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Experimental Identification – an Interactive Online Course

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Abstract: The aim of the article is to present an interactive online course on experimental identification. Besides teaching materials in the traditional workbook form, new computer based training and electronic media – Internet is used to enable interactive and computer supported way of learning.

Keywords: Education; Identification.

1. INTRODUCTION

University education in engineering curriculum has been shifting from traditional presence form to a combined presence/distance form in the past few years. This change is to a large degree supported by the use of modern information technologies and Internet.

This trend is also visible at the Slovak University of Technology and a fairly large amount of effort in development of courses is directed to a successful transformation to effective use of information technologies, removal of manual and repetitive work. At the Department of Process Control, several courses have been transformed, for example Process Dynamics (Bakošová and Fikar [2006]), Laboratory Exercises of Process Dynamics, Operating Systems (Fikar and Čirka [2005]), and Automatic Control Fundamentals (Bakošová et al. [2006], Fikar et al. [2007]).

In the majority of cases, open source software is preferred. The learning management system (LMS) Moodle (`http://moodle.org`) has been used for administrative part of the education process. Being open source, it is possible to change some parts that were not in agreement with our aims (for example registration module (Čirka and Fikar [2006]) or random assignment module (Čirka and Fikar [2007])).

For the engineering part of the problem we use MATLAB/Simulink for modelling, control and identification. We have developed several freely available toolboxes. Among them, EXPID and IDTOOL are focused on problems in identification. This paper also presents Internet versions of EXPID.

In this paper, we discuss several issues in two connected e-learning courses on Experimental Identification – lectures and laboratory exercises. Aims of lectures is to provide study material in several formats whereas laboratory exercises concentrate on learning activities (individual assignments, quizzes, etc). Both of them are implemented using LMS Moodle.

2. OVERVIEW OF THE COURSE

The course Experimental Identification at the FCFT STU in Bratislava is intended for undergraduate students in specialisation Process Control. It is divided into lectures and laboratory exercises. There are altogether 13 lectures (two hours each) in the course Experimental Identification (EI) and 13 exercises (two hours each) in the course Laboratory of Specialisation (LS). The new self-learning package covering all topics of the course has been established on the Internet. The idea is that the net course will in the future substitute the presentation form of lectures and exercises, so that the whole course could be studied totally as a self-study. Although the course is still lectured in the normal way, students are encouraged to master the exercises individually. The Internet suite has several components:

- study materials, files for download, information about the course,
- Internet version of all course topic problems,
- on-line quizzes and preparation for written tests,
- Moodle e-learning portal for gradebooks, attendances, quizzes, etc.

Both EI and LS courses are accessible on the self-educational portal "E-learning on FCFT STU" for students. This portal is located on the server of the Institute of Information Engineering, Automation, and Mathematics FCFT STU (`http://www.kirp.chtf.stuba.sk/moodle`). The current version of this portal uses the learning management system Moodle 1.8.

3. E-LEARNING IN THE COURSE EXPERIMENTAL IDENTIFICATION

The aim of e-learning in the course Experimental Identification is to offer basic information about the course (recommended literature, rules for the examination) and supply study materials (lecture book in pdf) so that students can access them freely and the teacher can update them when needed. The course in Moodle is split into 13 weeks. Each week contains the title of a discussed theme, short content of the talk and the lecture slides in the pdf format. Students have an opportunity to become familiar with the theme which will be presented and they can identify parts which are difficult to understand. In addition, occasionally one student prepares the lecture by himself and gives it to others with comments of the lecturer. This aims to better understand the material, to stimulate discussions during the lecture, and to improve presentation skills.

4. E-LEARNING IN THE COURSE LABORATORY OF SPECIALISATION

Similar situation occurs in the e-learning in the course LS. This course in Moodle is also split into 13 weeks. Students have to solve 5 complicated problems during the semester. Each student has her/his own assignment. MATLAB/Simulink is used as a simulation environment. Problems consist of the following parts:

- Identification from step responses I
- Identification from step responses II
- Frequency analysis
- Recursive least squares method
- Modifications of recursive least squares

Note: We have implemented a series of MATLAB scripts and functions that generate random numbers for a particular problem, solve it, generate data–files (in ASCII or binary code), and create assignments and results as HTML files (Fikar et al. [2007]).

The task of the students is to create electronic reports that include obtained results. These reports are then submited to lecturers via Moodle. The block for submissions contains information about the expiration date for assignment submission and the size of the submitted document. The teacher has a possibility to rate students in the frame of the same block. Here, it is possible to set up the maximum number of points for individual tasks. The teacher has a possibility to insert remarks and to comment submitted reports. Other used tasks of LMS in the course Laboratory of Specialisation are also attendance monitoring and quickmail block that makes possible to send e-mails to whole group of students or to selected members of a group. Each student can see only her/his own marking.

The contents of assignments is briefly discussed in the following sections. Finally, two support toolboxes implemented in MATLAB are presented.

4.1 Identification from Step Responses I

The first problem covers a data file with step responses of a linear aperiodic n-th order system (with n between 2 and 5), a linear underdamped system of the second order and a nonlinear second order system.

Data files can be of the following formats:

- ascii file – contains data in the comma separated values (CSV format) of multiple step responses (see Fig. 1),
- pdf file – printed version of a step response.

The task is to identify an unknown transfer function as either:

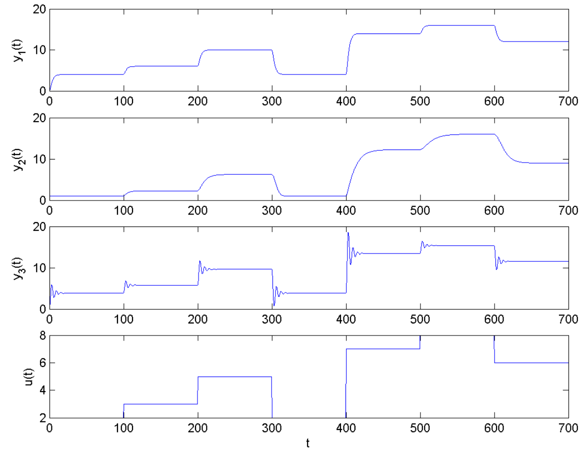

Fig. 1. Step responses of various systems

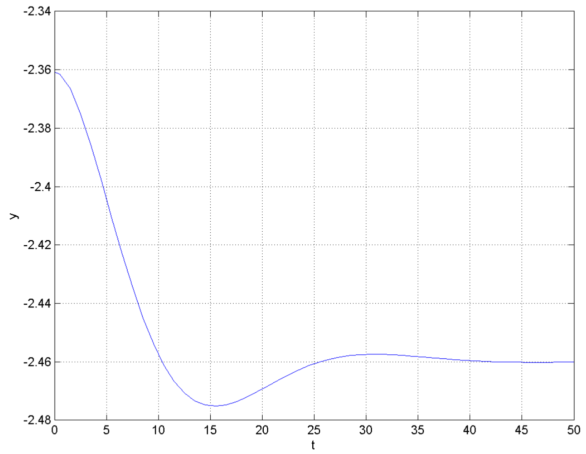

Fig. 2. Measured step response of an underdamped system

- first order system;
- underdamped second order system;
- system of a higher order (using the Strejc and Broida method).

Example of an Assignment: Consider a step response shown in Fig. 2 that has been measured from the steady-state characterised by the input variable at the value $u_0 = 0.2$ *changed to the value* $u_\infty = -0.3$. *Such step response can be obtained for example from a U-tube manometer by a step change of the measured pressure.*

Generated step responses are *ideal*, i.e. without any noise, transport delay, parasitic dynamics, etc.) so that students get acquainted with basic step response identification.

Students have the EXPID toolbox at disposal and its modifications described below. The toolbox is used to check correctness of their solution.

4.2 Identification from Step Responses II

The second assignment for step response identification uses an unknown black box block in Simulink (mex S-function so that it is not possible for the students to find its

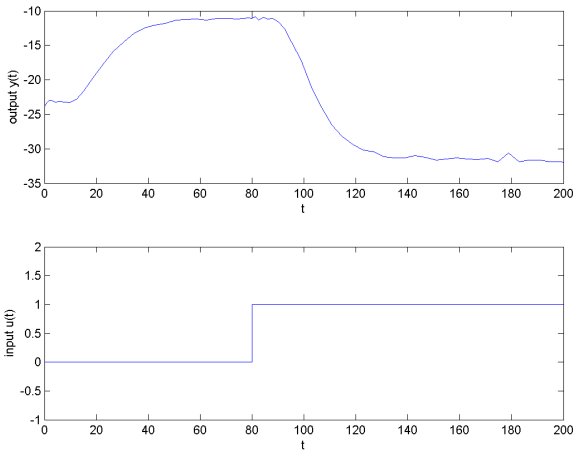

Fig. 3. Step response (top) and input signal (bottom). Note the effect of unsteady initial state

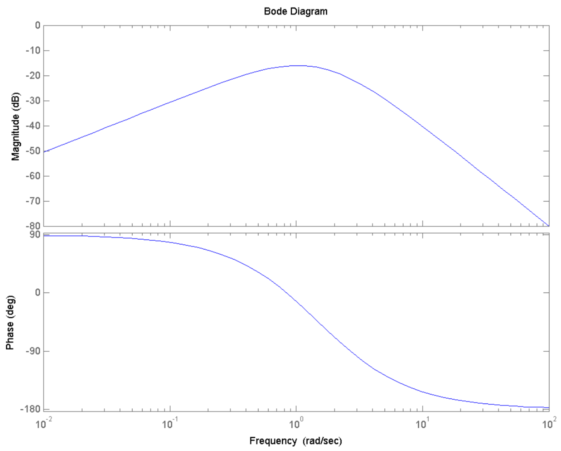

Fig. 4. Bode diagram of an unknown system

structure) using the same methods as above. The black-box model is noisy, contains time delay, and it is not in steady state at the beginning (see Fig. 3). For the future, we plan to implement virtual/remote laboratories so that it will be possible to measure step responses via Internet.

4.3 Frequency analysis

This assignment consists of two main parts. In the first, students obtain a Bode diagram of an unknown process (Fig. 4). The aim is to identify the corresponding transfer function.

The second part considers again the black-box model and students have to estimate its frequency response and to identify its transfer function.

4.4 Recursive Least Squares Method

Students write their own implementation of the RLS method as a Simulink S-function. This function is then used to identify a known linear system in continuous and discrete time domains. To do so, filtered derivatives or differences of inputs/outputs are needed. Verification of results is easy as students already know the parameters of the models.

4.5 Modifications of Recursive Least Squares

The last assignment combines all preceding steps. Students identify the black-box model using the IDTOOL toolbox which automatically creates filtered derivatives and differences. Here, students concentrate on issues regarding noise, normalisation of signals, unknown time delay, etc.

5. COMPUTER BASED SUPPORT IN LEARNING

Several toolboxes and aids have been implemented in MATLAB/Simulink to support education. This paper introduces two of them – EXPID and IDTOOL toolboxes. Both depend only on MATLAB a Simulink. External toolboxes are not required.

5.1 EXPID Toolbox

EXPID toolbox (Dováľ et al. [2007]) is a GUI application (Fig. 5) that simplifies the process of transfer function identification from step responses based on measured data. The identification procedure in this case is as follows:

(1) Measured data file is loaded (Fig. 5 – top). Data file is in CSV format without any headers.
(2) Time, input, and output signals are assigned to respective columns (rows). To check correctness, plots of respective variables can be inspected (Fig. 6 – left).
(3) If filtration of signals is required, the filter parameters are set.
(4) The desired transfer function structure is selected and the identification procedure is started. The results are the identified parameters (Fig. 5 – bottom) and graph (Fig. 6 – right) with comparison of the original and the estimated system.

Note: Somebody can argue that students can misuse the toolbox for the solution of assignments without understanding the underlying theory. However, assignments contain questions to intermediate results that are not provided by the toolbox.

The EXPID toolbox can be used under MATLAB 6.x and 7.x. The installation procedure is very easy. Just add the path to the directory where you have copied all the files to the standard MATLAB path. To run the GUI, simply write `expid` at the MATLAB command line.

Two modifications of EXPID toolbox have been created that are suitable for Internet. The first one is based on the MATLAB Web Server (MWS) and the second one is implemented entirely in the scripting language PHP.

MATLAB Web Server version All tasks in the exercises are based on MATLAB/Simulink. During the laboratory course students can use PC with MATLAB where the tasks can be solved. To allow the students to use the same or similar working environment individually on their home computers or even using an Internet connection, we use the MATLAB Web Server. MWS is a cgi-bin application that is used to launch MATLAB script files (m-files) remotely.

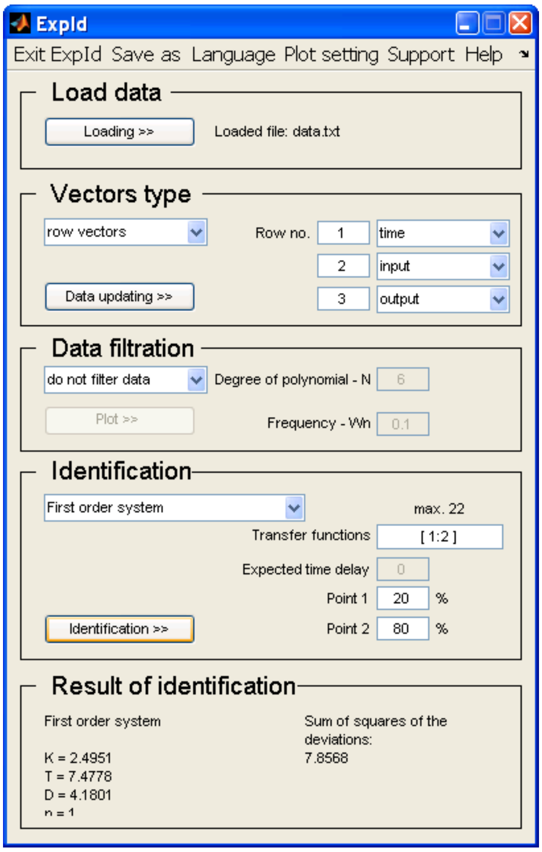

Fig. 5. EXPID Toolbox

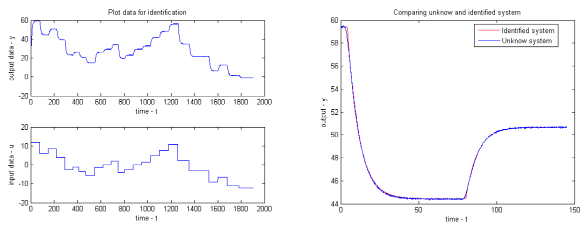

Fig. 6. Input data (left) and step responses of the identified and the unknown system (right)

The user can give parameters that are used during the m-file execution. With MWS, almost all built-in and self-written MATLAB functions can be called from the m-file, including functions that produce plots to be shown to the user. We have implemented a series of a relatively self-contained modules. It is possible to use these modules also in other subjects taught. Modules can be changed easily with minimal cost. The following set of step responses identification related problems can be solved:

- first order system
- damped and underdamped second order system
- higher order system (Broida and Strejc method)

The resulting MWS application is available at `http://www.kirp.chtf.stuba.sk/~cirka/expid` (in Slovak).

PHP version The second implementation modification is the module EXPIDPHP. MATLAB Web Server has not been supported by Mathworks since 2006b and we have

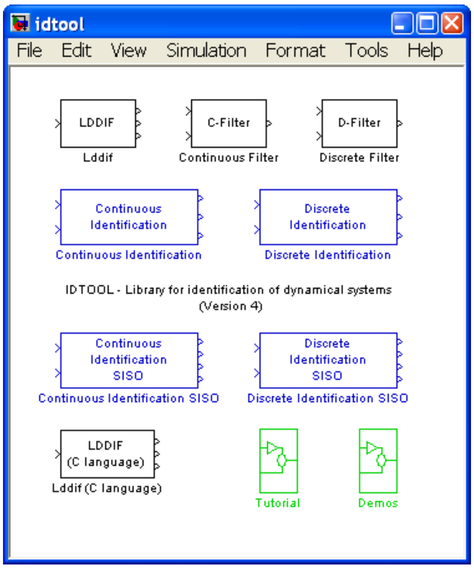

Fig. 7. IDTOOL library for identification of dynamical systems

to keep separate installation and licences of 2006a for this purpose.

Therefore, we have decided to implement the toolbox using the scripting language PHP without any dependence on MATLAB. Possible drawback is the non-existence of certain MATLAB functions that need to be implemented from scratch. The advantage is the open source nature and broad acceptance of PHP. Moreover, interesting possibilities exist with connection to a database engine (for example MySQL).

5.2 IDTOOL toolbox

The dynamical system identification toolbox IDTOOL for MATLAB/Simulink (Fig. 7) implements blocks for continuous-time and discrete-time recursive least squares parameter estimation methods, respectively.

The identification method used as a work-house routine is LDDIF — recursive least squares algorithm with exponential and directional forgetting by Kulhavý and Kárný [1984]. To improve the tracking performance, the corrections as suggested by Bittanti Bittanti et al. [1990] are implemented. In the principle, the corrections influence the covariance matrix of the estimated parameters by adding some multiple of identity matrix.

This recursive estimation algorithm for given observation vector $\boldsymbol{\phi}(t)$ and parameter vector $\boldsymbol{\theta}(t-1)$ can be described by the following equations:

$$\boldsymbol{\varepsilon}(t) = \boldsymbol{y}(t) - \boldsymbol{\phi}(t)^T \boldsymbol{\theta}(t-1)$$

$$r(t) = \boldsymbol{\phi}(t)^T \boldsymbol{P}(t-1) \boldsymbol{\phi}(t)$$

$$\boldsymbol{k}(t) = \frac{\boldsymbol{P}(t-1)\boldsymbol{\phi}(t)}{1 + r(t)}$$

$$\beta(t) = \begin{cases} \varphi - \dfrac{1-\varphi}{r(t)} & \text{if } r(t) > 0 \\ 1 & \text{if } r(t) = 0 \end{cases}$$

$$\boldsymbol{P}(t) = \boldsymbol{P}(t-1) - \frac{\boldsymbol{P}(t-1)\boldsymbol{\phi}(t)\boldsymbol{\phi}(t)^T\boldsymbol{P}(t-1)}{\beta(t)^{-1} + r(t)} + \delta \boldsymbol{I}$$
$$\boldsymbol{\theta}(t) = \boldsymbol{\theta}(t-1) + \boldsymbol{k}(t)\boldsymbol{\varepsilon}(t)$$

where φ is the exponential forgetting parameter. The initial values for the algorithm are usually $\varphi = 0.985$, $\boldsymbol{P}^{-1}(0) = 10^6\boldsymbol{I}$, $\delta = 0.01$.

The toolbox contains blocks for the identification of SISO (MIMO) linear time invariant systems. The toolbox supports only polynomial (transfer function) representation. Details about the toolbox have been published in Čirka et al. [2006].

6. CONCLUSIONS

The aim of this paper was to show an example of a course on identification and usage of some information and communication technologies in it. It is clear nowadays that although the contents of the course should not change substantially, its methods can and should reflect new methods and computer based learning.

Two toolboxes are used throughout the course. EXPID toolbox can help students to reduce time and possibility of errors in step response identification. IDTOOL is used not only for educational purposes but in research in the area of real time and adaptive control as well.

The course makes use of the techniques described in this paper for the first time. However, we have very good experience from other courses where similar technologies have been used. One major advantage of these technologies is that they allow on-line access to the course materials and exercises. This provides the students with the possibility to practice their skills and get an instant feedback about their performance. From our experience we can say that electronic learning increased the interest of students in the course, as well as in control in general.

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