NLMS Based Adaptive Control of Stable Plants

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***Abstract*— In this paper we propose a new stable adaptive controller for stable plants, which may be non-minimum phase. The controller is composed of adaptive finite impulse response (FIR) filter in the feedback loop. This adaptive FIR filter is designed online as an L-delay approximate inverse system of the given stable plant. The solution of Diophantine equation is not involved in the design procedure. Hence the numerical problems associated with the solution of Diophantine equation are avoided. Computer simulation results and real time experimental results are included in the paper to demonstrate the effectiveness of the proposed method.**

I. Introduction

Stable controllers can relatively protect the entire control system comparing to unstable controllers in case of sensor failure or actuator saturation happens. Several methods have been proposed for the design of stable controllers. The plants; which can be stabilized by stable controllers in the closed-loop are called strongly stabilizable plants. The plant is strongly stabilizable iff the number of poles of the plant between any pair of real right half plane blocking zeros is even. This property is called parity interlacing. Several methods have been proposed to design stable controllers for the strongly stabilizable plants [1]. Indirect adaptive control techniques are used to control the unknown non-minimum phase plants [2]. In these schemes, first parameters of the plant are estimated and then using the Diophantine equation the controller parameters are designed online. The solution of the Diophantine equation becomes ill posed problem, when in the estimation procedure some roots of the numerator and denominator polynomials of the plant become common [3]. Furthermore, using these techniques the stability of the closed-loop can be assured using the certainty equivalence approach of adaptive control but the stability of the controller cannot be assured. The available methods for the design of stable controllers are computationally expensive and use of these methods for the online controller design is quite limited.

In this work, we present a method for the design of stable adaptive controller for the stable discrete-time plant, which may be non-minimum phase. The parameters of the controller are directly estimated and hence the problems associated with solution of the Diophantine equation are avoided. If the plant is unstable, then first the plant can be stabilized by using robust control techniques and then the controller suggested in this paper can be used to improve the tracking properties of the overall system.

II. Problem Statement

Let us describe single-input single-output (SISO) stable linear discrete-time plant by

$$A(q)y(t) = q^{-d}B(q)u(t), \tag{1}$$

where

$$A(q) = 1 + \sum_{i=1}^{n} a_i q^{-i}, \qquad B(q) = \sum_{j=0}^{m} b_j q^{-j},$$

q^{-1} is a back shift operator, d represents a known time-delay and $b_0 \neq 0$. $A(q)$ and $B(q)$ are co-prime polynomials of degrees n and m, and $n \geq m$. It is supposed that parameters a_i and b_j are unknown. Further, degrees of $B(q)$ and $A(q)$ may be unknown. The plant can be a minimum or non-minimum phase system. $u(t)$ and $y(t)$ are the measurable input and output, respectively. In these circumstances, the objective is to synthesize a bounded control input $u(t)$ using a two degrees of freedom adaptive controller based on adaptive FIR filters such that the plant output $y(t)$ tracks desired bounded output sequence $y_d(t)$.

III. Controller Design

Let us synthesize the control input $u(t)$, from the following equation

$$u(t) = \hat{F}(q)\left[P(q)y_d(t) - \delta y(t)\right], \tag{2}$$

where $\hat{F}(q)$ is a polynomial, which satisfies the following approximation

$$q^{-d}\frac{B(q)}{A(q)}\hat{F}(q) \approx q^{-L}, \tag{3}$$

L is a positive integer and $L \geq d$. We say that $\hat{F}(q)$ is the L-delay approximate inverse system of the plant. The polynomial $\hat{F}(q)$ can be estimated using some suitable estimator like the normalized least squares (NLMS) estimator same as in adaptive equalization problem [4]. The polynomial $\hat{F}(q)$ can be considered as an adaptive FIR filter. δ is a constant such that $|\delta| < 1$ and $P(q) = 1 + \delta q^{-L}$. Using equations (1), (2) and (3), the following relation can be shown easily

$$\lim_{t\to\infty} y(t) = y_d(t-L). \tag{4}$$

This means the plant output will track the desired output with some delay. As $\hat{F}(q)$ is an adaptive FIR filter and $P(q)$ is an

FIR filter, so the controller will remain stable. It can also be shown by using equations (1), (2) and (3) that the characteristic polynomial is $P(q) = 1+\delta q^{-L}$ and $|\delta| < 1$, so the closed-loop will remain stable.

IV. Simulation Results

Now, we present computer simulation and real-time results for the proposed scheme.

Example 1: Let us consider a disturbance free plant

$$A(q) = 1 + 0.5q^{-1} + 0.3q^{-2}, \quad (5)$$
$$B(q) = 1 + 1.5q^{-1}, \quad (6)$$

and delay $d = 5$. This is a stable non-minimum phase plant. In this example we consider $\delta = 0.3$ and $L = 10$. NLMS estimator is used to estimate the parameters of the L-delay approximate system. In this example we choose the order of $\hat{F}(q)$ is 20. The simulation results are depicted in Figure 1. Figure 1a indicates that the plant output quickly converges to the desired output. Figure 1b shows that the control input to the plant is bounded.

Example 2: Now, we discuss the implementation of the proposed algorithm for the real time speed and position control of a brush DC motor (Cruzet 8285002). This motor has a maximum speed 3200 revolution per minute (rpm), which can be achieved by exciting the motor by 24 Volts DC. Speed is measured by using a tacho-meter, which produces a voltage proportional to the speed of the motor. Servo amplifier is used to provide variable voltage (control input) for the excitation of the motor. Advantech data-acquisition card PCI 1711 is used for the input and output signals and a preamplifier is used to interface the measured and control signals with PCI 1711 card. The controller is implemented in Simulink using real time windows target on a standard Pentium III IBM personal computer. The experimental setup is shown in Figure 2.

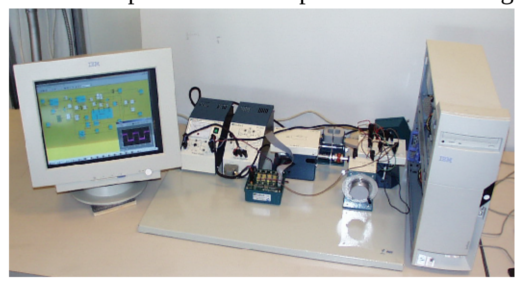

Fig. 2. Experimental setup DC Motor

Figure 3a shows that the motor speed quickly converges to the desired speed and Figure 3b indicates that the control input to the motor is bounded. This example shows the effectiveness of the proposed method on the actual plant. The real time simulation was run for several hours and the load on the shaft of the motor was changed manually. Here we present the real time simulation results for just twenty seconds for the sake of legibility.

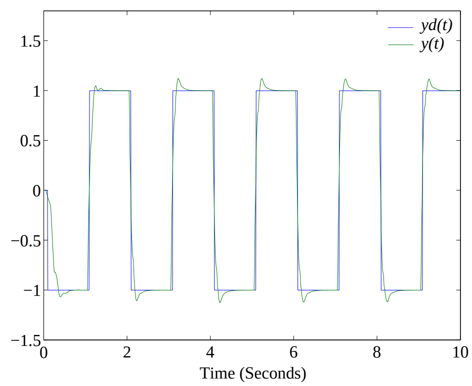

Fig. 1a.

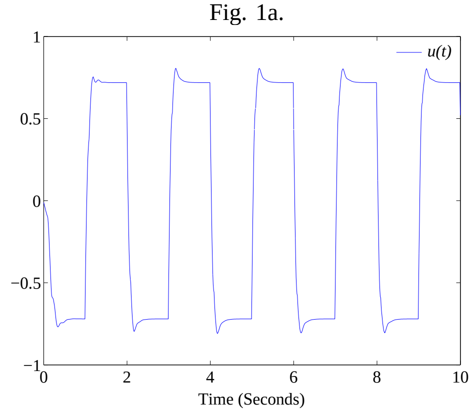

Fig. 1b.

Fig. 1. Simulation results for example 1

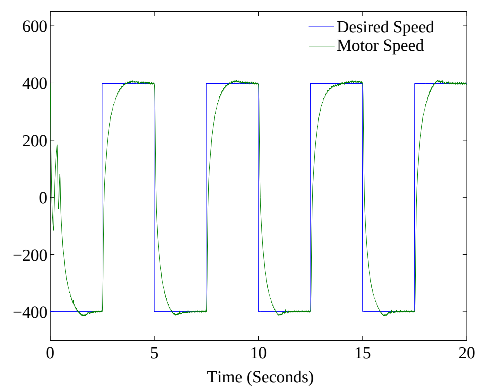

Fig. 3a.

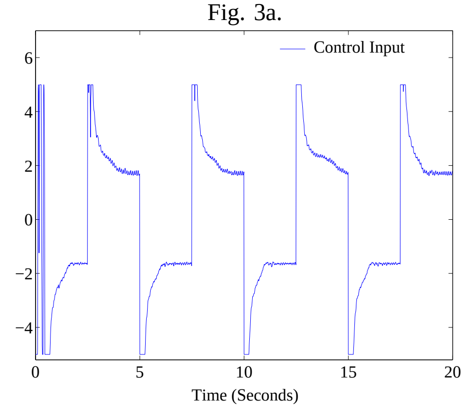

Fig. 3b.

Fig. 3. Outcomes of DC Motor Speed Control

Example 3: Magnetic levitation has been successfully implemented for several industrial applications. Frictionless bearing, high speed magnetically levitated trains, levitation of wind tunnel models, magnetic levitation of molten metal in induction furnaces, and levitation of magnetic slabs during manufacturing are the few examples [5]. Magnetic levitation system is a nonlinear unstable system. The stabilization and tracking of such systems is a challenging problem from both theoretical and practical point of view. Many researchers have used different approaches to control and track the position of a magnetically levitated body [6], [7], [8], [9], [10].

Using these techniques the span of the tracking is with in few mm. Feedback linearization technique has been to expand the span of the tracking region by using a very complex known nonlinear model [11]. To investigate the usefulness of the proposed method, we perform experiment on position tracking of magnetically levitated body. The schematic block diagram is shown below. In the experiment initial parameters

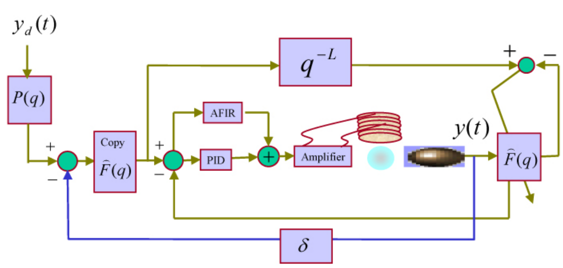

Fig. 4. Experimental setup Magnetic Levitation System

of the proportional, integral and derivative (PID) controller are chosen such that a body can be levitated under the force of an electromagnet at some arbitrary position. Then adaptive FIR (AFIR) filters are incorporated in the loop to improve the stability and tracking properties of the system. The block labelled **AFIR** in Figure 4 is introduced to improve the stability of the system and filters $\hat{F}(q)$ and $\hat{P}(q)$ are incorporated to improve the tacking properties.

It is important to note that all the filters are FIR and they are inherently stable. This means that nonlinear unstable plant has been stabilized by a combination of stable adaptive linear FIR filters and with a constant gain PID controller.

Figure 5a shows that magnetically levitated body tracks the desired position under the designed control action and Figure 5b indicates that the control input is bounded. Using this strategy, we are able to force the magnetically levitated body to track deired position to the full measurement capability of the position measuring sensor in the system; approximately two cm.

Advantech data-acquisition card PCI 1711 is used for the input and output signals and a preamplifier is used to interface the measured and control signals with PCI 1711 card. The controller is implemented in Simulink using real time windows target on a standard Pentium III IBM personal computer. In this experiment we use the magnetic levitation system manufacture by Feedback Instrument Ltd.

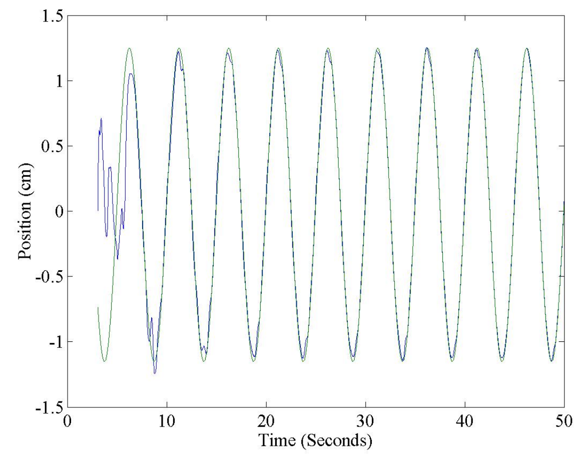

Fig. 5a.

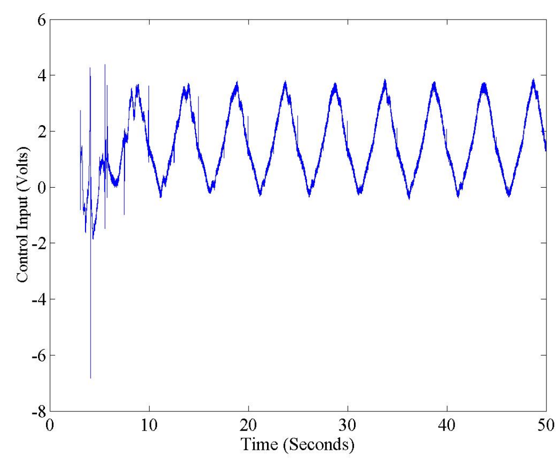

Fig. 5b.

Fig. 5. Outcomes of Magnetic Levitation System

V. Conclusion

In this paper we propose a new adaptive tracking strategy based on adaptive FIR filters for stable plants. This technique can be used for both minimum and non-minimum phase plants in the same configuration. The stability, convergence and tracking properties of the closed-loop system are discussed briefly in the paper from theoretical point of view. Computer simulation results are discussed for disturbance free non-minimum phase stable plant. The outcomes of experimental results of the brushed DC motor speed tracking and positions tracking of a magnetically levitated system are discussed in the paper.

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