FEEDBACK INVERSE MODELING FOR ADAPTIVE CONTROL

B.A. Abouzalam, Saad A. Ibrahim and S.G. Elnashar
Automatic Control and Measurements Department,
Faculty of Electronic Engineering, Menoufia, Egypt.

ABSTRACT

Adaptive inverse control is another motivation to adaptive control. An unknown plant will track an input command signal if the plant is proceeded by a controller whose transfer function approximates the inverse of the plant transfer function. In the adaptive inverse model proposed by Widrow [1,2,3], the controller is realized as an open loop adaptive finite impulse response (FIR) filter which needs a large number of coefficients to approximate the plant's transfer function. This increases the computation time. Another controller structure is proposed by Ibrahim- [4]. In this case the controller structure is an open-loop infinite impulse response (IIR) filter which reduces the number of coefficients and provide a good step response. This paper proposes a new feedback controller realization based on inverse modeling IIR filter. This controller provides the performances of the closed loop system, such as: a- direct pole assignment structure; b- low sensitivity of the performances due to parameters variation; c- facility of noise reduction; d- set point adjustment. In addition to the important specifications of closed loop response over the open loop one, a recursive least squares algorithm is used which is unbiased and fast algorithm in order to identify the inverse filter parameters.

I- INTRODUCTION

There is a great need for learning control systems which can adapt to the requirements of plants whose characteristics may be unknown and/or changeable in unknown way. Two principal factors have hampered the development of adaptive controls, the difficulty of dealing with learning processes embedded in feedback loops, and the difficulty in controlling non-minimum phase plants.

In this paper we continue with the development of an alternative approach, which was first presented by Widrow [1,2,3], and modified by Ibrahim [4]. This inverse model of the unknown plant can be formed as shown in Figure (1).

The adaptive filter input is the plant output and the filter is adapted to cause its output to be the best minimum error to the delayed plant input. A close fit implies that the cascaded of the unknown plant and the filter have a transfer function of essentially unit value at least within the frequency band of the input signal. The delay d accounts for the transportation lag in the plant.

This paper proposes a modified scheme for such a purpose where an IIR filter is used with feedback structure from the filter output instead of the open-loop case, stated in [4]. The new technique has several advantages over those given in [3,4] which in general are the advantages of the closed loop performances:

a- direct pole assignment structure;
b- low sensitivity of the performances due to parameters variation;
c- facility of noise reduction;
d- set point adjustment.

The publications [1-4] concern with inverse modeling control use the least mean square (LMS) techniques which in fact has a very slow convergence rate. In this paper, the recursive least squares algorithm is used in order to identify the inverse model parameters. This algorithm is unbiased and has fast convergence.

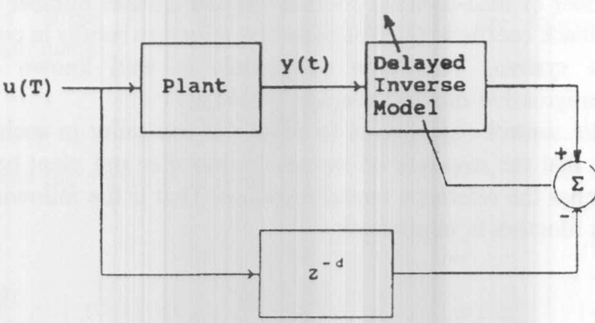

Figure 1. Adaptive inverse modeling.

II- OPEN-lOOP ADAPTIVE CONTROL USING INVERSE MODELING

The adaptive inverse control scheme is illustrated in Figure (2). It is assumed that u_n excites the plant at an adequate level so that adequate modeling can take place, a small dither signal can be added to plant input. Feed-forward controller is a copy of the inverse model and after the parameters converge, the plant output will track the reference command signal r_n, that is:

$$x_n = r_{n-d} \quad (1)$$

At the first time, the controlled scheme is realized by an FIR filter whose weights are updated using the LMS algorithm [3] as shown in Figure (2). A high-order filter has to be used to approximate the inverse of the plant's transfer function. This requires a huge amount of computation. Moreover, the delay between the output signal and the reference command is large.

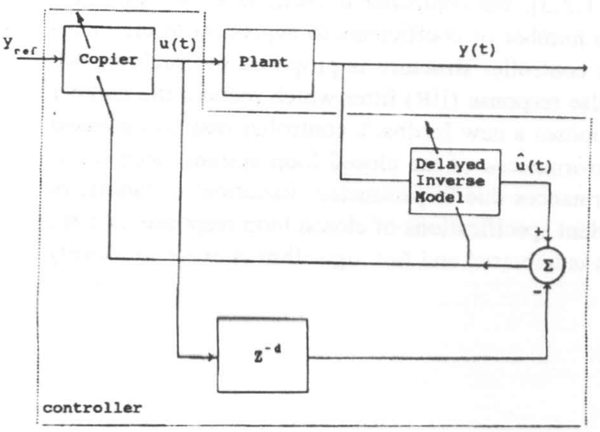

Figure 2. Open loop inverse model self-tuning controller.

Recently, IIR algorithm have been proposed based on different error minimization criteria [5-6]. In IIR structure the system is modeled by a discrete transfer function. In these types of filters the filter response is governed by a number of feed-forward coefficients and another number of feedback coefficients. This recursive structure results in pole zero system. This type of models is well known as autoregressive moving average (ARMA).

The control objective is to adapt the controller in such a way that the response of cascaded controller and plant best matches the reference model response. That is the following cost function is minimized:

$$J = \{c_n - y_n\}^2 \quad (2)$$

The open loop inverse modeling self tuning controller has some drawbacks, which are mentioned in the introduction, therefore the open loop self-tuning will be developed using the feedback inverse modeling self tuning controller.

III- FEEDBACK INVERSE MOELING (FBIM) CONTROLLER

In order to avoid the drawbacks of the open-loop self-tuning controller, it is necessary to use a feedback structure. This structure is shown in Figure (3).

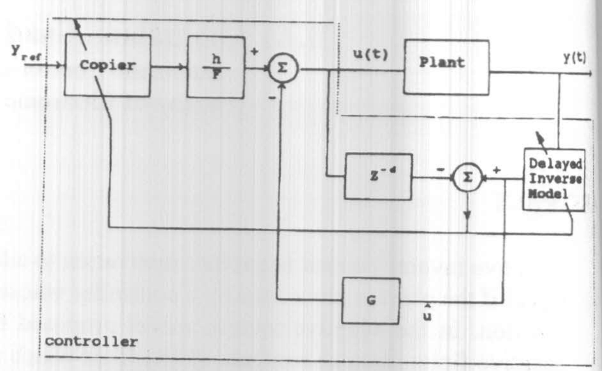

Figure 3. Closed-loop inverse model self-tuning controller.

The control objective for the system will require the output y (t) to follow a reference signal r (t) in some predetermined way and to reject random disturbances which nay corrupt the output. In this formulation the objective of servo following and disturbance regulation are combined. The pole assignment design for this combined objective is organized as follows.

$$A\, y(t) = B\, u(t-1) + C\, e(t)$$

where:

$$A = 1 + a_1 z^{-1} + \dots + a_n z^{-n}$$

$$B = b_o + b_1 z^{-1} + \dots + b_m z^{-m}$$

$$C = 1 + c_1 z^{-1} + \dots + c_n z^{-n}$$

where the controller is of the form [7]:-

$$F\, u(t) = H\, r(t) - G\, \hat{u}(t) \quad (4)$$

the polynomials F and G are given by:

$$F = 1 + f_1 z^{-1} + \dots + f_{nf} z^{-m}$$

$$G = g_o + g_1 z^{-1} + \dots + g_{ng} z^{-ng}$$

where $\hat{u}$ is the delayed inverse plant model output. This output can be obtained as a function o the system output as follows:

$$\hat{B}\, \hat{u}(t) = z^{-d} \hat{A}\, y(t) \quad (5)$$

Combining the controller, system equation and the inverse model equation yield the closed loop description:

$$(z^{-d} G B \hat{A} + \hat{B} A F) y(t) = z^{-1} B \hat{B} r(t) + C F B e(t) \quad (6)$$

when the tuning algorithm converges, $\hat{A} = A$ and $\hat{B} = B$, therefore equation (6) simplifies to:

$$A(G z^{-d-1} + F) y(t) = B H r(t-1) + C F e(t) \quad (7)$$

The above equation can be rewritten in a transfer function form:-

$$y(t) = \frac{B H}{A(F + z^{-d-1} G)} r(t-1) + \frac{C F}{A(F + z^{-d-1} G)} e(t) \quad (8)$$

H can be defined as:

$H = h H_1$

where H_1 is known as the copier transfer function, and h is the system gain that conserves the value of the set point.

Equation (8) shows that if the system is excited by a noise e (t), the feedback system response will be stable if A is a stable polynomial. The servo control problem is discussed in the following section.

SERVO CONTROL

In this section we consider the case of a noise-free process, therefore equation (8) can be rewritten as:

$$y(t) = \frac{B H}{A(F + z^{-d-1} G)} r(t-1) \quad (9)$$

The copier transfer function can be calculated as:-

$$H_1 = \frac{A}{B} \quad (10)$$

That is, this copier will have the same inverse model transfer function of the system. The closed loop system poles may be chosen as:-

$$W = F + z^{1-d} G \quad (11)$$

where

$$W(z^{-1}) = 1.0 + w_1 z^{-1} + w_2 z^{-2} + \ldots + w_{nw} z^{-nw} \quad (12)$$

where nw is the closed loop system order.

The gain h is calculated to conserve the desired set point of the closed loop system, therefore h will be given by:

$$h = 1 + w_1 + w_2 + \ldots + w_{nw}$$

From the algorithm it is shown that the closed loop inverse modeling self tuning controller is a direct pole assignment technique. This algorithm s simple and does not require identity solution as illustrated in the known self-tuning controller using parallel model [7,8]. The feedback inverse modeling self-tuning structure is shown in Figure (3).

IV- PARAMETER IDENTIFICATION

In what follows er show that the inverse model can be identified using the ordinary recursive least squares algorithm. The system to be controlled must be regular, i.e., the degree of the denominator must be greater than the nominator. Then, if the system model is inverted, the denominator becomes a numerator and the numerator becomes denominator, then the inverse model becomes irregular. So the inverse model parameters are impossible to be identified. The above problem can be solved by shifting back the input of the inverse model many times until the system becomes regular. The shift of the input is equivalent to adding a pole at the origin of the inverse model. Consider the block diagram shown in Figure (4), where the system transfer function is denoted by A/B and the output is y. Now if we consider that the ideal model output is denoted by C_n then the error e (t) will be given by:

$$e(t) = y(t) - c_n \quad (13)$$

The output y (t) can be calculated by the following relationship:

$$y(t) = \phi(t)^T \theta + e(t) \quad (14)$$

where the vector θ is given by:

$$\theta = [a_1\ a_2 \ldots a_n;\ b_o\ b_1 \ldots b_m] \quad (15)$$

$$\phi(t)^T = [-y(t-1) - y(t-2) \ldots y(t-n);\ u(t)\ u(t-1) \ldots u(t-m)] \quad (16)$$

Then the parameters of the inverse model of the system can be identified using the recursive least squares algorithm (RLS). This can be achieved if the following criterion is minimized:

$$Q = \| e(t) \| \quad (17)$$

Then the pseudo linear regression algorithm is then given by:

$$\hat{\theta} = \hat{\theta}(t-1) + K(t) e(t) \quad (18)$$

$$K(t) = P(t)\,\phi^T(t)\,[1+\phi(t)\,P(t)\,\phi^T(t)]^{-1} \qquad (19)$$

$$P(t+1) = P(t) - K(t)\,[1+\phi(t)\,P(t)\,\phi^T(t)]^{-1}\,K^T(t) \qquad (20)$$

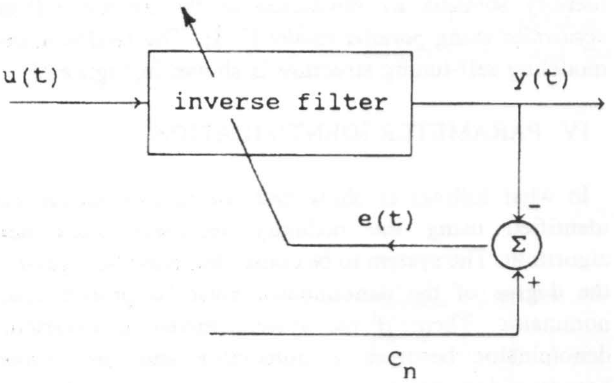

Figure 4. Parameter identification.

The recursive least squares algorithm is better than the least mean square algorithm in the convergence time an the obtained parameters are more correct and unbiased.

RESULTS

In order to examine the feedback inverse modeling self-tuning controller, a second order example have been chosen. The chosen example has two poles and one zero in the s-domain, and is given by:-

$$\frac{y(s)}{u(s)} = \frac{s+0.2}{s^2+0.2S+1}$$

The step response of the system is shown in Figure (5). It is clear from the system time response that the system is very slow.

The proposed algorithm is applied to the system by considering the following:

- choosing a time delay (d) equals 2 samples
- the closed loop system has three stable poles z_1 z_2, and z_3
- the polynomial F is chosen as second order
- the polynomial G is chosen as a gain

Figure (6) shows the step closed-loop system response for a three stable poles chosen arbitrarily. From the system response one depicts that when the magnitude of the poles are changed the overshoot and the rise time are modified. In general the studied cases indicate that:

- The algorithm is asymptotically stable.
- The closed loop system response is modified by changing the value of the desired poles
- The algorithm has fast convergence.

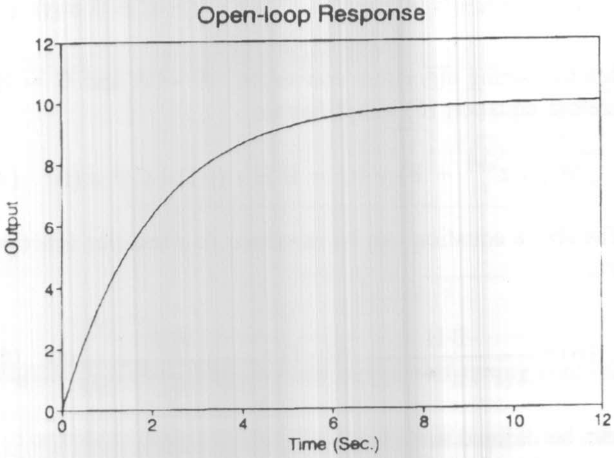

Figure 5. Open loop system response.

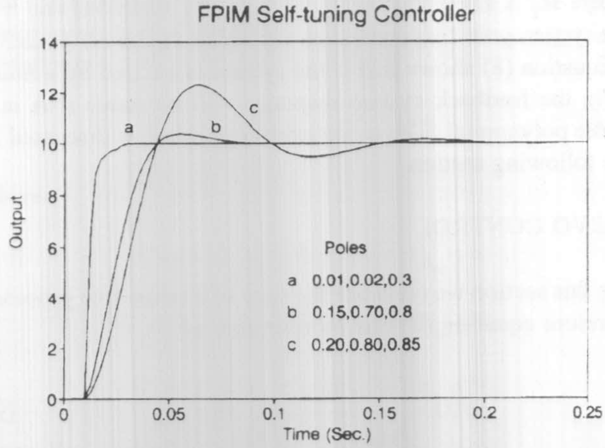

Figure 6. Closed loop system response.

CONCLUSION

The adaptive control algorithm based on open-loop inverse modeling has several drawbacks. The major drawback arises from the realization of adaptive model in open-loop structures. The corresponding system performances are bad.

In this paper, these problems are avoided by using the closed loop inverse modeling self-tuning controller. The proposed algorithm has many advantages over the pole assignment self-tuning controller using parallel model is that the pole assignment in the inverse modeling is direct, wherease the pole assignment in the parallel model needs to solve an identity.

The recursive least squares algorithm is better than the least mean square algorithm in the convergence time and the obtained parameters are more correct and unbiased. Therefore the RLS algorithm is modified in order to identify the inverse model parameters.

The given results show that the algorithm has fast convergence.

REFERENCES

[1] B. Widrow, J.M. Mc Cool, and B.P. Medoff, "Adaptive control by inverse modeling", Circuits, Systems and Computers, 12^{th} Asilomar Conf. Santa Clara Pacifico Grove, CA, Nov. 1978, pp. 90-94.

[2] B. Widrow, et al., "On adaptive inverse control", Fifteenth Asilomar conference on Circuits, Systems and Computers, Santa clara Pacifico Grove, CA, Nov. 1981, pp. 185-198.

[3] B. Widrow, "Adaptive signal processing for adaptive control", Proc. IEEE ICASSP 1984, Sandiago, CA, vol. 2, March 1984.

[4] A.S. Ibrahim and M.M. Hadhoud, "Inverse modeling for adaptive control", Proceeding of the sixth national radio science conference, Cairo, Feb 19-21, 1989.

[5] P.L. Feinntuch, "An adaptive recursive LMS filter", Proc. IEEE, vol. 65, September, 1977, pp. 1399-1402.

[6] Alan V. Oppenheim, and Ronald W. Schafer, Digital signal Processing Prentice-hall International Edition, 1975.

[7] P.E. Wellstead and M.B. Zarrop, "Self-tuning systems control and signal processing", (book), Jonn Wiley 1991.

[8] D.W. Clarke, D. Phil and P.J. Gawthrop, "Self-tuning controller", Proceeding of IEE, vol. 122, No. 9, September 1975.