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IDENTIFICATION FOR CONTROL OF MECHATRONIC SYSTEMS USING MATLAB/SIMULINK AND DSPACE PLATFORM

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Abstract: *Open loop and closed loop mechatronics systems identification are important for most of the applications in this field, especially when operating at high movement speed and/or accelerations. This paper presents the main steps to be taken to obtain a sufficiently precise model necessary especially when using model based control strategies. To identify the model parameters the recursive algorithm of least squares is used. The algorithm is implemented on-line to obtain a DC motor model using dSpace-Matlab platform. Finally, the paper presents experimental results. The experiments are useful for implementation of advanced control strategies.*
Key words: *Mechatronics systems, on-line identification, dc motor, Matlab, dSpace.*

1. INTRODUCTION

Knowledge of the controlled system characteristics is important in any industrial application [1]. Especially control and design for high performance mechatronics systems requires detailed information regarding process components, with his linear/nonlinear aspects, as well as static and dynamic characteristics [2].

DC engines as components of mechatronics systems are widely used for industrial control applications due to their advantages such as ease of position and speed control and for wide range of usability [3]. Therefore studying the operational behavior of DC motor is a useful effort for the analysis and control of many practical applications [1-3].

In modeling of a DC motor connected to a load through a shaft, a general approach is to neglect the non-linear effects and to build a transfer function that approximates the input/output relation of the DC motor with a load. This assumption is satisfying for many conventional control problems.

However if the DC motor runs at low speeds and rotates in both ways or if the operating domain is wide and requires high precision, the assumption that the non-linear effects are negligible may lead to highly significant model errors which implies a low quality control system [1-3].

When the physical system structure and/or the parameters are not accessible or time or operating conditions dependent mathematical model of the system may not be obtained. In this case, the system parameters can be obtained using identification procedures. Linear system identification is a mature research field providing a lot of methods [4,5,6].

In electromechanical systems like DC motors, based on data acquisition, examination and analysis for inputs/outputs experimental identification processes permits to obtain the system model parameters.

Of course, to raise the performances of control systems aspects regarding the non-linearity of the systems, Coulomb friction, stick-slip, backlash and have to be taken into consideration [7-9].

This paper addresses mainly to linear modeling problems and on mechanical system identification based on DC motors that don’t change the direction and do not have non-linearity such as Coulomb friction and dead zones.

The identification algorithms are implemented on-line to obtain a DC motor model using dSpace-Matlab platform. Finally, the paper presents experimental results and conclusions. The experiments are useful for implementation of advanced control strategies.

2. MATHEMATICALY MODEL

The mathematical models of the mechatronics systems can be obtained based on analytical approaches (using physics laws) or by experimental approach. Concerning the analytical approach, dependencies between the physical variables of the system are determined, mathematical equations are obtained such as algebraic equations, differential, partial derivatives, finite differenced equations etc. Determining the mathematical model implies using both theoretical and experimental procedures; high efficiency is obtained using the both procedures sequentially.

The obtained model can be really complex, thus implying to simplify it by linearization of the non-linear equations (if the system works in the vicinity of a nominal point), the approximation of partial derivative by ordinary differential equations as well as lowering the ordinary differential equations order.

Many times the obtained equation system cannot be explicitly solved, but the equations provide useful information for experimental analysis. A drawback of analytical modeling is high time such an approach requires; moreover, the models obtained analytical are generally complicated leading to complex control systems.

Simplifying such models is not always possible without losing the analytical modeling advantage; many times the simplifying effect is difficult to quantify; moreover there are a lot of processes that do not have well known objective laws.

The experimental approach has as purpose obtaining a mathematical model based on measuring the input/output signals. A priori knowledge of the process is used, obtained based on theoretical analysis or by previous measurements then the input and output signals are measured and through an identification procedure the link between the measured variables is established. The inputs may be the ones from normal functioning or can be introduced artificially.

The identification can be parametric or nonparametric if the model structure is known or not. The experimental model contains as parameters numerical values which functionally related to the physical data remains unknown. It generally describes the momentarily dynamic behavior of the system, is obtained with little effort and can be used for example for driving or predictive variables. Experimental analysis can be used for reevaluation of theoretical model; the modeling process becomes an iterative process.

3. SYSTEM IDENTIFICATION

Identifying the dynamic models parameters is important for model based advanced control algorithms, validation of the results obtained by simulation and precise path-planning algorithms. Especially in mechatronics model based control is important to increase the accuracy and safety of operation. The purpose is to obtain a mathematical model that can reproduce as exact as possible the real system so the prediction error of the outputs is minimized.

The steps used to identify the systems:

1. Design of the experiment: choosing the equipment and identifying strategy
2. Determining the structure model. Nonparametric models based on transitory answer analysis or frequency response can be chose, as well as parametric models based on differential equations or neural networks.
3. Creating the identification experiment which implies the choice of excitation signal (pulse, sinusoidal, random) system excitation, output data acquisition for a determined time period.
4. Choosing the identification algorithm
5. Validating the results.

The last step, the validation of the model permits the verification of the fact that the model satisfies the precision specifications. If the model doesn’t verify the validation tests then one or more steps of the procedure are resumed and some choices are reconsidered.

The general form of a recursive identification algorithm is presented in eq. 1:

$$\theta(t) = \theta(t-1) + K(t)(y(t) - \hat{y}(t)) \quad (1)$$

The term $\theta(t)$ is the model parameter vector at time *t*. The terms $y(t)$ and $\hat{y}(t)$ represents the value of the output and the output prediction respectively at the moment *t,* prediction based on observations up to time *t-1*.

Gain factor $K(t)$ determines the speed which the current prediction error changes the model parameters vector. The term $K(t)$ can be written as:

$$K(t) = Q(t)\psi(t) \quad (2)$$

where: $\psi(t)$- is the gradient with respect to θ

$Q(t)$- is a matrix that influences the gain factor adaptation as well as the direction in which this adaptation is made.

The $Q(t)$ matrix can be made in several ways. An approach is the exponential penalization of old measurements; therefore the new measurements to have a high share on the search of model parameters. This penalization depends on the forgetting factor λ, parameter chose between 0.97-0.995 margins.

The identification algorithm can be written as [4..6]:

$$Q(t) = \frac{P(t-1)}{\lambda + \psi(t)^T P(t-1)\psi(t)} \quad (3)$$

$$P(t) = \frac{1}{\lambda}\left(P(t-1) - \frac{P(t-1)\psi(t)\psi^T(t)P(t-1)}{\lambda + \psi(t)^T P(t-1)\psi(t)} \right) \quad (4)$$

It's observed that the model parameter vector $\theta(t)$ at the actual moment is equal to the old parameter vector added by a correction factor depending on the actual output and the estimated output in the precedent moment for the actual moment. *P* matrix is used in the model, named covariance matrix, which calculates iteratively by relation (4).

The name of the algorithm is Forgetting Factor Approach to Adaptation, with forgetting factor λ.

4. EQUIPMENT USED FOR IDENTIFICATION

The DC motor from *HPS Motor Board* module is used [10] (fig. 1). The module permits the coupling of a load (connectable mechanical centrifugal mass, realized electronically). Speed control and experimental system identification is made.

Motor features:

- input voltage ±12V;
- speed 0-7000 rpm.

The motor is controlled through DS1104 module [11] connected straight to a PC BUS. To read the speed the sensor (dual-channel encoder for direct acquisition of speed and direction of rotation) included in the *Motor Board* module is used. The measured data are processed through an electronic module, sent to ADC converter of DS1104 module and then to the PC.

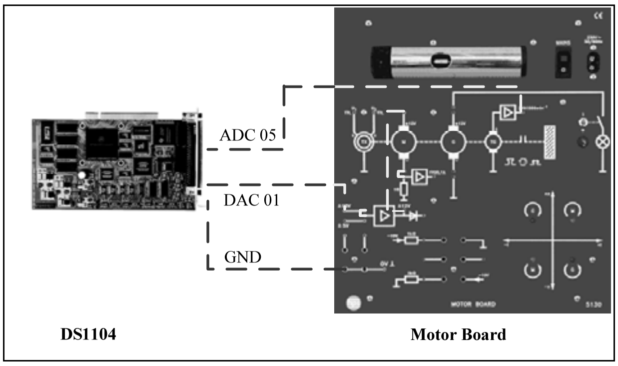

Fig. 1 The scheme of the application

5. EXPERIMENTS

The identification algorithms as well as the identification procedure are implemented and tested through Matlab-dSpace platform.

The identification algorithm will be used for on-line identification of DC motor parameters, when the motor works in a linear considered zone and without changing of direction. The Simulink model designed to implement the experiment is presented in figure 2.

The test signal for the motor is provided by the *Signal Generator* block. The generator produces square signals of different amplitudes and frequencies. The motor is connected to the dSpace board through a DAC port (command signal) and an ADC port (measured signal).

Booth signals are used by the *Identification* block to estimate the ARX model and to simulate the behavior of the system.

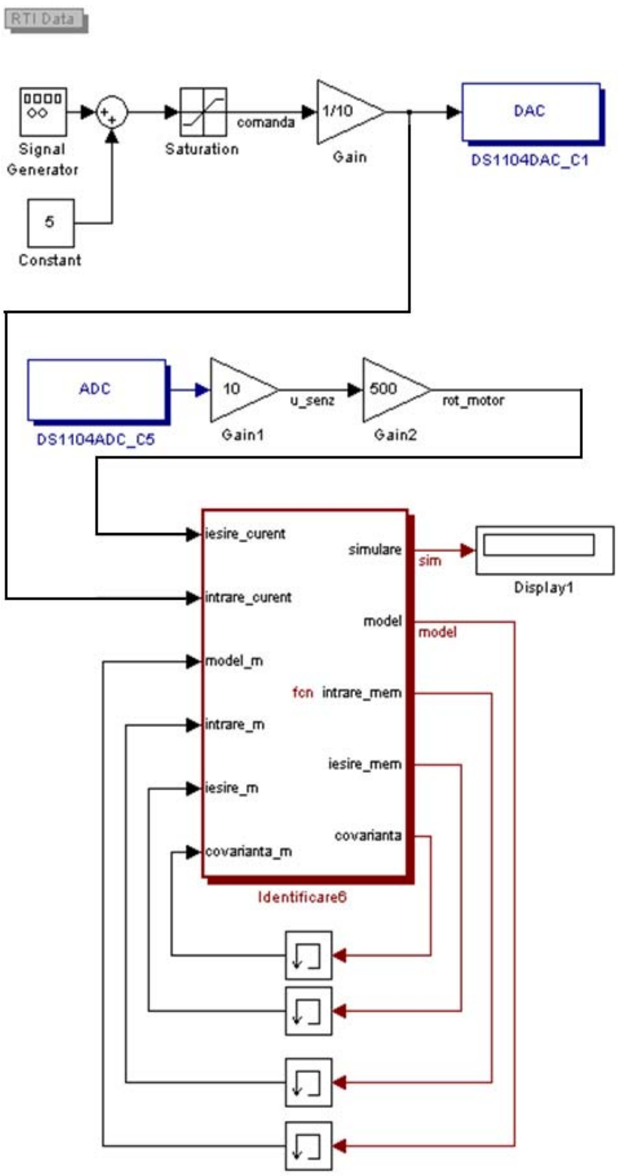

Fig. 2. Simulink Model

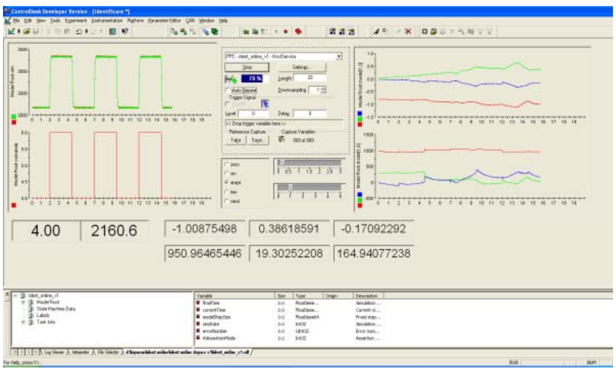

Fig. 3 ControlDesk user interface

The Simulink model is loaded on the dSpace platform and runs in real time. The values and variation of the model parameters can be observed in the ControlDesk user interface (fig. 3). The interface allows also to change the excitation signal and its parameters (signal type, amplitude, frequency).

The sampling interval of the data acquisition is chosen to be 5 [ms].

The linear model approximating the system behavior is:

$$a_1 y(t) + \dots + a_n y(t-n) = \\ b_1 u(t-1-d) + \cdots + b_m u(t-m-d) \quad (5)$$

where $y(t)$ is the output signal (angular velocity), $u(t)$ is the control signal (input voltage), m and n are the dimensions of the model, d is dead time, $a_{1..n}$, $b_{1..m}$ are the parameters of the model and usually a_1=1.

Parameters (n, m, d) define the model structure. This black-box type model is easy to use but the model does not use the physical parameters of the process; as a result it is not possible to obtain further information using these parameters.

Model structure was chose based on experimental tests: n=4, m=3, d=1.

The applied test signal has a random shape between 3.5 and 5.5 [V] with a frequency of 0.5 [Hz] (Fig. 4).

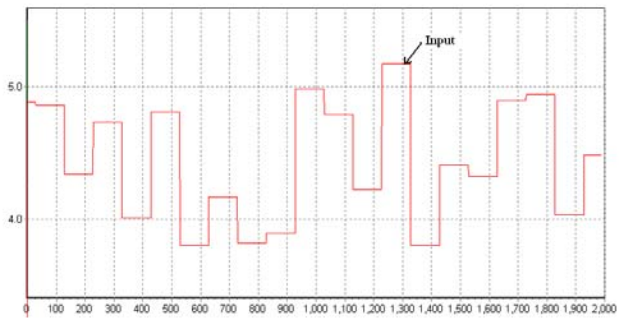

Fig. 4 Input signal

In fig. 5 open loop system response (motor speed) is presented, as well as the evolution of the gain factor identification and of the prediction error In fig 5 the gain factor is multiplied by 3.5 and the prediction error is exprimated as $1800 + 10 \cdot abs(error)$.

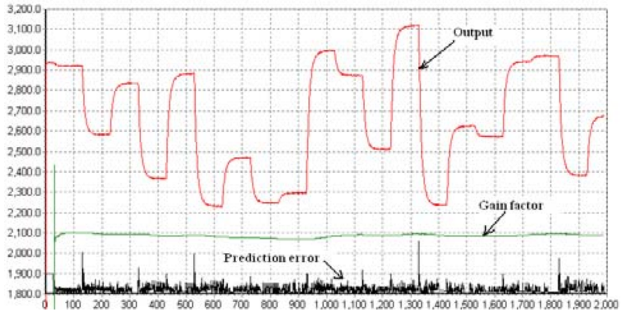

Fig. 5. Output, gain factor and prediction error

The identification algorithm used a forgetting factor $\lambda = 0.995$. The initial values of $a_{1..n}$, $b_{1..m}$ parameters are null.

It's observed (fig. 6, fig.7) the fact that $a_{1..n}$, $b_{1..m}$ parameters may vary significantly. However as shown in fig. 5, the gain factor doesn't vary significant and the poles and zeros variation (except time sample interval 0..200) is low.

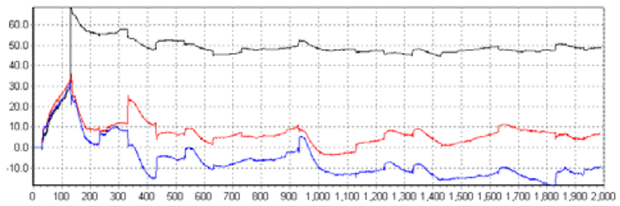
Fig. 6. Parameters identification - $b_{1..m}$

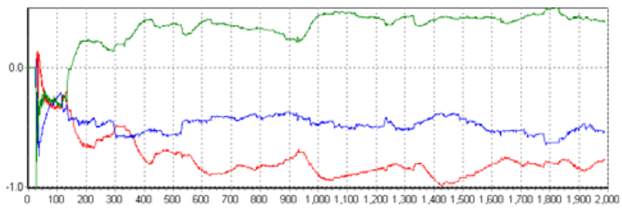
Fig. 7. Parameters identification - $a_{1..n}$

Poles and zeros position after 2000 sampling steps is presented in fig. 8. To compute the poles/zeros distribution it is used Barstow method.

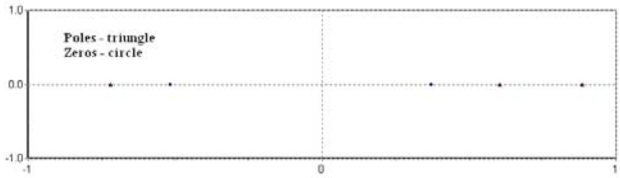

Fig. 8. Poles and zeros of the model (step 2000)

For model validation the method of mean square error (MSE) is used [12].

$$MSE = \frac{1}{N}\sum_{t=1}^{N}\left(y(t) - \hat{y}(t)\right)^2 \qquad (6)$$

where $y(t)$ is the system output, $\hat{y}(t)$ is the predicted output obtained from the model and N is the number of samples used in the identification process.

The difference between the estimation and the system response is about 0.49%, so the method can be used to identify the plant model without much loss in accuracy.

6. CONCLUSIONS

The paper presents aspects regarding experimental identification of the mechatronics systems, particularly of the DC motors. Using experimental identification methods permits implementing advanced model based control algorithms. If the motor changes direction non-linear characteristics have to be taken into consideration.

7. REFERENCES

[1] E. Camacho, C. Bordons, *Model Predictive Control,* Springer-Verlag, 1999.

[2] E. Irmak, R. Bayindir, I. Colak, M. Soysal, A remote laboratory experiment for 4-quadrant control of a DC motor, Computer Applications in Engineering Education, Volume 19, Issue 4, pages 747–758, December 2011

[3] E. A. Feilat, E.K. Maaitah, Identification and Control of DC Motors Using RBF Neural Network Approach, International Conference on Communication, Computer and Power (ICCCP'09) Muscat, February 15-18, 2009

[4] S. Calin, Th. Popescu, B. Jora, V. Sima "*Adaptive and flexible control of industrial processes*", Ed. Tehnica, Bucuresti 1988 (in Romanian)

[5] Tertisco M., Stoica P. - Identificarea si estimarea parametrilor sistemelor, Ed. Academiei, 1980.

[6] Soderstrom T., Stoica P.- System Identification, Pretince Hall, 1989.

[7] Jun Oh Jang, Gi Joon Jeon, Backlash compensation of nonlinear systems using fuzzy logic, International Journal of Systems Science
Volume 37, Issue 7, 2006

[8] Nordin M, Gutman P. Controlling mechanical systems with backlash—A survey. Automatica 2002;38(10):1633–49.

[9] K.-K. Shyu, Y.-Y. Lee, Identification of Electro-mechanical Actuators within Limited Stroke, Journal of Vibration and Control October 2010 vol. 16 no. 12 1737-1761

[10] http://www.hps-systemtechnik.com/

[11] http://www.dspace.com/en/pub/start.cfm

[12] Tolgay Kara, Ilyas Eker, *Nonlinear modeling and identification of a dc motor for bidirectional operaton with real time experiments*, Energy Conversion and Management, 2003

Identificarea pentru control a sistemelor mecatronice utilizând platforma Matlab/Simulink/dSpace

Rezumat: *Identificarea sistemelor mecatronice ce operează în buclă deschisă sau închisă este importantă pentru majoritatea aplicațiilor din domeniu mai ales atunci când sunt necesare viteze şi/sau accelerații mari de mişcare. În lucrare sunt prezentate principalele etape ce trebuie parcurse pentru obținerea unui model suficient de precis necesar în special în cazul utilizării strategiilor de control bazate pe model. Pentru identificarea parametrilor modelului se utilizează algoritmul recursiv al celor mai mici pătrate. Algoritmul este implementat on-line pentru obținerea modelului unui motor de cc. utilizându-se platforma dSpace-Matlab.*

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