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Real-Time Parameter Estimation of a MIMO System

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***Abstract*— An experiment based method is proposed for parameter estimation of a class of linear multivariable systems. The method was applied to a pressure-level control process. Experimental time domain input/output data was utilized in a gray-box modeling approach. Continuous-time system transfer matrix parameters were estimated in real-time by the least-squares method. Simulation results of experimentally determined system transfer function matrix compare very well with the experimental results. The proposed method can be implemented conveniently on a desktop PC equipped with a data acquisition board for parameter estimation of moderately complex linear multivariable systems.**

***Index Terms*— least-squares method, MIMO systems, System identification,**

I. INTRODUCTION

In control design for industrial processes an efficient real-time parameter estimation scheme is needed. These processes are usually in the form of multi-input multi-output (MIMO) systems with nonlinear dynamics. Prior knowledge of the dynamical relations between individual inputs and outputs often exists, or can be derived without much effort. The remaining part of the problem is to find out the correct parameters of these dynamical relations.

The system identification methods rely heavily on the method of least-squares [1].The least-squares method was first used by Karl Gauss for calculating the planets' orbits at the end of 18th century. Afterwards, the method has been widely accepted as a means for parameter estimation from experimental results. Readily available parameter identification methods have been associated with this method. The method is implemented easily, and can provide convenient closed-form solutions [7].

Identification methods for certain multi-input multi-output dynamical systems are available in the literature [3,6]. In this paper, emphasis is given to derivation of a real-time scheme [1]for parameter estimation of a class of linear MIMO dynamic systems. The method is applied to a MIMO system where the process outputs are pressure in a tank and liquid level in a connected container. Least-squares method was utilized to determine the parameter estimates. The method is implemented on a desktop PC computer equipped with a data acquisition board. An interface tool was developed for capturing and processing the data. The method can be utilized for parameter estimation of a class of MIMO systems, where prior knowledge of the form of dynamical relations between the inputs and outputs exist.

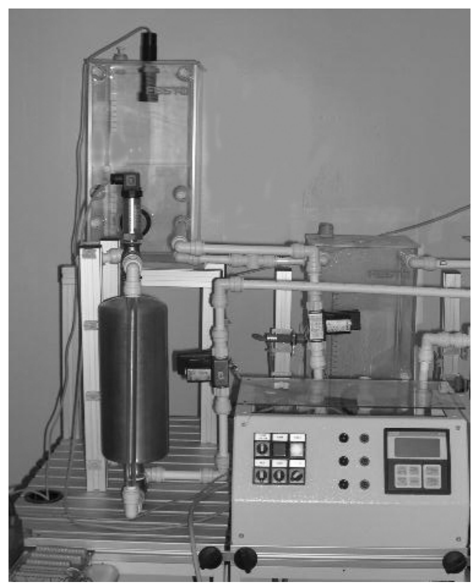

Fig. 1 *A Picture of the pressure-level system*

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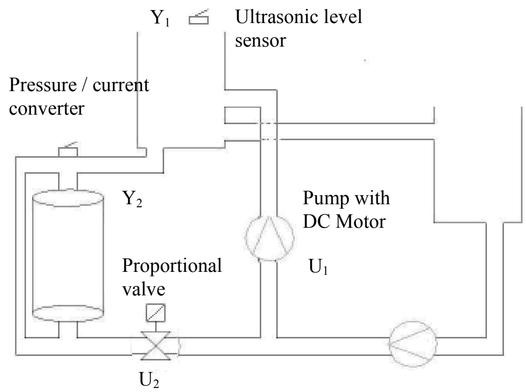

Fig. 2 *Block diagram of the pressure-level system*

II. IDENTIFICATION OF THE PRESSURE-LEVEL SYSTEM BY THE REAL-TIME PARAMETER ESTIMATION METHOD

An experimental method is proposed for modeling of the pressure-level system. A black-box model along with a curve fitting approach was used to identify the input-output behavior of the system [2,5].The pressure-level system has two inputs and two outputs.

The inputs to the system are,

U_1: control signal applied to the pump,

U_2: control signal applied to proportional valve.

The outputs are

Y_1: liquid level output signal,

Y_2: pressure value output signal.

The following 2x2 system transfer function matrix is obtained

$$Y_1(s) = G_{11}(s).U_1(s) + G_{12}(s).U_2(s) \quad (1)$$

$$Y_2(s) = G_{21}(s).U_1(s) + G_{22}(s).U_2(s) \quad (2)$$

The input-output relation of the system is shown in Fig.3.

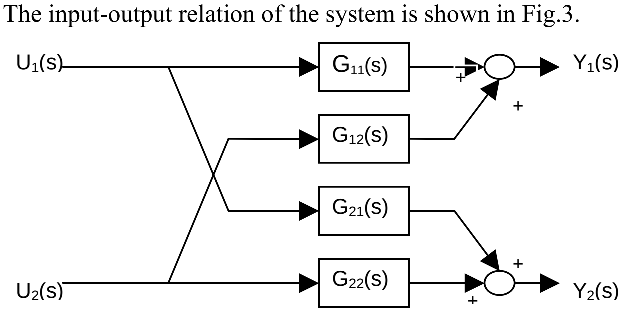

Fig. 3 Input-output model of the system

G_{11} is a transfer function showing the relation between input 1 and output 1. Likewise, $G_{12}(s)$ is the transfer function that shows the effect of input 2 to output 1, $G_{21}(s)$ indicates the effect of input 1 to output 2, and $G_{22}(s)$ indicates the effect of input 2 to output 2.

Initially, a first order transfer function $\frac{K}{\tau s+1}$ is chosen for each input-output relation $G_{ij}(s)$. To find $G_{11}(s)$, an input $U_2=0$ is applied and the relation between input1 (U_1) and output1 (Y_1) is found.

$$Y_1(s)= \frac{K}{\tau s+1} U_1(s) \quad (3)$$

In this equation, for calculating K and τ constants denominators are equalized and constants are left.

$$Y_1(s).\tau s+Y_1(s)=K.U_1(s) \quad (4)$$

$$\frac{\tau}{K} Y_1(s) + \frac{1}{K}\frac{Y_1(s)}{s} = \frac{U_1(s)}{S} \quad (5)$$

Transforming the expression from s-domain to t-domain, the 1/s term is converted to an integrator. Equation for Y_1

$$\frac{\tau}{K} y_1(t) + \frac{1}{K}\int y_1(t)dt = \int u_1(t)dt \quad (6)$$

$$\frac{\tau}{K} y_1(t) = -\frac{1}{K}\int y_1(t)dt + \int y_1(t)dt \quad (7)$$

$$y_1(t) = -\frac{1}{\tau}\int y_1(t)dt + \frac{K}{\tau}\int u_1(t)dt \quad (8)$$

Let’s define the regressors

$$\int y_1(t)dt = \phi_1(t) \quad (9)$$

$$\int u_1(t)dt = \phi_2(t) \quad (10)$$

$$y(t) = \begin{bmatrix} -\frac{1}{\tau} & \frac{K}{\tau} \end{bmatrix} \begin{Bmatrix} \phi_1 \\ \phi_2 \end{Bmatrix} \quad (11)$$

$$\begin{bmatrix} -\frac{1}{\tau} & \frac{K}{\tau} \end{bmatrix} = \theta \quad (12)$$

The output equation can be obtained as below

$$Y = \theta.\phi \quad (13)$$

The regression vector is

$$\theta = \left(\phi^T \phi\right)^{-1} \phi^T Y \quad (14)$$

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Same calculations are also used for $G_{12}(s)$, $G_{21}(s)$, and $G_{22}(s)$. Calculation of system transfer function parameters are not done in real-time. A MATLAB program is used for this operation.

III. INTERFACED USED FOR REAL-TIME SYSTEM MODELING

An interface is designed for calculating the transfer function parameters of the experimental system by the least-squares (LS) method. MATLAB Simulink Real-Time Windows Target Toolbox (RTW) is used for the interface program (Fig.4). Besides, a data acquisition board (NI-DAQ PCI-6024E) is utilized for recording and processing the data. When the interface software runs, signals are applied to system inputs. System outputs are recorded and calculations to determine system parameters are done during run-time.

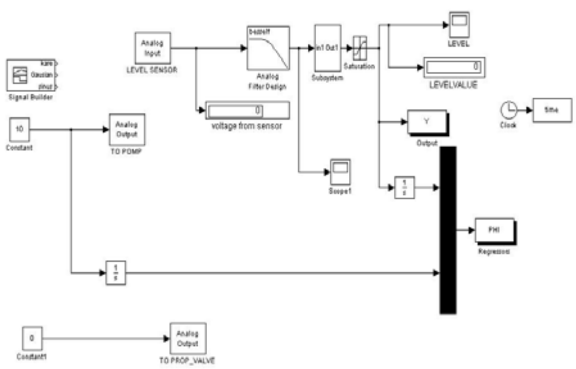


Fig. 4 MATLAB interface for real-time system modeling

The procedure to identify the transfer functions' are described as follows:

To find $G_{11}(s)$:

- U_2 control input is initialized (zero volt is applied to the proportional valve input),
- U_1 control signal is set to several different values (several different voltages are applied to the pump),
- Y_1 output (liquid level in the tank) is measured.

To find $G_{22}(s)$:

- U_1 control input is initialized (zero volt is applied to the pump),
- U_2 control signal is set to several different values (several different voltages are applied to proportional valve),
- Y_2 output (pressure in the tank) is measured.

To find $G_{12}(s)$:

- U_1 control input is initialized (zero volt is applied to the pump),
- U_2 control signal is set to several different values (several different voltages are applied to proportional valve),
- Y_1 output (liquid level in the tank) is measured.

To find $G_{21}(s)$:

- U_2 control input is initialized (zero volt is applied to the proportional valve input),
- U_1 control signal is set to several different values (several different voltages are applied to the pump),
- Y_2 output (pressure in the tank) is measured.

Here ϕ and Y values are recorded. θ is found as

$$\begin{bmatrix} -\frac{1}{\tau} & \frac{K}{\tau} \end{bmatrix} = \theta \quad (15)$$

By using this equation, parameters of G_{ij} transfer function are calculated. At the end of the experiments, elements of system's transfer function matrix are found as below.

$$G(s) = \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} \quad (16)$$

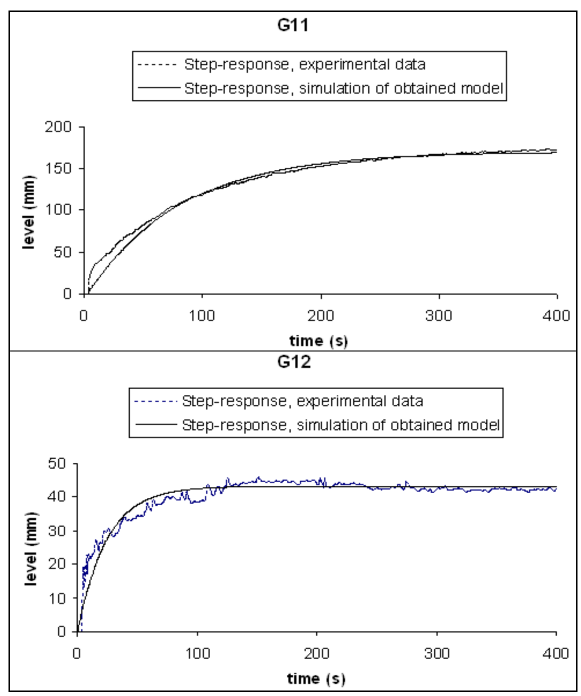
$$G_{11} = \frac{16.97638}{78.74016\,s + 1} \quad (17)$$

$$G_{12} = \frac{4.30343}{24.09639\,s + 1} \quad (18)$$

$$G_{21} = \frac{2.1395}{232.558\,s + 1} \quad (19)$$

$$G_{22} = \frac{9.995875}{2.426595\,s + 1} \quad (20)$$

For comparison, the simulated step responses of the transfer functions obtained by the real-time identification and experimental step-responses of the system are shown in Fig. 5.



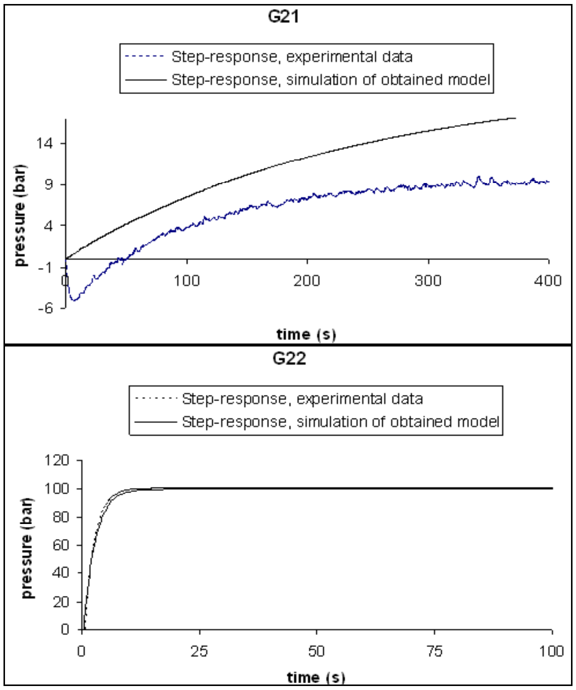


Fig.5 Comparison of experimental step-responses and transfer functions obtained by real-time identification

As shown in Fig. 5, G_{11}, G_{12}, and G_{22} transfer functions that are found by parameter estimation are fairly close to real system attitude. G_{21} transfer function does not reflect the real system's attitude. Because, the real system dynamics is not of a first order dynamics and it is a nonminimum phase system. Thus, G_{21} transfer function is chosen as indicated.

$$G_{21} = \frac{-as + k}{bs^2 + cs + 1} \tag{21}$$

Then, parameters are re-calculated after adding an integrator to the interface in MATLAB. The new transfer function for G_{21}, which express the relation between the input U_1 and the output Y_2 is found.

$$G_{21} = \frac{-57.1756s + 0.98}{141.2236s^2 + 106.193s + 1} \tag{22}$$

Simulated step-response obtained from G_{21} is compared to experimental step-response. Results indicate that the simulation and experimental results follow very closely each other (Fig. 6).

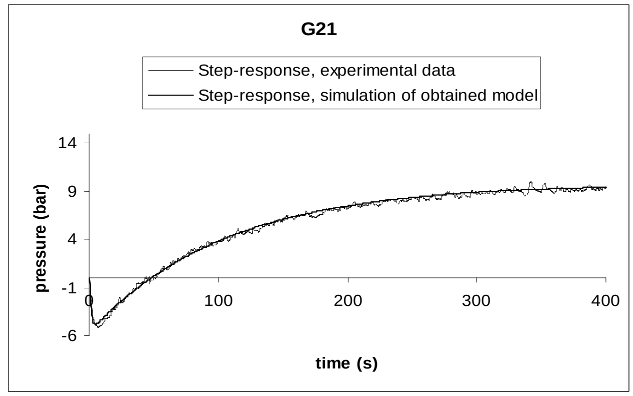


Fig.6 Comparison of G_{21} simulated step-response with the experimental result.

System's transfer function matrix is found as below

$$G(s) = \begin{bmatrix} \frac{16.97638}{78.74016s + 1} & \frac{4.30343}{24.09639s + 1} \\ \frac{-57.1756s + 0.98}{141.2236s^2 + 106.193s + 1} & \frac{9.995875}{2.426595s + 1} \end{bmatrix} \tag{23}$$

For comparison of the identified model with the real system, a MATLAB/Simulink model is formed and tested under various inputs. Fig.7. shows the responses of the system to unit-step applied at both system inputs. Results indicate that the proposed real-time identification method can capture the dynamic behavior of the experimental pressure-liquid level control system successfully.

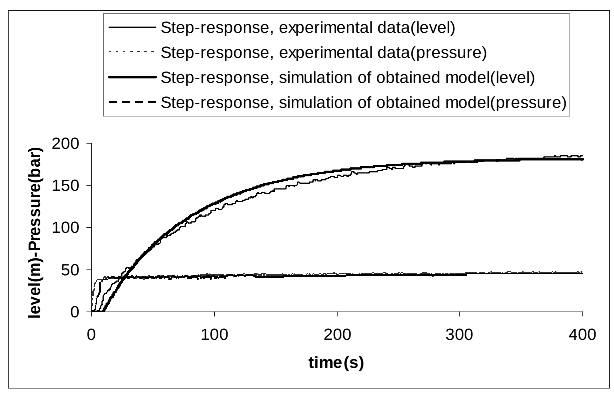


Fig.7. Comparison of simulated system models and experimental unit-step responses

IV. CONCLUSIONS

In this paper a real-time parameter estimation method for a class of linear MIMO systems is developed. The method is applied to an experimental pressure-level process. The prior knowledge of the form of input/output dynamic relations exists. Results indicate that the method can capture the dynamics of the moderately complex dynamic processes with a good accuracy. Easy implementation and less computational burden required make the proposed method a viable alternative to more complicated multivariable system identification methods.

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