The Third AFSS(1998). 680-684

On-line Estimation of Systems with Unmodeled Dynamics using D-L Networks

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Abstract

This paper presents an efficient method which estimates the systems with unmodeled dynamics using D-L networks. This method is applied for estimating the system with unmodeled dynamics from only input-output information, so it can exclude additional procedure for system description and reduce the computational burden required for real-time estimation. Higher convergence speed is achieved in this manner in comparison with widely-used conventional methods.

Keywords: D-L networks, On-line Estimation, Unmodeled Dynamics

1. Introduction

Most process industries have difficulty in obtaining an exact mathematical modeling on input-output relation, so conventional control methods based on transfer functions or state equations cannot be applied directly. To complement these problems, AI(artificial intelligence) methods based on fuzzy logic, networks schemes(neural and neuro-fuzzy) and genetics are introduced to system theories of estimation, identification, control, and *etc*[1,2,3].

Though the accurate mathematical modeling is required for satisfactory performance of designed control system, it cannot be achieved in fact for most systems. Therefore, the performance degration and slow convergence of designed control systems are still problems to be solved. These problems are mainly due to the fact that the process cannot be described exactly because of *unmodeled dynamics* such as dynamic uncertainty and parameter uncertainty[4,5].

This paper presents an efficient method which can estimate systems with unmodeled dynamics by introducing D-L networks[6]. This proposed method estimates the systems with unmodeled dynamics using only input-output relation, so it can exclude additional procedure for plant description and thus allows designed control systems to be real-time implemented. Also, higher convergence speed is achieved by reducing the computational burden required for real-time estimation in comparison with widely-used conventional methods. Therefore, it is expected that the proposed scheme can be effective for system identification and controller design based on on-line implementation.

2. D-L networks

The discrete Laguerre functions are defined in z-domain as [6,10]

$$l_i(z) = \frac{\sqrt{1-a^2}}{z-a}\left[\frac{1-az}{z-a}\right]^{k-1} \tag{1}$$

where $a\,(|a|<1)$ is called time scale factor and $i=1,2,\cdots,N$.

Any system with transfer function $G(z)$ can be expressed by using this Laguerre expantions such as

$$G(z) = \sum_{i=1}^{N} g_i l_i(z) \tag{2}$$

where g_i is called the Laguerre coefficients.

For the approximation using eq(2), the *priori* knowledge including degrees of system, numbers of parameters and *etc* must be known, and those systems are called structured systems or structured models. However, most systems cannot obtain the *priori* knowledge for exact modeling because of unmodeled dynamics. Therefore, for the systems with unmodeled dynamics, the classical method such as eq(2) cannot applied directly.

Let $L_i(z)$ be each output of eq(1) such as

$$L_i(k) = l_i(z)\, L_{i-1}(k) \quad , \; i=2,3,\cdots,N \tag{3}$$

where $L_1(k) = l_1(z)\, U_c(k)$

Using above equation, networks such as following figure can be constructed, and it is called the D-L (discrete-Laguerre) networks[6].

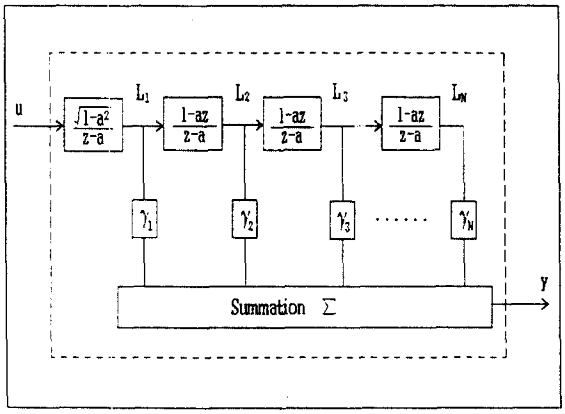

Fig. 1. The D-L networks

The relation of D-L networks such as Fig 1 can be expressed as follows

$$L(k+1) = A_L L(k) + B_L U_c(k) \tag{4}$$

$$y_L(k) = \Gamma^T L(k) \tag{5}$$

where $L(k) = [\, L_1(k), L_2(k), \cdots, L_N(k)\,]^T \in R^N$,
$A_L \in R^{N \times N}$, $B_L \in R^N$ and $\Gamma \in R^N$

A_L, B_L of eq(4) are determined matrices such as eq(6), and $\Gamma^T = [\, \gamma_1, \gamma_2, \cdots, \gamma_N]$ is unknown matrix to be determined.

$$A_L = \begin{bmatrix} a & 0 & 0 & \cdots & 0 \\ 1-a^2 & a & 0 & \cdots & 0 \\ -a(1-a^2) & 1-a^2 & a & \cdots & 0 \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ (-a)^{N-2}(1-a^2) & \cdots & \cdots & 1-a^2 & a \end{bmatrix} \tag{6.a}$$

$$B_L = \begin{bmatrix} \sqrt{(1-a^2)} \\ -a\sqrt{(1-a^2)} \\ a^2\sqrt{(1-a^2)} \\ \cdot \\ \cdot \\ (-a)^{N-1}\sqrt{(1-a^2)} \end{bmatrix} \tag{6.b}$$

where, $A_L(1,1) = a$ and for the range of scale factor such as $a(|a|<1)$, A_L is stable[6].

3. On-line Estimation of Unmodeled Systems via proposed scheme

From previous chapter, although any system with $G(z)$ has unmodeled dynamics which cannot be modeled, the system can be estimated from only input-output information via D-L networks if unknown matrix Γ of eq(5) is available. We thus would detemine the unknown matrix Γ by an efficient algorithm introduing the D-L networks.

To determine the unknown matrix Γ of eq(5), most general adaptive parameter estimation scheme, RLS(recursive least squares) algorithm[7-9] is introduced as

$$\hat{\theta}(i) = \hat{\theta}(i-1) + K(i)[y_{unmod}(i) - \phi^T(t)\hat{\theta}(i-1)] \quad (7)$$

$$K(i) = P(i-1)\phi(i)[\lambda + \phi^T(i)P(i-1)\phi(i)]^{-1} \quad (8)$$

$$P(i) = [\lambda - K(i)\phi^T(i)]P(i-1) \quad (9)$$

where P is a covariance matrix, ϕ a regression vector.

Now applying eq(4) by D-L networks into above equations such as eq(7), (8) and (9), simplified equations can be obtained as

$$\Gamma(i) = \Gamma(i-1) + \frac{P(i-1)L(i)}{\lambda + L^T(i)P(i-1)L(i)} \times [y_{umod}(k) - y_L(k)] \quad (10)$$

$$P(i) = P(i-1) - \frac{P(i-1)L(i)L(i)^T P(i-1)}{\lambda + L^T(i)P(i-1)L(i)} \quad (11)$$

where, $y_{umod}(k)$ is the output of system with unmodeled dynamics and $y_L(k)$ is the output of D-L networks.

Block diagram by the proposed scheme is given in the following figure.

The unknown matrix Γ of eq(5) can be determined from eq(10) and (11) in a recursive manner, which allows on-line estimation of systems with unmodeled dynamics irrespective of *priori* knowledge required for exact modeling.

Since unmodeled systems can be estimated from only input-ouput information, the proposed method does not involve any additional procedure such as system identification required by conventional approach.

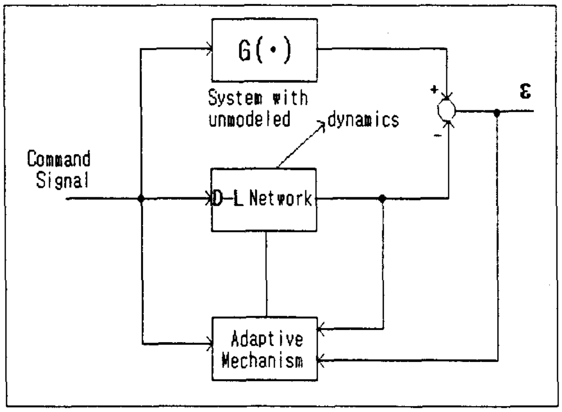

Fig 2. Summary of the proposed scheme

By reducing the computational burden considerably required for on-line estimation, it is expected that the higher convergence can be achieved with our proposed method when compared to conventional method.

4. Simulation Results and Discussion

To demonstrate the availability of the proposed method, two examples are considered and simulated. One example is the minimum phase system and the other is nonminimum phase system.

Example 1. Minimum phase system

Consider following unmodeled system $G(\cdot)$ whose dynamics is given by[7]

$$G(\cdot) = \frac{0.1761z^{-1}}{1 - 1.3205z^{-1} + 0.4966z^{-2}} \quad (12)$$

The output responses by the proposed method are given in Fig. 3 and Fig. 4 using different values of time scale factor a.

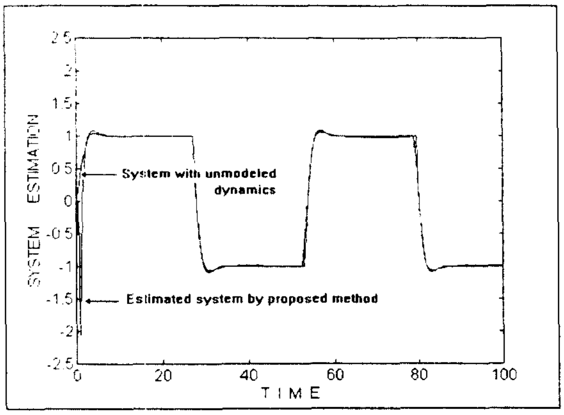

Fig. 3. Output response comparison of unmodeled system and estimated system by the proposed method for square command input signal (using optimal vlaue $a=0.6096$)

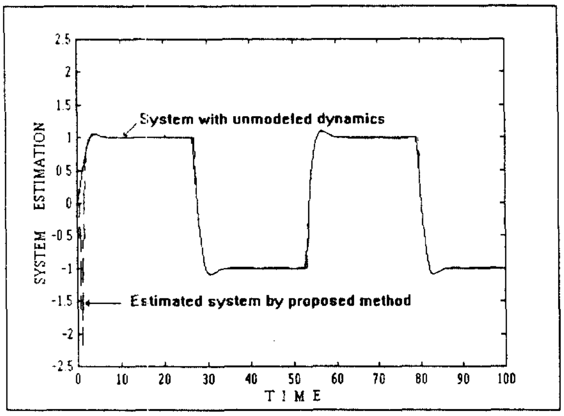

Fig. 4. Output response comparison of unmodeled system and estimated system by the proposed method for square command input signal (using average value $a=0.5$)

From the Fig 3 and Fig 4, it is shown that the estimated results by the proposed method are good except for the initial transcient response. The term number is chosen by $N=4$ and the initial value of covraiance matrix, $P=100 \cdot I$ is used for the simulation.

Example 2. Nonminimum phase system

Consider following unmodeled system $G(\cdot)$ whose dynamics is given by[9]

$$G(\cdot) = \frac{0.1z^{-1} + 0.2z^{-2}}{1 - 1.7z^{-1} + 0.72z^{-2}} \tag{13}$$

The output responses by the proposed method are given in the Fig. 5 and Fig. 6 using different values of time scale factor.

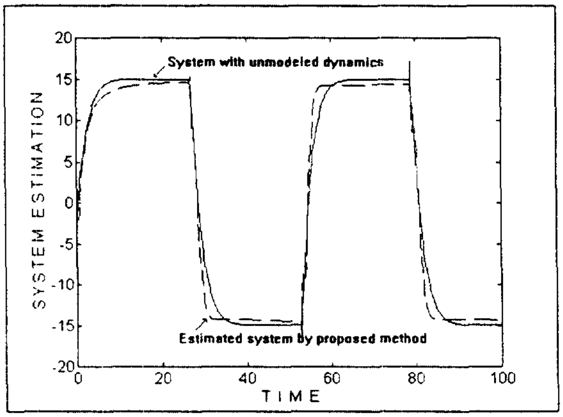

Fig. 5. Output response comparison of unmodeled system and estimated system by the proposed method for square command input signal (using optimal vlaue $a=0.6096$)

From the Fig 5 and Fig 6, it is shown that the estimated results by the proposed method are satisfactory. However in this case, the results are not better than those for example 1.

The term number is chosen by $N=4$ and the initial value of covraiance matrix, $P=I$ is used for the simulation. The different choices of time scale factor for D-L networks are from [10] and [6]. The former is the average value used previously, and the latter is the optimal value used recently.

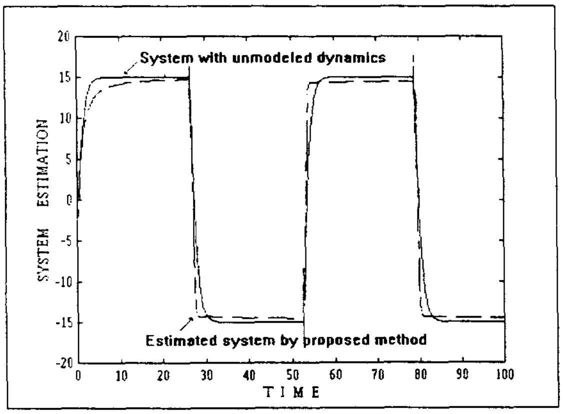

Fig. 6. Output response comparison of unmodeled system and estimated system by the proposed method for square command input signal (using average value $a=0.5$)

From the simulation results, it can be seen that the estimated results by the proposed method are good whether the system with unmodeled dynamics is minimum phase or nonminimum phase.

By facilitating on-line estimation of unmodeled systems without additional identification procedure, the higher convergence speed is achieved with our proposed manner. If the estimated result by the proposed method is not good like example 2, one can change the value of term number N arbitrarily such that the performance be satisfied. Therefore, the proposed method is expected to be very effective when applied to the controller design for real-time implementation using only input-output information.

5. Conclusion

In this paper, an efficient algorithm is presented for the on-line estimation of systems with unmodeled dynamics using D-L networks. The proposed algorithm is a method to approximate an unmodeled system in a recursive manner, which aviods the identification procedure required for conventional approach. It does not involve any additional identification procedure, hence the computatioal burden required for conventioal method can be reduced considerably. By simple on-line estimation using only input-output relation, higher convergence speed can be achieved in comparison with widely-used conventional method. Therefore, it is expected that the proposed method is very effective for the on-line controller design and system identification using only input-output relation.

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