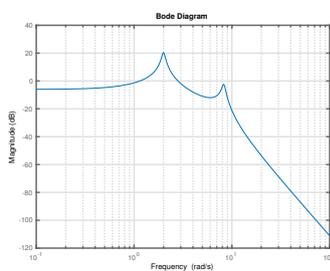(b) To which of the following Bode plots is your model most similar? [2p]
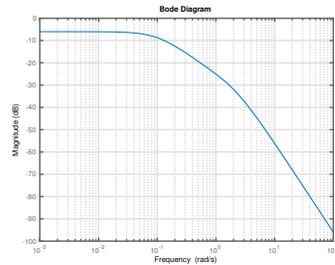
(a)

(b)

(c)

(d)

4. Consider the dishwasher machine of Fig. 2(a), in which the water (of density ρ) is pumped from the bottom of the tank through a pipe and then sprayed back in through the water sprayers. The flow of water
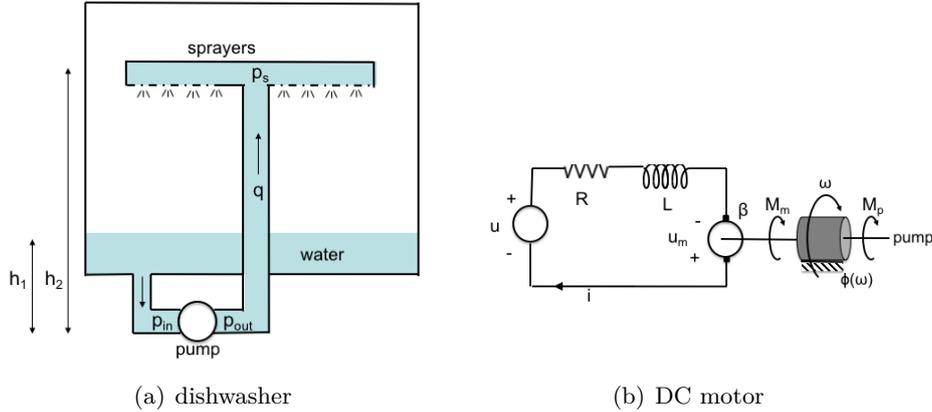

(a) dishwasher   (b) DC motor

Figure 2: Exercise 4

up the pipe is q, and the water pressure at the sprayers, p_s, is related to the flow q by the friction-like law

$$p_s = \psi(q).$$

The pump can be described approximately as

$$q = k_p \omega$$

$$\Delta p = p_{out} - p_{in} = \frac{1}{k_p} M_p$$

where ω is the pump angular velocity, M_p is its torque, k_p is a constant, and p_{in} and p_{out} are the water pressures upstream and downstream of the pump. The pump is driven by a DC-motor shown in Fig. 2(b) with EMF constant β (i..e, $M_m = \beta i$, $\omega = \frac{1}{\beta} u_m$), moment of inertia J_m and friction coefficient $\phi(\omega)$. The voltage u is the input of the motor. The pump has no inertia. For simplicity we assume that the water flows in the pipes without losses and that the pipes are always full. The water levels h_1 and h_2 are also assumed constant. Gravitation must be taken into account.

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

(b) Write the state space equations for the system.   [4p]

(c) Assume that $\phi(\cdot)$ and $\psi(\cdot)$ are not invertible: is there any difference in the state space model?   [1p]

5. Consider the DAE model

$$\dot{x}_1 = -2x_3$$
$$\dot{x}_2 = x_1 + 3x_3 + 2u$$
$$0 = x_1 + x_2 - u$$

where u is an input.

(a) What is the index of the system? Motivate your answer.   [4p]

(b) Which of the following feedback laws allow to have a closed loop system with differentiability index $=1$?

$$u = k_1 x_1$$
$$u = k_2 x_2$$
$$u = k_3 x_3$$

[3p]

(c) Consider the feedback law

$$u = k_1 x_1 + k_2 x_2 + k_3 x_3.$$

For which values of k_i is the system uniquely solvable?   [3p]