EXAM IN MODELING AND SIMULATION (TSRT62)

SAL: ISY:s datorsalar

TID: Friday 10th January 2020, kl. 8.00–12.00

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. 9 och kl. 10

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 2020-01-23 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) Why is the ARX model class used so frequently, even though ARMAX or BJ are more general? [2p]

(b) Use scaling to obtain the solution of

$$\dot{x} = -2x^3 + 5$$
$$x(0) = 0$$

from the solution of

$$\dot{z} = -z^3 + 1$$
$$z(0) = 0$$

[2p]

(c) How many state variables do you need to transform

$$\frac{d^{117}y}{dt^{117}} + y^3 = u$$

into state space form? Suggest a choice of state variables in this example. [2p]

(d) The numerical algorithm

$$x_{n+1} = x_n + hf(x_{n+1})$$

is used to solve the system of ODEs

$$\dot{x} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & -10 & 0 \\ 0 & 0 & -100 \end{pmatrix} x$$

For which values of h will the solution be stable? Motivate your answer. [2p]

(e) The system

$$\dot{x}_1(t) = -10x_1(t) + 100x_2(t) - 2u(t)$$
$$\dot{x}_2(t) = -100x_2(t) + 10u(t)$$
$$y(t) = 10x_1(t) + 100x_2(t)$$

is driven by a slowly varying input $u(t)$. Write a simpler model that gives approximately the same output signal. [2p]

2. Consider the "true" system

$$y(t) - 0.5y(t-1) = u(t-1) + e(t) \tag{1}$$

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

(a) Show that the autocorrelation $R_y(1) = E(y(t)y(t-1))$ of the system can be expressed as $R_y(1) = 0.5R_y(0)$. [3p]

(b) To identify the system (1), we use the ARX model structure

$$y(t) - a_1 y(t-1) - a_2 y(t-2) = bu(t-1) + w(t) \tag{2}$$

where $w(t)$ is a white noise independent from $u(t)$. If you use the principle of minimization of the prediction error, which parameters of (2) have an asymptotic estimate that is guaranteed to converges to the exact value? Motivate your answer. [4p]

(c) Assume the system (2) is controlled via a proportional gain

$$u(t) = -k\, y(t-m) \tag{3}$$

where m = delay (in number of steps, i.e., $m = 1, 2, 3 \ldots$). Under the assumption that k is known, for what values of the delay m is the system (2)-(3) identifiable? [3p]

3. The data for this exercise are in a file called `sysid_data_20200110.mat` located in the directory `/courses/TSRT62/exam/`. To load it into your Matlab workspace use any of the following:

   - type in the Matlab window

     `load /courses/TSRT62/exam/sysid_data_20200110.mat`

   - copy the file to your current directory and then load it into your Matlab workspace (typing `load sysid_data_20200110.mat` at the Matlab prompt).

   Inside `sysid_data_20200110.mat` you will find the sampled signals u and y (the sample time is $T_s = 0.1$).

   (a) Compute the frequency function. Is there any sign of resonances?

   [2p]

   (b) Use the data to construct one or more appropriate black-box models. For your best model report:

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

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

4. Consider the hydro-mechanical system shown in Fig. 1, where the pressures p_1 and p_2 are the external inputs. On the right-hand side pipe the fluid of flow Q_2 is subject to a friction which can be expressed as $p_3 - p_2 = rQ_2^2$ (p_3 is the pressure in the pipe before the restriction). The piston has external section A_1 and internal section A_2. The two carts of mass m_1 and m_2 have no friction. The parameters k and b are a spring constant and a friction constant in the damper.

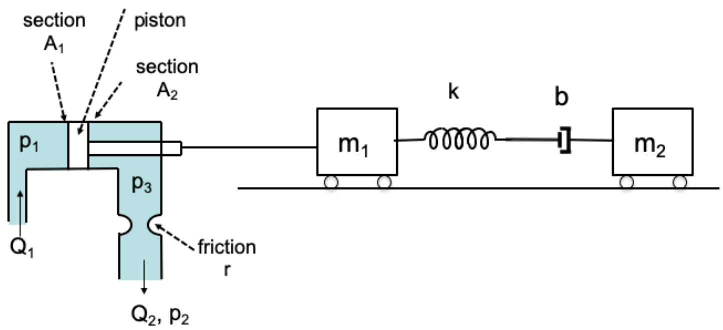

Figure 1: System of Exercise 4.

(a) Set up a bond graph and compute its causality. [5p]

(b) Construct a state space model. [5p]

5. Consider the DAE equation

$$\begin{aligned} \dot{x}_1 &= -x_1 + 2x_2 \\ 0 &= 2x_1 + x_1 x_2 + u \end{aligned} \tag{4}$$

(a) Compute the differentiability index. *[Obs: if at some point you reach a differentiability index* ≥ 2 *then you can stop calculations; no need to go further].* [5p]

(b) Assume that in the DAE (4) you apply the feedback law

$$u = x_2 - x_1 x_2.$$

Is the differentiability index for the closed loop system different from the one at the previous point? [3p]

(c) Assume you can choose u as a PD (P=proportional, D=derivative) controller from the state of the DAE (4). What would you choose in order to have a closed loop system with the lowest possible differentiability index? [2p]