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Two New Control Signal Approaches for Obtaining the MRAS-CDM and a Real-time Application

Ömür Öcal[1] Atilla Bir[1] Bernd Tibken[2]
[1]Department of Electrical Engineering, Istanbul Technical University, Istanbul 34230, Turkey
[2]Department of Electronic Engineering, University of Wuppertal, Wuppertal 42097, Germany

Abstract: The coefficient diagram method (CDM) is one of the most effective control design methods. It creates control systems that are very stable and robust with responses without the overshoot and small settling time. Furthermore, all control parameters of the control systems are changed by varying some adjustment parameters in CDM depending on the demands. The model reference adaptive systems (MRAS) are the systems that follow and change the control parameters according to a given model reference system. There are several methods to combine the CDM with MRAS. One of these is to use the MRAS parameters as a gain of the CDM parameters. Another is to directly use the CDM parameters as the MRAS parameters. In the industrial applications, the system parameters can be changed frequently, but if the controller, by self-tuning, recalculates and develops its own parameters continuously, the system becomes more robust. Also, if the poles of the controlled systems approach the jw axis, the response of the closed-loop MRAS becomes more and more insufficient. In order to obtain better results, CDM is combined with a self-tuning model reference adaptive system. Systems controlled by a model reference adaptive controller give responses with small or without overshoot, have small settling times, and are more robust. Thus, in this paper, a hybrid combination of MRAS and CDM is developed and two different control structures of the control signal are investigated. The two methods are compared with MRAS and applied to real-time process control systems.

Keywords: Coefficient diagram method (CDM), coefficient diagram method, adaptive control, process control, model reference adaptive systems (MRAS).

1 Introduction

Today, control system designers try to apply different control algorithms in order to find the best controller parameters to obtain the best solutions. Some of these methods are very successful for special cases while unsuccessful for other general applications. In this paper, according to this context, two effective controller algorithms are applied simultaneously and investigated to obtain the best results for all purpose systems.

There are hybrid systems previously developed by using the model reference adaptive systems (MRAS) and coefficient diagram method (CDM) methods simultaneously. In [1], sliding – mode control is combined with MRAS. The so-called SM-MRAS uses an estimator for the speed estimation in a sensorless vector-controlled induction machine drive. To obtain more robust control systems, neural network-based model reference adaptive systems are used to control high performance motor drive and motion control systems. In [2], a permanent magnet synchronous motor (PMSM) drive application is described. Since the adaptive systems are generally linear and neural networks are very good at estimating or controlling nonlinear systems, these kinds of solutions are frequently proposed. In terms of neural networks, it is not necessary to know the system parameters, and this kind of approach can easily be applied to linear or nonlinear control systems. This is the reason why they are so popular worldwide. In [3], for the model reference adaptive control, new output feedback adaptive control schemes are developed for linear multiple-input multiple-output systems. This approach is known as an output feedback model reference adaptive control mechanism. In [4], a sensorless position vector-control system based on MRAS is developed to use for a low speed and high torque PMSM drive. In [5], a nonlinear adaptive state-feedback speed control of a voltage-fed induction motor with varying parameters is presented. Here, MRAS is used for correcting the rotor-resistance error adaptively.

Another common design method is known as the CDM. This was developed by Manabe et al.[6−10]. Using this design method, it is possible to obtain systems that are very stable and robust, having small settling time without overshoot. Furthermore, it can be easily applied to any kind of linear control system. If it is possible to combine the CDM with other controller design methods, it would be very attractive. Similar to MRAS, there are some other hybrid systems developed for CDM. In [11], CDM is combined with integral-proportional derivative acceleration (I-PDA), incorporating a feed-forward controller (FFC). Here, the I-PDA control system structure is given as an FFC, and the parameters of PIDA and I-PDA are designed by CDM. PIDA and I-PIDA are in the form of feedback controller (FBC) and FFC, respectively. In [12], proportional-integral (PI) controller is added to CDM as a feed-forward controller. This method is similar to the method given in [11], but here acceleration and derivative parameters are not present in the FBC controller. In [13, 14], to obtain the most robust system, a pole assignment method containing pole coloring is used in CDM. In [15, 16], the adaptive-CDM algorithm is used for active queue management in congested networks. This is a very popular research area, especially in video streaming systems. The output of the adaptive CDM-AQM controller system is satisfactory, the parameter

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identification is converged and the stability is guaranteed. In [17], the CDM and MRAS-CDM structure is briefly introduced, and a real-time process control application is investigated. It is shown that the system outputs obtained with MRAS-CDM are much better for the poles near the origin and also for the poles that are far away in the negative s-plane.

In this paper, in addition to [17], using a different control approach, two design methods are developed for real time systems that have poles far away in the s-plane. It is shown that the designed new control systems give better results than the MRAS.

2 Theory

Consider a system described by the model

$$\frac{\mathrm{d}y}{\mathrm{d}t} = -d_0 y + n_0 u \tag{1}$$

where u is the control and y is the output signal. Assume that we want to obtain a closed-loop system described by

$$\frac{\mathrm{d}y_m}{\mathrm{d}t} = -d_m y_m + n_m u_c. \tag{2}$$

2.1 CDM

In this section, only the structure, performance parameters, target characteristic polynomial of CDM and the design procedure are given and discussed. The details of the CDM method can be found in [6−8].

The standard single-input single-output (SISO) block diagram of the CDM is shown in Fig. 1. Here, $R(s)$ is the input reference; $Y(s)$ is the output; $U(s)$ is the control; $Q(s)$ is the disturbance; $E(s)$ is the error, and $M(s)$ is the measurement disturbance signal of the system.

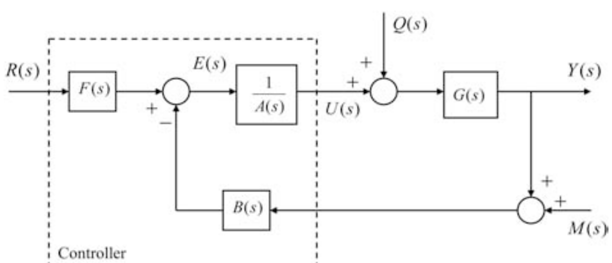

Fig. 1 The standard block diagram of CDM

In Fig. 1, $A(s)$, $B(s)$, and $F(s)$ are controller polynomials. The system to be controlled is represented by $G(s)$ transfer function that is given by

$$G(s) = \frac{N(s)}{D(s)}. \tag{3}$$

It is assumed that $\deg\{D(s)\} \geqslant \deg\{N(s)\}$. Also, it is easy to show that

$$Y(s) = \frac{A(s)N(s)}{P(s)}Q(s) + \frac{F(s)N(s)}{P(s)}R(s) - \frac{B(s)N(s)}{P(s)}M(s)$$

$$U(s) = \frac{F(s)D(s)}{P(s)}R(s) - \frac{B(s)N(s)}{P(s)}Q(s) - \frac{B(s)D(s)}{P(s)}M(s)$$

where $P(s)$ is the characteristic polynomial of the closed-loop system given by

$$P(s) = A(s)D(s) + B(s)N(s) = \sum_{i=0}^{n} a_i s^i. \tag{4}$$

While obtaining the hybrid system, an equivalent block diagram of CDM will be used, as shown in Fig. 2.

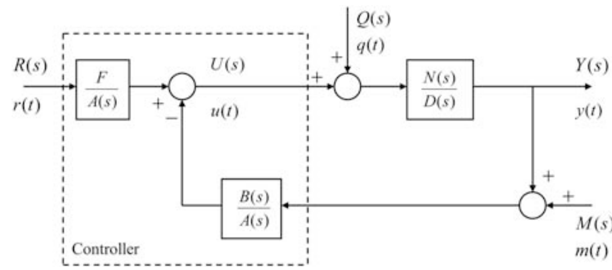

Fig. 2 Equivalent block diagram of CDM

2.1.1 Performance parameters and the target characteristic polynomial

CDM needs some design parameters with respect to the characteristic polynomial coefficients, such as the equivalent time constant τ, the stability indices γ_i, and the stability limits γ_i^*. The relations between these parameters and the coefficients of the characteristic polynomial a_i are given in (5):

$$\gamma_i = \frac{a_i^2}{a_{i+1}a_{i-1}}, \quad i = 1, \cdots, n-1 \tag{5a}$$

$$\tau = \frac{a_1}{a_0}, \quad \gamma_i^* = \frac{1}{\gamma_{i-1}} + \frac{1}{\gamma_{i+1}}. \tag{5b}$$

Using the relations in (5), it is possible to formulate the characteristic polynomial $P(s)$ in terms of the design parameters τ and γ_i as follows:

$$P_T(s) = a_0 \left[\left\{ \sum_{i=2}^{n} \left(\prod_{j=1}^{i-1} \frac{1}{\gamma_{i-j}^{j}} \right) (\tau s)^i \right\} + \tau s + 1 \right] \tag{6}$$

where $P_T(s)$ is the target characteristic polynomial. Note that the coefficients a_i of this polynomial can be expressed as

$$a_i = \frac{\tau^i}{\prod_{j=1}^{i-1} \gamma_j^{i-j}} a_0. \tag{7}$$

This is a relation between equivalent time constant τ and the settling time T_s. Since $\tau = T_s/\alpha$, where $\alpha \in [2.5, 3]$.

2.1.2 CDM design procedure

Equating the closed-loop system characteristic polynomial found in Section 2.1 to the target characteristic polynomial given in Section 2.1.1, one obtains the following Diophantine equation

$$P(s) = A(s)D(s) + B(s)N(s) = \sum_{i=0}^{n} a_i s^i = a_0 \left[\left\{ \sum_{i=2}^{n} (\prod_{j=1}^{i-1} \frac{1}{\gamma_{i-j}^{j}})(\tau s)^i \right\} + \tau s + 1 \right]. \tag{8}$$

If the polynomials are defined as

$$A(s)=\sum_{i=0}^{p} l_i s^i \quad \text{and} \quad B(s)=\sum_{i=0}^{q} k_i s^i$$

and then the equivalent Sylvester form equation is obtained

$$[C]_{r\times r}\begin{bmatrix} l_i \\ k_i \end{bmatrix}_{r\times 1}=[a_i]_{r\times 1}. \tag{9}$$

The coefficients of the matrix C and the parameters a_i are known values. Therefore, the coefficients of the controller polynomials $A(s)$ and $B(s)$ can be easily calculated.

The coefficient F is calculated by using the expression

$$F=\left(\frac{P(s)}{N(s)}\right)\Bigg|_{s=0}. \tag{10}$$

2.1.3 Stability analysis of CDM

In addition to Routh-Hurwitz criterion, CDM inserts the Lipatov-Sokolov criterion[8].

According to Lipatov-Sokolov criterion, the stability and instability conditions are shown as below[18,19]:

1) Necessary condition for instability

$$\gamma_{i-1}\gamma_i \leqslant 1 \quad \text{for } \exists i, \quad i=2,3,\cdots,n-1$$

and

$$a_{i-1}a_i \leqslant a_{i-2}a_{i+1} \quad \text{for } \exists i, \quad i=2,3,\cdots,n-1$$

2) Necessary condition for stability

Condition 1.

$$\gamma_i\gamma_{i-1} > 2.1505 \quad \text{for } \forall i, \quad i=2,3,\cdots,n-1$$

and

$$a_i a_{i-1} > 2.1505 a_{i+1}a_{i-2} \quad \text{for } \forall i, \quad i=2,3,\cdots,n-1$$

Condition 2.

$$\gamma_i > 1.1236\gamma_i^* \quad \text{for } \forall i, \quad i=2,3,\cdots,n-2$$

and with respect to a_i

$$a_i > 1.1236\left(a_{i+2}\frac{a_{i-1}}{a_{i+1}}+a_{i-2}\frac{a_{i+1}}{a_{i-1}}\right) \quad \text{for } \forall i, \quad i=2,3,\cdots,n-1.$$

To find a suitable desired (target) characteristic polynomial, these conditions can be used for choosing design parameters.

Details about the stability analysis of CDM are given in [6–8, 18, 19].

2.2 Hybrid MRAS-CDM configuration

The hybrid system configuration can be seen in Fig. 3. This system is controlled adaptively according to the model reference output $y_m(t)$, and the control variables are applied to the CDM controller as gain parameters.

According to the explanations given in Section 2 and using (8)–(10) for the system (1), the controller polynomials $A(s)$ and $B(s)$, the parameter F and the characteristic polynomial $P(s)$ are calculated as

$$A=\ell_0=a_0\tau \tag{11a}$$

$$B=k_0=\frac{a_0-a_0d_0\tau}{n_0} \tag{11b}$$

$$F=\frac{d_0\ell_0+k_0n_0}{n_0}=\frac{a_0}{n_0} \tag{11c}$$

$$P(s)=a_0\tau s+a_0=\ell_0 s+(d_0\ell_0+n_0k_0). \tag{11d}$$

The block diagram of the system can be seen in Fig. 4.

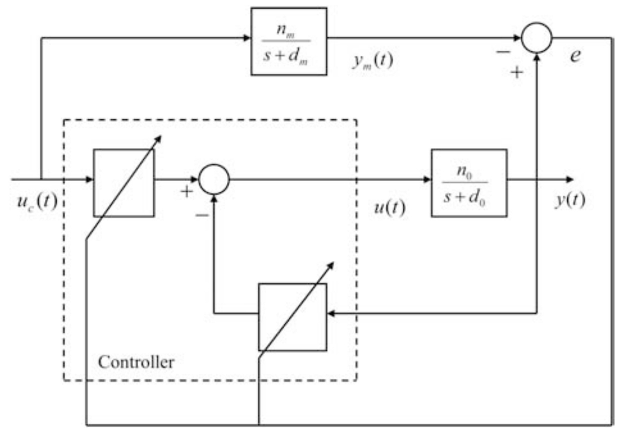

Fig. 3 Hybrid MRAS-CDM block diagram

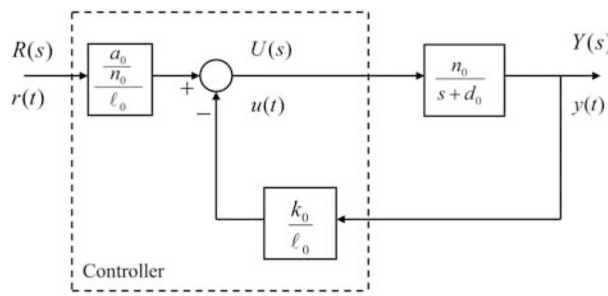

Fig. 4 The block diagram of the system

Since according to the changes of parameter F, the controller will produce new parameters adaptively, the change of F cannot affect the system after producing new controller parameters. It is used only for the standard CDM structure.

Furthermore, $u_c(t)$ in Fig. 3 and $r(t)$ in Fig. 4 are both reference signals of the control systems. $R(t)$ is the reference signal for the standard CDM structure in Fig. 1. $u_c(t)$ is the reference signal of the MRAS-CDM structure.

According to these results, if a hybrid control system structure is applied, the parameters of the control system can be changed adaptively.

2.2.1 The first method to obtain the control signal

The controller is given by

$$u=\frac{a_0}{n_0\ell_0}\theta_1 u_c-\frac{k_0}{\ell_0}\theta_2 y. \tag{12}$$

As seen in (12), the controller has two free parameters, θ_1 and θ_2. In order to obtain the classical MRAS control signals given in the literature, one has to investigate the references[20, 21]. The stability analyses are given in [20, 22]. For the non-linear system, the proposed adaptive controller in [23] and the stability analysis in [24, 25] may be considered as an alternative. If we assume that the input-output relations of the system and the model reference system are identical, then the following relations can be written

$$\theta_1 = \theta_1^0 = \frac{n_m}{\frac{a_0}{a_0 n_0 \ell_0}} \tag{13a}$$

$$\theta_2 = \theta_2^0 = \frac{d_m - d_0}{n_0\left(\frac{k_0}{\ell_0}\right)}. \tag{13b}$$

As a perfect model following system, the output of the closed-loop system is obtained from (1) and (12) as

$$y = \frac{\left(\frac{a_0}{n_0\ell_0}\right) n_0\theta_1}{s + d_0 + n_0\left(\frac{k_0}{\ell_0}\right)\theta_2} u_c. \tag{14}$$

To apply the Massachusetts Institute of Technology (MIT) rule[20], let the error be defined as

$$e = y - y_m. \tag{15}$$

If (2) and (14) are applied to (15), the sensitivity derivatives are obtained by taking partial derivatives with respect to controller parameters θ_1 and θ_2:

$$\frac{\partial e}{\partial \theta_1} = \frac{\left(\frac{a_0}{n_0\ell_0}\right) n_0}{s + d_0 + n_0\left(\frac{k_0}{\ell_0}\right)\theta_2} u_c \tag{16}$$

$$\frac{\partial e}{\partial \theta_2} = \frac{\left(\frac{k_0}{\ell_0}\right) n_0}{s + d_0 + n_0\left(\frac{k_0}{\ell_0}\right)\theta_2} y. \tag{17}$$

The following equation can be used in the approximation:

$$s + d_0 + n_0\left(\frac{k_0}{\ell_0}\right)\theta_2 \cong s + d_m. \tag{18}$$

Finally, the following equations are necessary in order to update the controller parameters[17]:

$$\frac{\partial \theta_1}{\partial t} = -\gamma\left(\frac{\left(\frac{a_0}{n_0\ell_0}\right) n_0}{s + d_m} u_c\right) e \tag{19a}$$

$$\frac{\partial \theta_2}{\partial t} = \gamma\left(\frac{\left(\frac{k_0}{\ell_0}\right) n_0}{s + d_m} y\right) e. \tag{19b}$$

Stability analysis. According to the Lyapunov stability analysis[20], the time derivative of the positive definite Lyapunov function function has to be negative or

$$\frac{\mathrm{d}V}{\mathrm{d}t} < 0. \tag{20}$$

By means of (1), (2), (12), (15), and the control signal given in (12), the time derivative of the error is calculated as

$$\frac{\mathrm{d}e}{\mathrm{d}t} = -d_m e - \left(n_0\frac{k_0}{\ell_0}\theta_2 + d_0 - d_m\right) y + \left(\frac{a_0}{\ell_0}\theta_1 - n_m\right) u_c. \tag{21}$$

If the positive definite Lyapunov function is chosen as follows:

$$V(t,\theta_1,\theta_2) = \frac{1}{2}\left(e^2 + \frac{\ell_0}{n_0 k_0 \gamma}\left(n_0\frac{k_0}{\ell_0}\theta_2 + d_0 - d_m\right)^2\right) + \frac{1}{2}\left(\frac{\ell_0}{a_0\gamma}\left(n_0\frac{a_0}{\ell_0}\theta_1 - n_m\right)^2\right). \tag{22}$$

The time derivative can be written as

$$\begin{aligned}\frac{\mathrm{d}V}{\mathrm{d}t} &= e\frac{\mathrm{d}e}{\mathrm{d}t} + \frac{1}{\gamma}\left(n_0\frac{k_0}{\ell_0}\theta_2 + d_0 - d_m\right)\frac{\mathrm{d}\theta_2}{\mathrm{d}t} + \frac{1}{\gamma}\left(\frac{a_0}{\ell_0}\theta_1 - n_m\right)\frac{\mathrm{d}\theta_1}{\mathrm{d}t} = \\ &-d_m e^2 + \frac{1}{\gamma}\left(n_0\frac{k_0}{\ell_0}\theta_2 + d_0 - d_m\right)\left(\frac{\mathrm{d}\theta_2}{\mathrm{d}t} - \gamma y e\right) + \frac{1}{\gamma}\left(\frac{a_0}{\ell_0}\theta_1 - n_m\right)\left(\frac{\mathrm{d}\theta_1}{\mathrm{d}t} + \gamma u_c e\right).\end{aligned} \tag{23}$$

This suggests the adaptation law

$$\frac{\mathrm{d}\theta_1}{\mathrm{d}t} = -\gamma u_c e \tag{24a}$$

$$\frac{\mathrm{d}\theta_2}{\mathrm{d}t} = \gamma y e. \tag{24b}$$

Thus as

$$\frac{\mathrm{d}V}{\mathrm{d}t} = -d_m e^2 \tag{25}$$

$$\frac{\mathrm{d}V}{\mathrm{d}t} < 0 \tag{26}$$

the system is asymptotically stable.

2.2.2 The second method to obtain the control signal

The controller f with two free parameters m_0 and f_0 is applied as

$$u = \frac{a_0}{n_0}\frac{1}{\ell_0}u_c - \frac{k_0}{\ell_0}y \tag{27a}$$

$$u = \frac{a_0}{n_0}m_0 u_c - k_0 m_0 y, \quad \text{for } m_0 = \frac{1}{\ell_0} \text{ and } k_0 m_0 = f_0. \tag{27b}$$

If assuming that the input-output relations of the system and the model system are identical, we obtain

$$\ell_0 = \ell_0^0 = \frac{n_m}{a_0} \tag{28a}$$

$$k_0 = k_0^0 = a_0\frac{d_m - d_0}{n_0 n_m}. \tag{28b}$$

This is again a perfect model following system. Using (1) and (27), the output of the closed-loop system can be calculated as

$$y = \frac{a_0 m_0}{s + d_0 + n_0 f_0} u_c. \tag{29}$$

To apply the MIT rule[20], let the error be defined as

$$e = y - y_m. \tag{30}$$

If (2) and (29) are applied to (30), the sensitivity derivatives are obtained by taking partial derivatives with respect to controller parameters m_0 and f_0:

$$\frac{\partial e}{\partial m_0} = \frac{a_0}{s + d_0 + n_0 f_0} u_c \tag{31}$$

$$\frac{\partial e}{\partial f_0} = \frac{n_0 m_0}{s + d_0 + n_0 f_0} y. \tag{32}$$

For the approximation, the following equation can be used:

$$s + d_0 + n_0 f_0 \cong s + d_m \tag{33}$$

and finally, the following equations are necessary in order to update the controller parameters:

$$\frac{\partial m_0}{\partial t} = -\gamma e \frac{a_0}{s + d_0 + n_0 f_0} u_c \tag{34a}$$

$$\frac{\partial f_0}{\partial t} = \gamma e \frac{n_0 m_0}{s + d_0 + n_0 f_0} y. \tag{34b}$$

Stability Analysis. The stability of the system can be examined by using the Lyapunov stability analysis once again.

The control signal and the error equation are given as

$$u = \frac{a_0}{n_0} m_0 u_c - f_0 y \tag{35}$$

$$\frac{\mathrm{d}e}{\mathrm{d}t} = -d_m e - (n_0 f_0 + d_0 - d_m) y + (a_0 m_0 - n_m) u_c. \tag{36}$$

If the Lyapunov function is chosen as follows:

$$V(t, f_0, m_0) = \frac{1}{2}\left(e^2 + \frac{1}{n_0 \gamma}(n_0 f_0 + d_0 - d_m)^2\right) + \frac{1}{2}\left(\frac{1}{a_0 \gamma}(a_0 m_0 - n_m)^2\right). \tag{37}$$

taking the time derivative

$$\begin{aligned}\frac{\mathrm{d}V}{\mathrm{d}t} = & e\frac{\mathrm{d}e}{\mathrm{d}t} + \frac{1}{\gamma}(n_0 f_0 + d_0 - d_m)\frac{\mathrm{d}f_0}{\mathrm{d}t} + \\ & \frac{1}{\gamma}(a_0 m_0 - n_m)\frac{\mathrm{d}m_0}{\mathrm{d}t} = \\ & -d_m e^2 + \frac{1}{\gamma}(n_0 f_0 + d_0 - d_m)\left(\frac{\mathrm{d}f_0}{\mathrm{d}t} - \gamma y e\right) + \\ & \frac{1}{\gamma}(a_0 m_0 - a_0)\left(\frac{\mathrm{d}m_0}{\mathrm{d}t} + \gamma u_c e\right)\end{aligned} \tag{38}$$

the adaptation law can be suggested as

$$\frac{\mathrm{d}m_0}{\mathrm{d}t} = -\gamma u_c e \tag{39a}$$

$$\frac{\mathrm{d}f_0}{\mathrm{d}t} = \gamma y e \tag{39b}$$

thus

$$\frac{\mathrm{d}V}{\mathrm{d}t} = -d_m e^2 \tag{40}$$

$$\frac{\mathrm{d}V}{\mathrm{d}t} < 0 \tag{41}$$

and the system is asymptotically stable.

In the first control design scheme in Section 2.2.1, the parameters l_0 and k_0 introduced and combined in the hybrid MRAS system are known as design parameters. But in the second control design scheme in Section 2.2.2, the parameters l_0 and f_0 are directly applied as control signals in MRAS, so that their values are unknown at the beginning. Thus, if system parameters change according to the difference between the model reference output and the output of the system, the system would automatically determine the values of the new parameters.

In the next section, the results are checked on a real-time process control system and the simulated system outputs are evaluated.

3 A real-time process control application

In this section, by using MRAS-CDM, the two control signal algorithms are applied to a process control system and the results are compared with the MRAS outputs.

The model of the controlled process is given in Fig. 5.

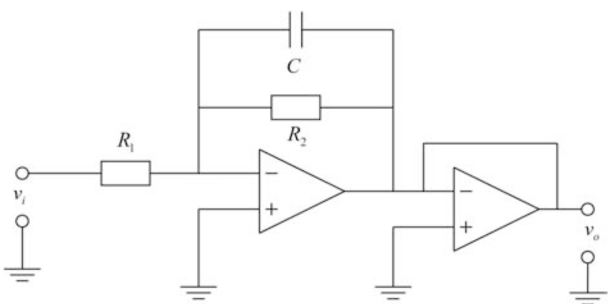

Fig. 5 The model of the controlled process

The transfer function of the process can be expressed as follows:

$$\frac{v_o(s)}{v_i(s)} = \frac{R_2}{R_1}\left(\frac{1}{R_2 C s + 1}\right). \tag{42}$$

To have unity gain, the ratio and the values of the system parameters are chosen as $R_2/R_1 = 1$, $R_1 = R_2 = 1\,\mathrm{M\Omega}$, $C = 1\,\mu\mathrm{F}$, $a_m = b_m = n_m = d_m = 2$, and $\gamma = 1$.

If these values are applied to the given equations, the following transfer functions are obtained:

$$\frac{v_o(s)}{v_i(s)} = \frac{1}{s+1} \tag{43}$$

and

$$\frac{N_m}{D_m} = \frac{2}{s+2}, \quad \frac{B_m}{A_m} = \frac{2}{s+2}. \tag{44}$$

In Figs. 6–8, the output signals for MRAS-CDM and MRAS are given respectively. For both control signals, MRAS-CDM response is better than the MRAS control performance.

Furthermore, if the controller parameters are adjusted according to the plant characteristics, the system performance can be improved. But first under similar conditions, we must determine which one is the best among the three methods.

Fig. 6 shows that this approach is satisfactory in control applications. In fact, applications without overshoot dynamics can also be achieved by adjusting the free parameters of the MRAS-CDM controller[17]. We keep in mind that in all cases the basic parameters are equal.

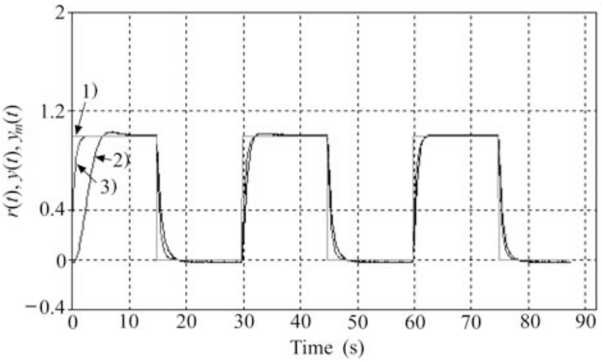

Fig. 6 The output signals. 1) The reference signal $r(t)$; 2) The output signal $y(t)$ for MRAS-CDM using the first method for the model control reference; 3) The output signal $y_m(t)$ of the reference model

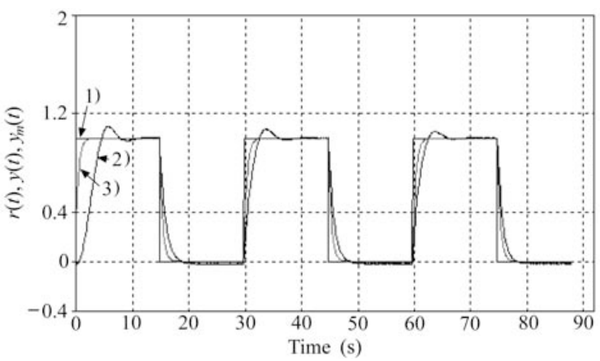

Fig. 7 The output signals. 1) The reference signal $r(t)$; 2) The output signal $y(t)$ for MRAS-CDM using the second method for the model control reference; 3) The output signal $y_m(t)$ of the reference model

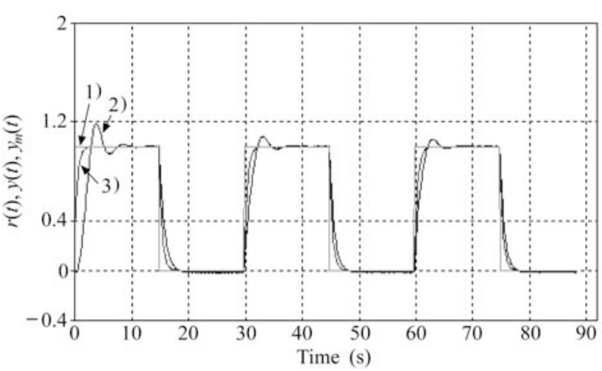

Fig. 8 The output signals. 1) The reference signal $r(t)$; 2) The output signal $y(t)$ for MRAS controlled system; 3) The output signal $y_m(t)$ of the reference model

As seen from Figs. 9–11, the control system obtained by using the first control signal applying method is the best. The worst one is the system controlled by MRAS. The dynamics of the MRAS and the MRAS-CDM control system using the second method are similar to a second order system. Since the control signal parameters are almost identical, this is an expected result.

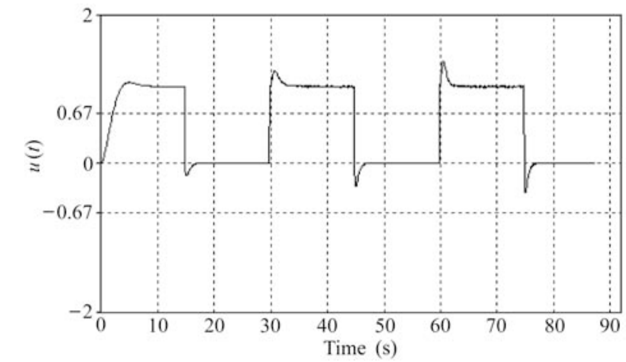

Fig. 9 Control signal $u(t)$ for MRAS-CDM using the first method

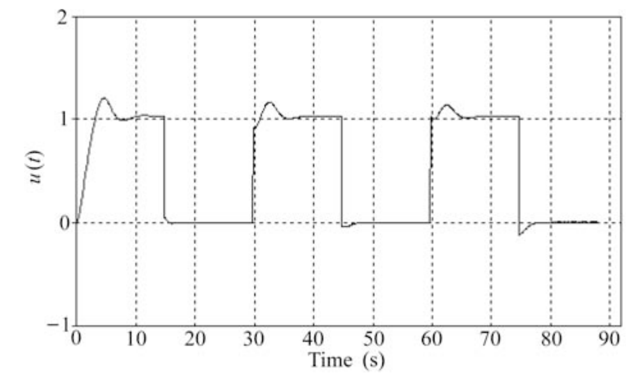

Fig. 10 Control signal $u(t)$ for MRAS-CDM using the second method

For both control signal applying methods, the control signals $u(t)$ are satisfactory. But for the system with MRAS, control signals become worse after the second period of the reference signal. The variations of the control parameters θ_1, θ_2, m_0, and f_0 are shown in Figs. 12–14.

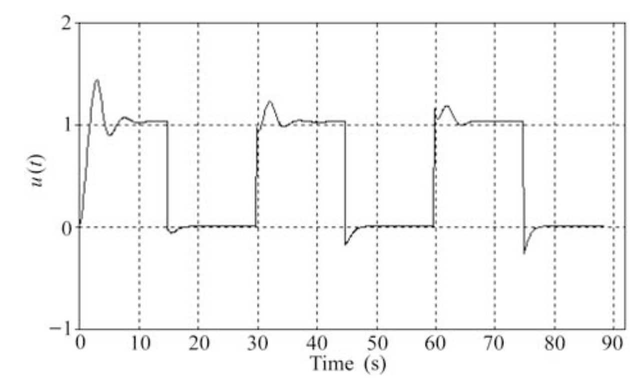

Fig. 11 Control signal $u(t)$ for the system using MRAS

As seen from Figs. 12 and 14, control parameter θ_2 of MRAS-CDM using the first method produces the signal without overshoot. This is the reason why the parameters of MRAS-CDM using the first method, and the second method and MRAS are so different from each other.

In Fig. 15–17, the block diagrams are given in real-time applications. In Fig. 15, MultiQ-PCI denotes multiq-peripheral component interconnect, DAC denotes digital-to-analog converter, and ADC denotes analog-to-digital converter. In Fig. 16, Q_1 and Q_2 are the controller parameters in (19).

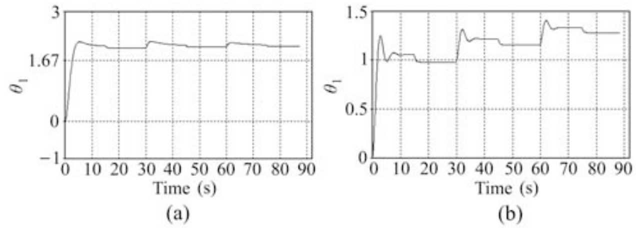

Fig. 12 Variation of the control parameter θ_1 for (a) MRAS-CDM using the first method and for (b) MRAS

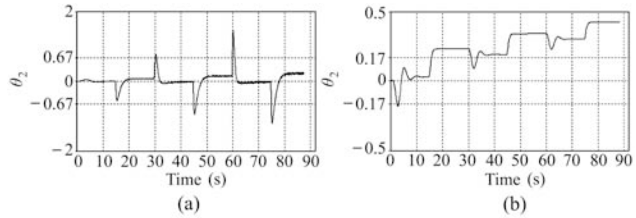

Fig. 13 Variation of the control parameter θ_2 for (a) MRAS-CDM using the first method and for (b) MRAS

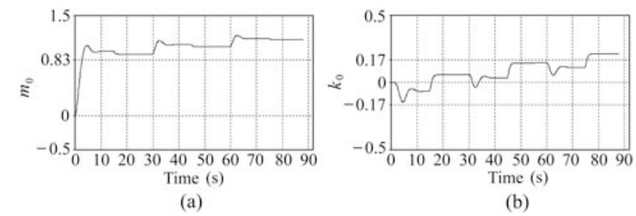

Fig. 14 MRAS-CDM using the second control signal method. (a) Variation of the control parameter m_0; (b) Variation of the control parameter k_0

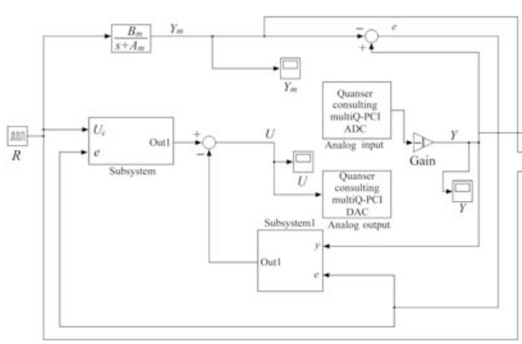

Fig. 15 The block diagram of MRAS-CDM using the first control signal method

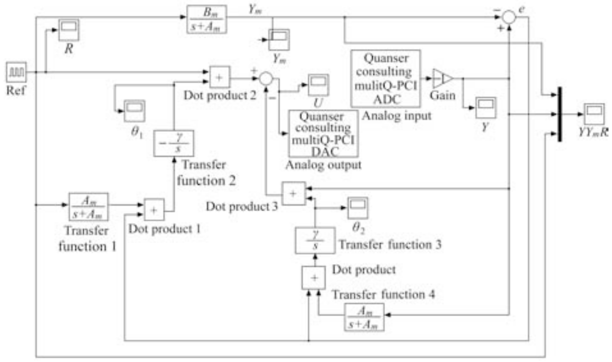

Fig. 16 The block diagram using MRAS control

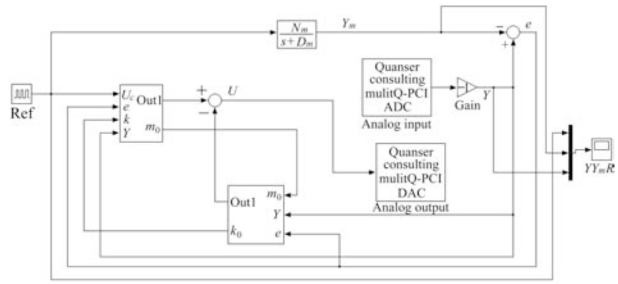

Fig. 17 The block diagram of MRAS-CDM using the second control signal method

4 Conclusions

In this paper, an MRAS-CDM control configuration, which consists of the hybrid combination of MRAS and CDM control strategies, has been analyzed, the method has been applied to a real-time process control and the results have been discussed in detail. As demonstrated, the new control design procedures and performances are better than the classical MRAS.

In this design procedure, the control parameters of the CDM are changed adaptively by estimating the control parameters based on a given reference model. In classical control systems designed by CDM, the system parameters are calculated according to the special plant parameters.

If plant parameters change, the performance of the control system diminishes and begins to give poor solutions. In control systems controlled by MRAS-CDM, the control parameters are changed adaptively according to the reference model.

In addition, if a control system is controlled by model reference adaptive systems and the reference model parameters are chosen near the jw axis, the performance of the system is unsatisfactory[17], because the closed-loop responses have large overshoots. These kinds of problems are overcome by using the MRAS-CDM. This is true only for limited changes of the plant parameters.

In the future, MRAS-CDM control method can be applied to more complex real time systems. In general, it can be said that systems like satellites and robots using adaptive controls would achieve very successful results. The new design method is suggested to be applied to these kinds of work as an alternative.

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Ömür Öcal graduated from Osmangazi University, Eskisehir, Turkey in 2001. He received the B. Sc. degree in electrical and electronic engineering, M. Sc. degree at the Control and Automation Engineering Program from Istanbul Technical University (ITU), Istanbul, Turkey in 2004, and the Ph. D. degree at the Control and Automation Engineering Program in ITU in 2010. He worked as a research and teaching assistant at the Computer Engineering Department of Kadir Has University, Istanbul, Turkey from 2004 to 2007.

His research interests include linear control systems theory and design, automatic control, digital control, real time control, adaptive control, robust control, industrial control, neural networks, and fuzzy logic control.

E-mail: oocal@itu.edu.tr (Corresponding author)

Atilla Bir received the B. Sc. and M. Sc. degrees in T. H. Karlsruhe-Nachrichtentechnik, Karlsruhe, Germany in 1966. For one year, he worked as a design engineer for Siemens, Karlsruhe, Germany. He received the Ph. D. degree at the Electrical Faculty in Istanbul Technical University (ITU), Istanbul, Turkey in 1975. He worked as a research and teaching assistant in ITU from 1970 to 1980. Then, he became an assistant professor at the Electrical Faculty of ITU, Istanbul, Turkey in 1980. He has worked as a professor in ITU since 1989. He was also department chair between 1994 and 1996 and the Control Department chair in 1991–1994 and 1996–2004.

His research interests include linear control systems theory and design, multivariable systems, robust control, optimal control, non-linear control, stochastic control, industrial control, and history of science and technology.

E-mail: bir@itu.edu.tr

Bernd Tibken graduated from the University of Hamburg, Germany in the winter semester 1979–1980 and in physics from the University of Hamburg in 1985. He received the Ph. D. degree from the Technical University of Hamburg-Harburg, and the Habilitation degree from the University of Ulm, Germany in 1990 and 1996, respectively. Since 1999, he has been a full professor for automatic control in the Faculty of Electrical, Information, and Media Engineering (Faculty E) of the University of Wuppertal, Germany. He received calls to full professor positions at Technical University of Freiberg in 1999 and the Helmut Schmidt University, Hamburg (former University of the Armed Forces) in 2003. Since 2002, he has been the dean of Faculty E at the University of Wuppertal.

His research interest includes nonlinear control theory, especially polynomial systems and the application of real algebra to control problems.

E-mail: tibken@uni-wuppertal.de