Real-Time System Identification Using TMS320C30®

Digital Signal Processor

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ABSTRACT

In order to design a controller for a linear physical plant, the transfer function of the plant must be obtained. A system consisting of Texas Instruments TMS320C30® digital signal processor, an analog interface board and a personal computer is used as a test bench platform for real-time system identification. The recursive least squares algorithm is implemented on the TMS320C30® digital signal processor to determine the coefficients of the plant transfer function in real-time using input-output data from the plant. The program for identification can be called from the Matlab® environment. Three system identification examples are presented.

I. INTRODUCTION

A system which facilitates rapid identification of the transfer function of a control system plant is a useful tool in a control laboratory. A system which consists of a Texas Instruments TMS320C30® digital signal processor (DSP), a custom-built analog interface board (AIB) and a personal computer has been developed for rapid identification of the parameters of a linear plant transfer function. The input and output data from the plant are collected and processed in real-time using a recursive least squares algorithm to determine the coefficients of the plant transfer function. The Bode plots of the identified transfer function and the actual transfer function are compared.

An interface program on the personal computer makes it convenient to run the identification program from the Matlab® environment. The system is described in section II, the identification algorithm and software are presented in section III. Results on the identification of the transfer functions of a passive first order low pass filter, and a passive second order low pass filter, and a second order dc servo system are presented in section IV, conclusions are given in section V.

II. SYSTEM DESCRIPTION

The system for the identification of the parameters of a plant transfer function consists of Texas Instruments TMS320C30® DSP evaluation board, a custom-built analog interface board with two 10-bit A/D converters and two 12-bit D/A converters. The TMS320C30® DSP evaluation board equipped with 16K of memory occupies a slot in the personal computer. The TMS320C30® can perform 33 million multiply-accumulate operations per second. The personal computer is used for developing code, downloading code to the TMS320C30® processor, for collecting the results and displaying the transfer function parameters. The identification program is run from the Matlab® environment.

A block diagram of the system set-up for plant transfer function identification is shown in Figure 1.

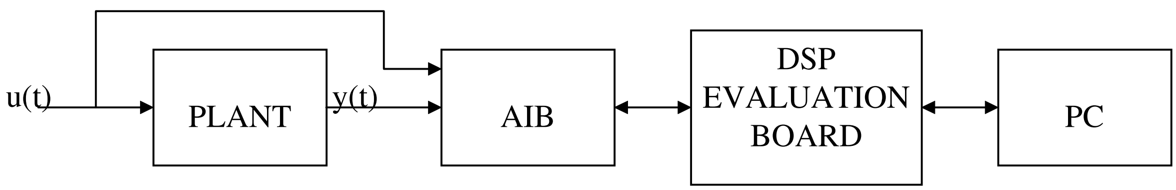

Figure 1 Block Diagram for System Identification

The plant input data u(t) and output data y(t) are digitized by the AIB board and sent to the TMS320C30® for processing.

III. IDENTIFICATION ALGORITHM AND SOFTWARE

Suppose the continuous-time plant to be identified is represented by a transfer function,

$$G_p(s) = \frac{Y(s)}{U(s)} = \frac{N(s)}{D(s)} \quad (1)$$

where N(s) and D(s) are polynomials. Selecting a sampling interval T and assuming that a zero-order hold precedes the plant, an equivalent discrete time transfer function of the plant is,

$$G_p(z) = \frac{Y(z)}{U(z)} = \frac{b_1 z^{-1} + \cdots + b_n z^{-n}}{1 - a_1 z^{-1} - \cdots - a_n z^{-n}} \quad (2).$$

The objective is the determination of a_i and b_i from the plant input-output sequence u(k) and y(k) using recursive least squares algorithm implemented on the TMS320C30® processor [1]. The least squares algorithm is given in the following steps [4]. Let the estimate of the coefficients of the plant transfer function be denoted by a vector,

$$\vec{\Theta} = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \\ b_1 \\ \vdots \\ b_n \end{bmatrix}$$

1. Select a, γ, and N where a=γ=weighting factors=1 for least squares, and N samples.
2. Select initial values for P(N) and $\vec{\Theta}(N)$ were P(N) is an error estimation and $\vec{\Theta}(N)$ are the present estimated system coefficients.
3. Collect $y(0),\ldots,y(N)$,the outputs, $u(0),\ldots,u(N)$, the inputs, and form $\Phi^T(N+1)$, the arma model.
4. Let $k \leftarrow N$.
5. Let $L(k+1) \leftarrow \dfrac{P(k)}{\gamma}\Phi(k+1)\left(\dfrac{1}{a}+\dfrac{\Phi^T(K+1)P(k)\Phi(K+1)}{\gamma}\right)^{-1}$ a new gain correction factor matrix.
6. Collect a new y(k+1) output and u(k+1) input.
7. $\vec{\Theta}(k+1) \leftarrow \vec{\Theta}(k) + L(k+1)\left(y(k+1) - \Phi^T(k+1)\vec{\Theta}(k)\right)$ the next estimate of system coefficients.
8. $P(k+1) = \dfrac{1}{\gamma}\left[I - L(k+1)\Phi^T(k+1)\right]P(k)$ a new error estimate.
9. Form a new $\Phi(k+2)$ using $y(k+1)$ and $u(k+1)$.
10. Let $k = k+1$.
11. Go to step 5.

The recursive least squares algorithm in step 1-11 was programmed in C programming language on the PC. A C compiler was used to translate the C program into assembly language, and the machine code of the assembled program was downloaded to the TMS320C30® processor for execution [2]. A program was written to run the identification program from the Matlab® environment [5-6]. After the computation of the transfer function parameters, the coefficients are displayed on the screen of the PC. A flow chart showing the execution of the recursive least squares algorithm is shown in Figure 2.

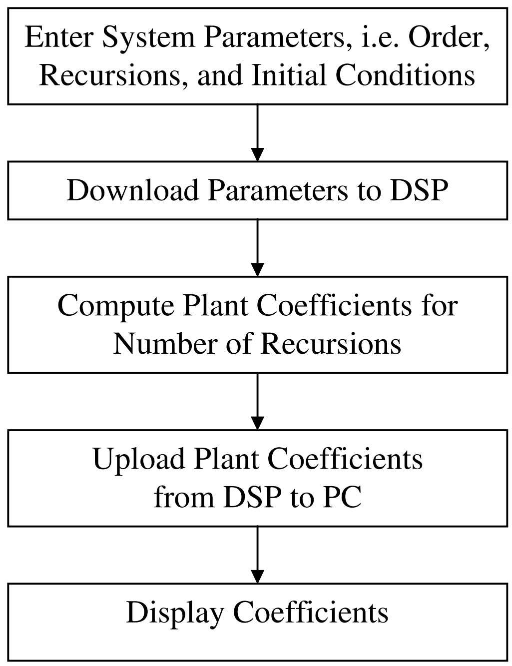

Figure 2 Flow Chart Showing Execution of Recursive Least Squares Algorithm

The computer programs for the identification may be obtained from the authors.

IV. APPLICATION EXAMPLES

Three transfer function identification examples are presented in this section. The first example is a first order passive low pass filter shown in Figure 3

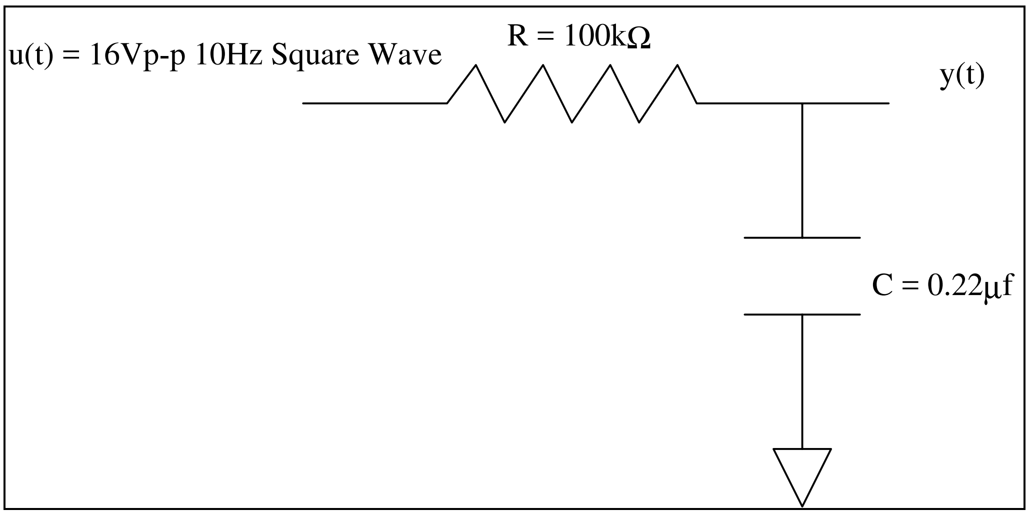

Figure 3 Passive Low Pass Filter

The transfer function is,

$$H_1(s) = \frac{45.\overline{45}}{s + 45.\overline{45}} \quad (3).$$

Using a sampling interval T = 2 x 10^{-4} sec, and a zero-order hold gives the discrete equivalent of (3) as,

$$H_1(z) = \frac{.009z^{-1}}{1 - .991z^{-1}} \quad (4).$$

Using a 10Hz square wave of 16Vp-p amplitude as input signal u(t), the identification algorithm produced an estimated transfer function of,

$$\hat{H}_1(z) = \frac{.0084z^{-1}}{1 - .9911z^{-1}} \quad (5)$$

after 200 recursions. Bode plots which compare the ideal transfer function and the estimated transfer function as the number of recursions is varied are shown in Figure 4.

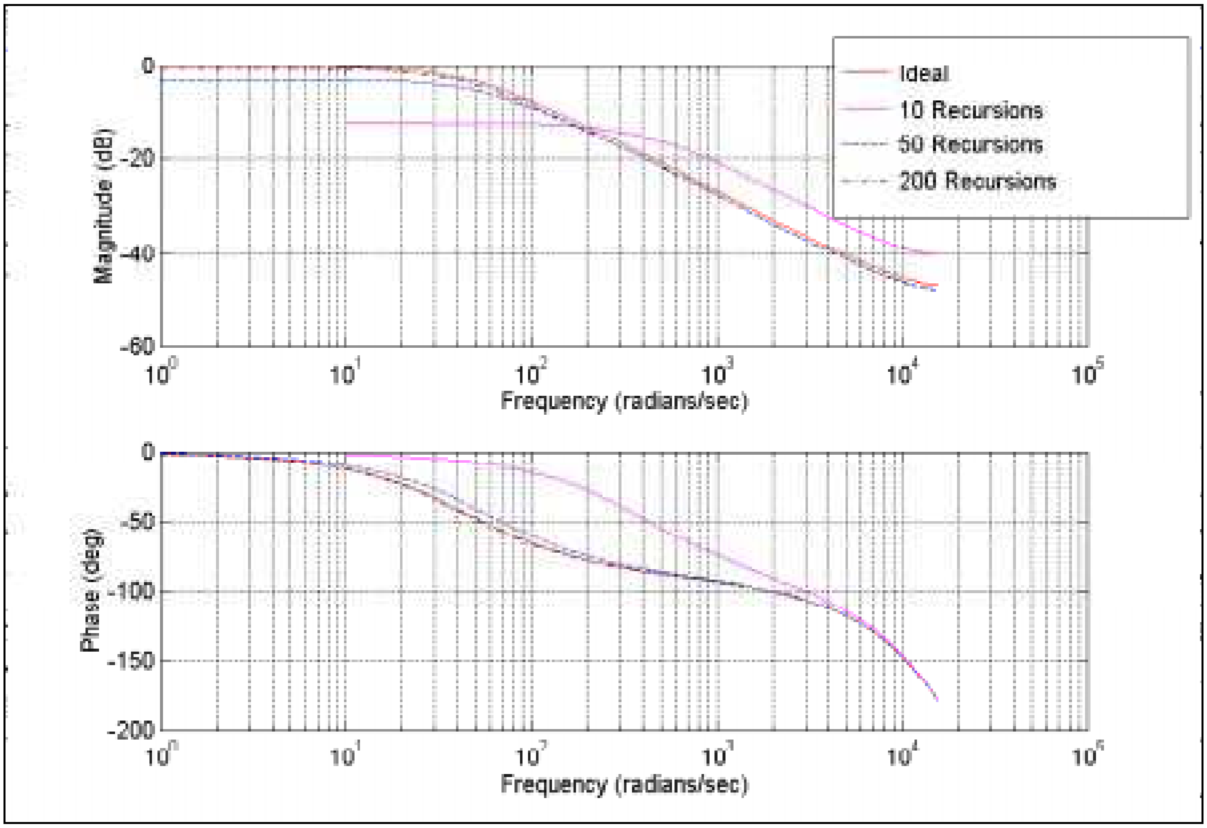

Figure 4 Comparison of Bode Plots of $H_1(z)$ and $\bar{H}_1(z)$

The next example is a second order low pass shown in Figure 5.

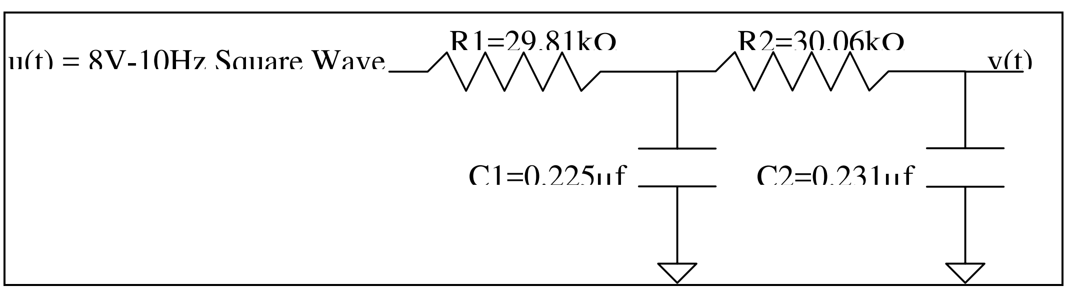

Figure 5 Second Order Low Pass Filter

The transfer function is,

$$H_2(s) = \frac{2.14711 \times 10^4}{s^2 + 4.40957 \times 10^2 s + 2.14711 \times 10^4} \quad (6)$$

Using a sampling interval T = 1 X 10^{-3} sec, and a zero-order hold gives the discrete equivalent of (6) as,

$$H_2(z) = \frac{0.0093011z^{-1} + 0.0083055z^{-2}}{1 - 1.62609z^{-1} + 0.64342z^{-2}} \quad (7).$$

Using a 10Hz square wave of 8Vp-p amplitude as input signal u(t), the identification algorithm produced an estimated transfer function,

$$\hat{H}_2(z) = \frac{0.05216z^{-1} + 0.0089013z^{-2}}{1 - 1.26614z^{-1} + 0.330407z^{-2}} \quad (8)$$

after 500 recursions. Bode plots which compare the ideal transfer function and the estimated transfer function as the number of recursions is varied are shown in Figure 6.

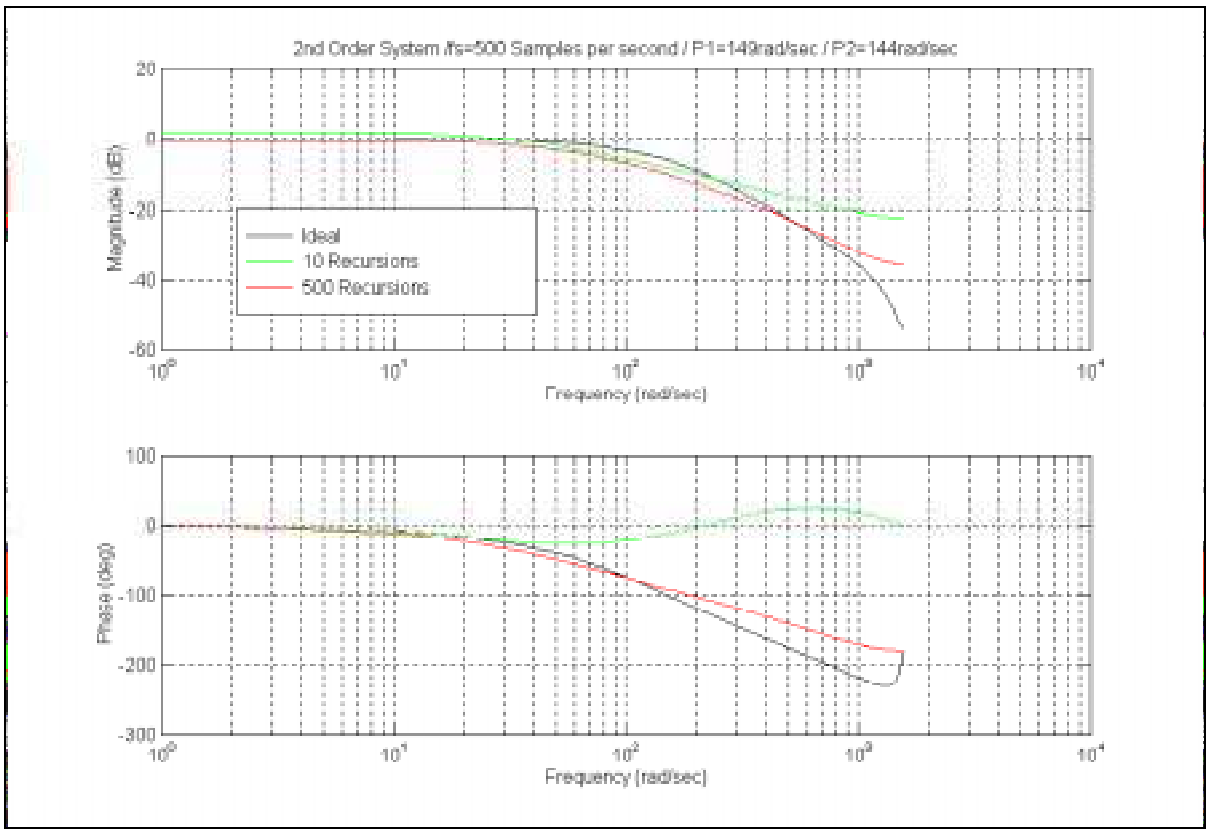

Figure 6 Comparison of Bode Plots of $H_2(z)$ and $\hat{H}_2(z)$

The final plant whose transfer function is to be identified is a 2nd order servo system whose transfer function is,

$$H_3(s) = \frac{-1331.52}{s^2 + 26.688s + 1328.9656} \quad (9).$$

Using a sampling interval T = 1 x 10^{-3} sec, and a zero-order hold gives the discrete equivalent of (9) as,

$$H_3(z) = \frac{-0.6598 \times 10^{-3} z^{-1} + -0.6540 \times 10^{-3} z^{-2}}{1 - 1.9724 z^{-1} + 0.9737 z^{-2}} \quad (10).$$

Using a 1Hz square wave of 1V amplitude as input signal u(t), the identification algorithm produced an estimated transfer function,

$$\hat{H}_3(z) = \frac{0.00677 z^{-1} - 0.032165 z^{-2}}{1 - 0.610122 z^{-1} - 0.361248 z^{-2}} \quad (11)$$

after 500 recursions. Bode plots which compare the ideal transfer function and the estimated transfer function of the number of recursions is varied are shown in Figure 7.

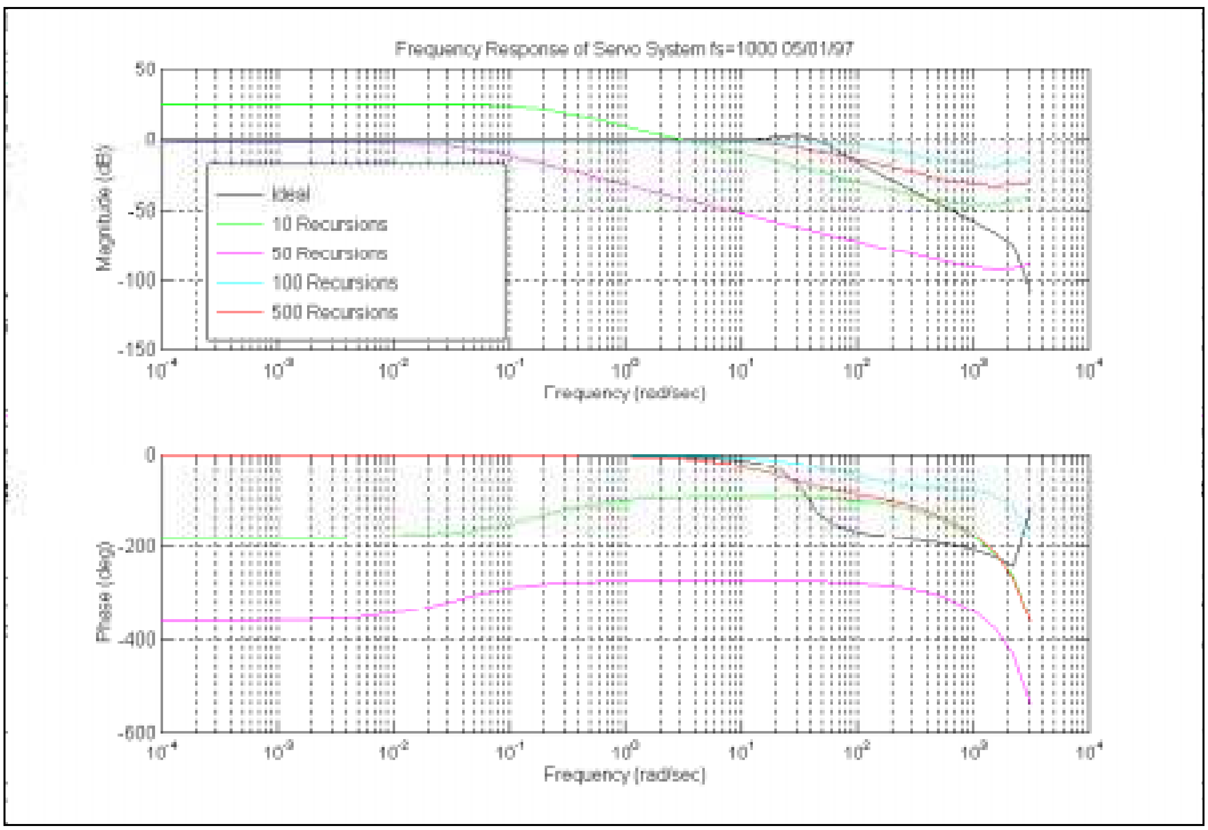

Figure 7 Comparison of Bode Plots of $H_3(z)$ and $\hat{H}_3(z)$

The identification of the 1st order transfer function $H_1(z)$ in (4) produced $\hat{H}_1(z)$ with parameters very close to those of $H_1(z)$. Figure 4 shows that the magnitude and phase plots of $H_1(z)$ and $\hat{H}_1(z)$ are very close after 200 recursions. The identification of the 2nd order low pass transfer function $H_2(z)$ in (7) produced an $\hat{H}_2(z)$ with coefficients which were not very close to those in (7), however, the magnitude and phase plots in Figure 6 show that $\hat{H}_2(z)$ is a fairly good approximation of $H_2(z)$. The identification of the transfer function of the 2nd order servo system was not very successful. The coefficients of the identified transfer function $\hat{H}_3(z)$ were very far off from those of the ideal transfer function $H_3(z)$ in (10). The recursive least squares algorithm was unable to identify the resonant frequency of the servo system. Further investigation is required to determine the cause of the discrepancy between the ideal and estimated transfer functions.

V. CONCLUSIONS

A digital signal processor based system for the real time identification of the plant transfer function using the Texas Instruments TMS320C30® processor has been developed. The TMS320C30® processor computes the coefficients of the plant transfer function from input-output data using a recursive least squares algorithm. The computed transfer function coefficients are displayed on the screen of the PC. The system is useful for rapid real-time identification of system transfer functions in a control laboratory. Further refinements of the algorithm are needed to make the system a more accurate identification tool.

ACKNOWLEDGEMENTS

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