1-1-1992

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Proceedings of the 31st Conference
on Decision and Control
Tucson, Arizona • December 1992

EXPERIMENTAL IMPLEMENTATION OF MRAC FOR A DC SERVO MOTOR

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ABSTRACT

This paper describes a hardware implementation of adaptive controllers using a Digital Signal Processor (TMS320C25). The research explores two model reference adaptive control schemes and some of the practical problems associated with their implementation.

1 Introduction

Our research explores model reference adaptive control (MRAC) schemes in a real system. The motivation being that although the theory of adaptive control is highly developed, its practice has been limited [3]. We successfully implemented two MRAC schemes to control a DC servo motor using a digital signal processor. In addition, we studied the following practical aspects of adaptive control:

1. The existence of "*Limit Cycles*" in the adaptive gains.
2. The influence of the γ modification.
3. The influence of the external input.

Other effects were also studied as described in [1] but are not included in this short paper. Additionally, we derived and implemented a new controller that adjusts the γ in the application of the γ *modification* [3].

2 Hardware Implementation

The overall system - plant, controller, and display block - is shown in Figure 1. The plant is a DC servo motor. The controller includes

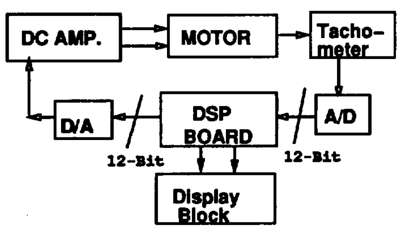

Figure 1: Block Diagram of the Physical System

the hardware (A/D, DSP board D/A, DC power amplifier, etc.) and the software that implements the adaptive controllers. The display block contains the parallel port, D/As, oscilloscopes, etc. and the software necessary to display some signals in real time [1].

3 Software Implementation of the controllers

The TMS320C25 is a fixed-point microprocessor so that in our experiments filters, difference equations, sine wave generations and random sequences are implemented using Q formats [2].

In our experiments, the plant is given by $K_p/(s+P_p)$, the desired model is $K_m/(s+P_m)$, the output of the plant is y_p, that of the model is y_m, the input to the plant is x_p and that of the model is x_m. The error is defined as $e_1 = y_p - y_m$. All assumptions for the existence of a stable adaptive controller as described in [3] are satisfied. Equation (1) constitute the adaptive law to adjust the proportional gain [3] for case 1, where only the high frequency gain is unknown. Equation (2) is the discrete version of this law, obtained

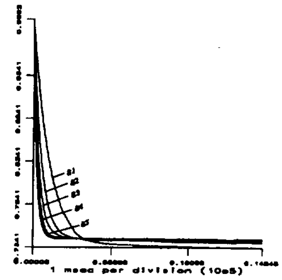

Figure 2: kt vs $time$ when $\gamma = 10, 20, 30, 40, 50$

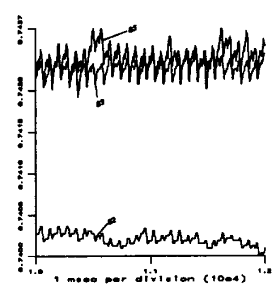

Figure 3: kt vs $time$ when $\gamma = 20, 30, 50$

using the backward approximation [4], where h is the sampling time,

$$\dot{kt}(t) = -\gamma \cdot sgn(K_p) \cdot e_1(t) \cdot x_m(t) \tag{1}$$

$$kt(i) = -\gamma \cdot sgn(K_p) \cdot h \cdot e_1(i) \cdot x_m(i) + kt(i-1) \tag{2}$$

Equations (3) and (4) represent the adaptive laws of case 2 where both the high frequency gain and the pole are unknown [3]. Equations (5), and (6) are the discrete time implementations.

$$\dot{kt}(t) = -\gamma sgn(K_p) \cdot e_1(t) \cdot x_m(t) \tag{3}$$

$$\dot{th}(t) = -\gamma sgn(K_p) \cdot e_1(t) \cdot y_m(t) \tag{4}$$

$$kt(i) = -\gamma sgn(K_p) h e_1(i) x_m(i) + kt(i-1) \tag{5}$$

$$th(i) = -\gamma sgn(K_p) h e_1(i) y_p(i) + th(i-1) \tag{6}$$

4 Experimental Results

4.1 K_p Unknown case

The first set of experiments were designed using equation (2) to study the effect of γ. We found that γ has a dual function in our experiments; it makes the convergence possible by eliminating the limit-cycle effect due to truncation, and it increases the convergence speed of the gains. Figure 2 shows the convergence of the gain K_p for different γs. There is an important trade-off in the use of γ; A large γ produces large oscillations of the adaptive parameter(s). Figure 3 shows the oscillations around the final values for 3 different γ's.

The other important study performed using the K_p unknown case examined the influence of the input on the convergence of kt. Figure 4 shows the convergence of kt for 6 different step inputs. A

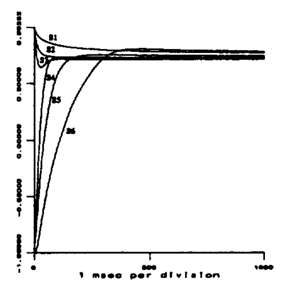

Figure 4: kt vs $time$ [$S1$: $kt = 1, x_m = -2.5$ $S2$: $kt = 1, x_m = -5$ $S3$: $kt = 1, x_m = -7.5$ $S4$: $kt = -1, x_m = -2.5$ $S5$: $kt = -1, x_m = -5$ $S6$: $kt = -1, x_m = -7.5$]

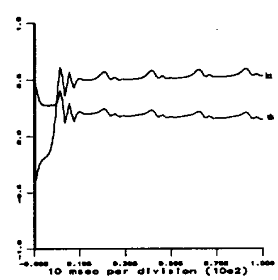

Figure 5: A Close Look at kt and th

larger magnitude step is shown to produce a faster convergence of the adaptive parameter.

4.2 K_p and P_p Unknowns Case

In the second case, two adaptive gains were adjusted using equations (5) and (6). The input to the model used in this study is a sinusoidal wave form. The amplitude of this sinusoid was adjusted experimentally to make the convergence of *kt* and *th* possible. The DC value of the sinusoid was set to avoid an input which crossed the level of 0 *Volts* in order to avoid the nonlinear region of the motor [1]. One of the models used to test the controller (*model1*) was :

$$G_m(s) = \frac{100}{s+100}, \tag{7}$$

During the first second of operation, the controller adjusted a large portion of the parameters (*kt*, and *th*). Figure 5 shows 1 second of the trajectory of *kt* and *th*, and Figure 6 shows the first 600 *msecs* of the trajectories of y_m, y_p, and e_1.

An effect similar to the one obtained by updating only K_p was observed in this case. The speed of convergence is related to the magnitude of γ, as is the oscillatory behavior of the parameters. Figure 7 provides a close look at the oscillations in one of the parameters after 20 *secs* of operation of the controller. The curve C2k1 corresponds to a γ of 50, C2k2 corresponds to a γ of 100, and C2k3 corresponds to a γ of 200. Increasing the convergence speed has one drawback; it creates more oscillations in the gains.

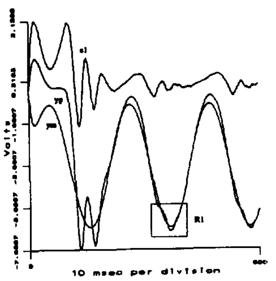

Figure 6: A Close Look at y_m, y_p, and e1

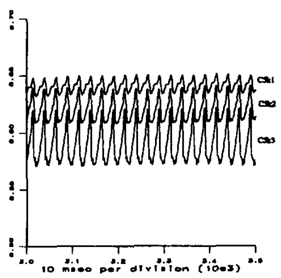

Figure 7: Close Look of *kt* oscillations for γ = 50, 100, 200

4.3 Adjusting γ

The (γ) modification increases the speed of convergence significantly, but it produces an oscillatory behavior around the final value of the adaptive gains. A filter was designed to adjust γ as a function of the output error e_1. Figure 8 shows a block diagram of this filter. The first block represents a low-pass filter followed by a rectifier that finds the absolute value of the filter output. This value is multiplied by a constant term

The new controller runs for 18 *secs* using a fixed γ as the previous controller did. Then the subroutine that implements the γ filter is called every 500 $\mu secs$ and the process of adjusting the factor γ begins. The results obtained by using this controller can be observed

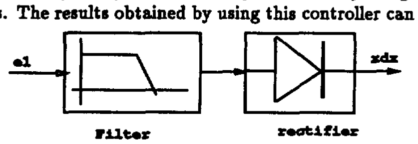

Figure 8: Adjustment of γ esquematic block

in Figure 9 (*kt*[0] = −0.5, *th*[0] = 0.5 and initial γ = 200). The trajectories that the parameters follow in both plots is similar. The gains *kt* and *th* converge to constant values, and the oscillation in the gains disappear.

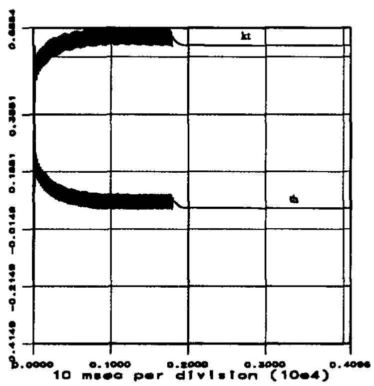

Figure 9: Parameter Trajectories for *kt*[0] = −0.5 and *th*[0] = 0.5

5 Conclusions

The effect of finite register length in digital signal processing is an important factor to consider when a controller is implemented using a fixed-point microprocessor. In our case, the truncation that occurs when a 32-bit hardware register is stored in a 16-bit memory location, is one of the main factors of the *limit cycle* present in the convergence of the adaptive gains. The solution to this problem was to use the γ-*modification*. The γ *modification* which has commonly been used to increase the speed of convergence in computer simulation, actually has a dual function in our experiments; it makes the convergence possible, and it can be used to increase the convergence speed of the gains. A larger γ produces a faster convergence of the parameters, but unfortunately, the adaptive gains oscillate around the expected final value.

A special controller was designed and implemented to adjust γ as a function of the output error e_1. This controller reduces the oscillations of the adaptive gains around the final value.

Finally, the magnitude of a step input was shown to have an important influence on the time of convergence of the adaptive gain.

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