Paper:

Self-Tuning Generalized Minimum Variance Control Based on On-Demand Type Feedback Controller

Akira Yanou, Mamoru Minami, and Takayuki Matsuno

Graduate School of Natural Science and Technology, Okayama University
3-1-1 Tsushimanaka, Kita-ku, Okayama 700-8530, Japan
E-mail: yanou-a@cc.okayama-u.ac.jp
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This paper proposes a design method of self-tuning generalized minimum variance control based on on-demand type feedback controller. A controller, such as generalized minimum variance control (GMVC), generalized predictive control (GPC) and so on, can be extended by using coprime factorization. Then new design parameter is introduced into the extended controller, and the parameter can re-design the characteristic of the extended controller, keeping the closed-loop characteristic that way. Although strong stability systems can be obtained by the extended controller in order to design safe systems, focusing on feedback signal, the extended controller can adjust the magnitude of the feedback signal. That is, the proposed controller can drive the magnitude of the feedback signal to zero if the control objective was achieved. In other words the feedback signal by the proposed method can appear on demand of achieving the control objective. Therefore this paper proposes on-demand type feedback controller using self-tuning GMVC for plant with uncertainty. A numerical example is shown in order to check the characteristic of the proposed method.

Keywords: on-demand type feedback control, coprime factorization, generalized minimum variance control, self-tuning control

1. Introduction

Generalized Minimum Variance Control (GMVC) has been proposed by Clarke and others [1]. GMVC is one of the control methods for application in industry and the controller is designed by generalized output to make the closed-loop system stable. The control law can be obtained by minimizing the variance of generalized output. Once the generalized output is designed, the derived controller cannot be re-designed without changing the closed-loop characteristic. Industrial safety considerations make it desirable that both the closed-loop system and controller be stable, i.e., even if the closed-loop characteristic has been designed, it is better that there is the margin of re-designing the controller in order to design safe systems. Authors have proposed the extended GMVC design method [2, 3]. The extended method introduces a new design parameter for conventional GMVC by using Youla-Kucera parameterization [4–6]. In the method, the controller can be re-designed by its parameter without changing the closed-loop characteristic. Therefore a strong stability system, which means that both closed-loop system and controller are stable, can be obtained by re-designing the controller [7–11]. The authors have proposed a concept of strong stability rate [12–14] by using coprime factorization and showed that strong stability system can be obtained. Under the assumption that the controlled plant is stable, the research about strong stability rate has focused on a stable open-loop output. For example, if the value of strong stability rate becomes 1, the controlled output becomes equal to reference signal in the steady state whether the feedback loop is cut or not. This situation indicates that the control objective is achieved and the feedback signal is not demanded (that is, the feedback signal becomes zero) in the steady state. In other words, new concept controller is considered by using coprime factorization, whose feedback signal emerges based on demand to make controlled output follow the reference signal, and becomes zero if controlled output becomes equal to the reference signal. In this method, the role and the benefit that the feedback signal becomes zero contribute to constructing safe systems because the output of the proposed system does not diverge even if the feedback signal becomes zero by an accident. In particular, when controlled output of thermal process is defined as temperature [K], what the feedback signal becomes zero means that the measured temperature becomes 0 K. In this case, the controller will always operate to heat the controlled plant in order to make the controlled output follow the reference signal. Consequently, it causes abnormal temperature increase to the controlled plant. Although it should be shutdown immediately in consideration of safety if the feedback signal becomes zero by an accident, the shutdown based on the predetermined procedure is desirable. Because the proposed method can keep system safety even if the feedback signal is zero, it can be shutdown safely. This characteristic is useful for actual systems from the viewpoint of safety margin. Although authors have newly proposed on-demand type feedback controller [15], the case with plant uncertainty has not been considered. Therefore this paper proposes self-tuning GMVC based on on-demand type feedback controller. A numerical example is shown in order to check the behavior of the proposed controller.

This paper is organized as follows. Section 2 describes problem statement and conventional GMVC. Section 3 extends GMVC through coprime factorization and gives the proposed self-tuning controller. Section 4 shows a numerical example to check the behavior of on-demand type feedback controller. Section 5 summarizes the result of this paper.

Notations: This paper assumes that the controlled plant is stable. z^{-1} means backward shift operator $z^{-1}y(t) = y(t-1)$. $A[z^{-1}]$ and $A(z^{-1})$ mean polynomial and rational function with z^{-1} respectively. Steady state gain $A(1)$ of transfer function is calculated as $z^{-1} = 1$ under the assumption that signals such as input and output for system does not change with regard to time t.

2. Problem Statement and Conventional GMVC

A single-input single-output system is considered.

$$A[z^{-1}]y(t) = z^{-k_m}B[z^{-1}]u(t) + C[z^{-1}]\xi(t) \quad \ldots (1)$$
$$t = 0, 1, 2, \ldots$$

$u(t)$ and $y(t)$ are input and output respectively. k_m is time delay, $\xi(t)$ is white Gaussian noise with zero mean. $A[z^{-1}]$, $B[z^{-1}]$ and $C[z^{-1}]$ are the polynomials with degrees n, m and l.

$$\begin{cases} A[z^{-1}] = 1 + a_1 z^{-1} + \cdots + a_n z^{-n} \\ B[z^{-1}] = b_0 + b_1 z^{-1} + \cdots + b_m z^{-m} \\ C[z^{-1}] = 1 + c_1 z^{-1} + \cdots + c_l z^{-l} \end{cases} \quad \ldots (2)$$

On the system (1) the following assumptions are hold.

1. The degrees n, m and l of $A[z^{-1}]$, $B[z^{-1}]$ and $C[z^{-1}]$, and the time delay k_m are known.
2. The coefficients of $A[z^{-1}]$, $B[z^{-1}]$ and $C[z^{-1}]$ are known.
3. The polynomials $A[z^{-1}]$ and $B[z^{-1}]$, $A[z^{-1}]$ and $C[z^{-1}]$ are coprime.
4. The polynomial $C[z^{-1}]$ is stable.

The control objective is to make the output $y(t)$ follow the reference signal $w(t)$. To achieve this objective, performance index J averaged over the noise is minimized.

$$\Phi(t+k_m) = P[z^{-1}]y(t+k_m) + Q[z^{-1}]u(t) - R[z^{-1}]w(t) \quad \ldots (3)$$
$$J = \mathrm{E_X}[\Phi^2(t+k_m)] \quad \ldots (4)$$

$\Phi(t+k_m)$ is generalized output. $P[z^{-1}]$, $Q[z^{-1}]$ and $R[z^{-1}]$ are polynomials with degrees of n_p, n_q and n_r. These polynomials are selected to obtain a stable closed-loop characteristic. In conventional GMVC, Diophantine equation is introduced to find $E[z^{-1}]$ and $F[z^{-1}]$.

$$P[z^{-1}]C[z^{-1}] = A[z^{-1}]E[z^{-1}] + z^{-k_m}F[z^{-1}] \quad \ldots (5)$$

where

$$E[z^{-1}] = 1 + e_1 z^{-1} + \cdots + e_{k_m-1} z^{-(k_m-1)} \quad \ldots (6)$$
$$F[z^{-1}] = f_0 + f_1 z^{-1} + \cdots + f_{n_1} z^{-n_1} \quad \ldots (7)$$
$$n_1 = \max\{n-1, n_p + l - k_m\} \quad \ldots (8)$$

The solution $E[z^{-1}]$ of Diophantine equation is used to calculate the following polynomial $G[z^{-1}]$. $T[z^{-1}]$ gives the closed-loop characteristic.

$$G[z^{-1}] = E[z^{-1}]B[z^{-1}] + C[z^{-1}]Q[z^{-1}] \quad \ldots (9)$$
$$T[z^{-1}] = P[z^{-1}]B[z^{-1}] + Q[z^{-1}]A[z^{-1}] \quad \ldots (10)$$

From Eqs. (5) and (9), the generalized output and the prediction $\hat{\Phi}(t+k_m|t)$ can be given.

$$\Phi(t+k_m) = \hat{\Phi}(t+k_m|t) + E[z^{-1}]\xi(t+k_m) \quad \ldots (11)$$
$$\hat{\Phi}(t+k_m|t) = \frac{F[z^{-1}]y(t) + G[z^{-1}]u(t) - C[z^{-1}]R[z^{-1}]w(t)}{C[z^{-1}]} \quad (12)$$

Since $\hat{\Phi}(t+k_m|t)$ and the noise term $E[z^{-1}]\xi(t+k_m)$ have no correlation each other, the control law $u(t)$ to minimize J can be obtained by the following equation.

$$\hat{\Phi}(t+k_m|t) = 0 \quad \ldots (13)$$

Then the control law is obtained as following equation.

$$u(t) = \frac{C[z^{-1}]R[z^{-1}]}{G[z^{-1}]}w(t) - \frac{F[z^{-1}]}{G[z^{-1}]}y(t) \quad \ldots (14)$$

The closed-loop system for Eq. (14) can be given as,

$$y(t) = \frac{z^{-k_m}B[z^{-1}]R[z^{-1}]}{T[z^{-1}]}w(t) + \frac{G[z^{-1}]}{T[z^{-1}]}\xi(t) \quad . (15)$$

where $T[z^{-1}]$ is defined in Eq. (10).

3. Extension of GMVC by Coprime Factorization

3.1. Coprimely Factorized Control Systems

For coprime factorization, the family of stable rational functions RH_∞ is considered,

$$RH_\infty = \left\{ G(z^{-1}) = \frac{G_n[z^{-1}]}{G_d[z^{-1}]} \right\}. \quad \ldots (16)$$

$G_d[z^{-1}]$ is stable polynomial. Transfer function $G_p(z^{-1})$ in Eq. (1) between $u(t)$ and $y(t)$ is expressed by a ratio of rational functions in RH_∞,

$$\begin{aligned} y(t) &= \frac{z^{-k_m}B[z^{-1}]}{A[z^{-1}]}u(t) \\ &= G_p(z^{-1})u(t) \\ &= N(z^{-1})D^{-1}(z^{-1})u(t). \end{aligned} \quad \ldots (17)$$

$N(z^{-1})$ and $D(z^{-1})$ are rational functions in RH_∞ and coprime each other. This paper assumes that the controlled system $G_p(z^{-1})$ is stable. In the next step, the Bezout identity is introduced.

$$X(z^{-1})N(z^{-1})+Y(z^{-1})D(z^{-1})=1 \quad . \quad . \quad . \quad . \quad (18)$$

The solutions $X(z^{-1})$ and $Y(z^{-1})$ of Bezout identity are in RH_∞. From Eqs. (17) and (18), all the stabilizing controller can be expressed in Youla-Kucera parameterization [4].

$$u(t)=C_1(z^{-1})w(t)-C_2(z^{-1})y(t) \quad . \quad . \quad . \quad . \quad (19)$$

$$C_1(z^{-1})=(Y(z^{-1})-U(z^{-1})N(z^{-1}))^{-1}K(z^{-1}) \quad (20)$$

$$C_2(z^{-1})=(Y(z^{-1})-U(z^{-1})N(z^{-1}))^{-1} \cdot(X(z^{-1})+U(z^{-1})D(z^{-1})) \quad . \quad . \quad . \quad . \quad (21)$$

$U(z^{-1}),\ K(z^{-1}) \in RH_\infty$ are free parameters. From Eqs. (19), (20), (21) and (17), the closed-loop transfer function is given.

$$\begin{aligned} y(t) &= N(z^{-1})D^{-1}(z^{-1})(Y(z^{-1})-U(z^{-1}) \\ &\quad \cdot N(z^{-1}))^{-1}K(z^{-1})w(t)-N(z^{-1})D^{-1}(z^{-1}) \\ &\quad \cdot(Y(z^{-1})-U(z^{-1})N(z^{-1}))^{-1}(X(z^{-1}) \\ &\quad +U(z^{-1})D(z^{-1}))y(t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22) \end{aligned}$$

From Eq. (18),

$$y(t)=N(z^{-1})K(z^{-1})w(t). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

If the controller is designed for settling control, the output $y(t)$ follows and converges to $w(t)$ as time progresses. It means that the steady-state gain of closed-loop transfer function (Eq. (23)) is designed to be $N(1)K(1)=1$. Moreover it finds that the design parameter $U(z^{-1})$ in the stabilizing controller (Eq. (19)) is independent of Eq. (23). Therefore when closed-loop system (Eq. (23)) is designed to be stable and stabilizing controller (Eq. (19)) is also designed to be stable through $U(z^{-1})$, strong stability system can be obtained.

3.2. Concept of On-Demand Type Feedback Controller

In the previous research [16], the authors have proposed a design method of strong stability system and defined the selection method of design parameter $U(z^{-1})$, which can equate steady state gains of the closed-loop system and the open-loop system. In that research, it was found that the derived closed-loop system allows that the feedback signal becomes zero in the steady state because the controller is designed to make the open-loop gain equal to the closed-loop gain. It means that the feedback signal appears so as to achieve the control objective, and its signal becomes zero when the control objective was achieved in the steady state. Therefore this paper defines such a controller as on-demand type feedback controller [15].

In this subsection, the concept is described briefly. Assuming that the feedback signal $C_2(z^{-1})y(t)$ in the stabilizing controller (Eq. (19)) becomes zero, and considering the open-loop system for the closed-loop system (Eq. (23)), the controller (Eq. (19)) is given as follows.

$$u(t)=(Y(z^{-1})-U(z^{-1})N(z^{-1}))^{-1}K(z^{-1})w(t) \quad (24)$$

From Eq. (17), the open-loop transfer function from $w(t)$ to $y(t)$ is given.

$$\begin{aligned} y(t) &= N(z^{-1})D^{-1}(z^{-1})u(t) \\ &= N(z^{-1})D^{-1}(z^{-1}) \\ &\quad \cdot\left(Y(z^{-1})-U(z^{-1})N(z^{-1})\right)^{-1}K(z^{-1})w(t) \\ &= \left(Y(z^{-1})D(z^{-1})-U(z^{-1})N(z^{-1})D(z^{-1})\right)^{-1} \\ &\quad \cdot N(z^{-1})K(z^{-1})w(t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25) \end{aligned}$$

Because of $Y(z^{-1})D(z^{-1})=1-X(z^{-1})N(z^{-1})$, the open-loop system can be obtained as shown in the following equation.

$$\begin{aligned} y(t) &= \left\{1-(X(z^{-1})+U(z^{-1})D(z^{-1}))N(z^{-1})\right\}^{-1} \\ &\quad \cdot N(z^{-1})K(z^{-1})w(t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26) \end{aligned}$$

The steady state output $y(t)$ of open-loop system is given.

$$\begin{aligned} y(t) &= \{1-(X(1)+U(1)D(1))N(1)\}^{-1} \\ &\quad \cdot N(1)K(1)w(t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27) \end{aligned}$$

Moreover the design parameter $U(z^{-1})=U(1)$ is selected as follows.

$$U(1)=-D^{-1}(1)X(1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

Then the steady state output $y(t)$ in Eq. (27) can be expressed as following equation.

$$y(t)=N(1)K(1)w(t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

The design parameter $U(1)$ can give the poles of controller (Eq. (19)) with keeping the closed-loop transfer function (Eq. (23)) that way. From Eq. (29), the steady state gain of open-loop system becomes equal to the closed-loop's gain, even if the feedback signal $C_2(z^{-1})y(t)$ in Eq. (19) becomes zero. In other words, the open-loop system's output becomes equal to the reference signal $w(t)$ in the steady state because $N(1)K(1)$ is designed to be 1 through conventional GMVC. This means that the feedback signal of closed-loop system becomes zero in the steady state by choosing $U(1)$ as Eq. (28). That is, on-demand type feedback controller can be obtained.

In the next step, GMVC based on on-demand type feedback controller is designed under the assumption that the controlled plant is stable and the unknown plant parameters converge on true values. In the case that $P[z^{-1}]$ and $Q[z^{-1}]$ in generalized output $\Phi(t+k_m)$ are chosen for $T[z^{-1}]$ to be stable, comparing transfer function (Eq. (17)) to Eq. (15), $N(z^{-1})$ and $D(z^{-1})$ can be chosen as follows;

$$N(z^{-1})=\frac{z^{-k_m}B[z^{-1}]}{T[z^{-1}]} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

$$D(z^{-1})=\frac{A[z^{-1}]}{T[z^{-1}]}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

Substituting Eqs. (30) and (31) into Bezout equation (Eq. (18)) and comparing it to Diophantine equation

(Eq. (5)), the solutions $X(z^{-1})$ and $Y(z^{-1})$ of Bezout equation are given.

$$X(z^{-1}) = \frac{F[z^{-1}]}{C[z^{-1}]} \quad (32)$$

$$Y(z^{-1}) = \frac{G[z^{-1}]}{C[z^{-1}]} \quad (33)$$

From Eqs. (19), (20) and (21), the control law (Eq. (14)) can be expressed by selecting the free parameters as follows.

$$K(z^{-1}) = R[z^{-1}] \quad (34)$$

$$U(z^{-1}) = 0 \quad (35)$$

To extend the controller (Eq. (14)), instead of choosing $U(z^{-1})$ as 0, on-demand type feedback controller uses $U(1) = -D^{-1}(1)X(1)$ as given in Eq. (28). Then the extended controller through $U(1)$ is obtained as follows.

$$\begin{aligned}\left(G[z^{-1}]T[z^{-1}] - U(1)z^{-k_m}B[z^{-1}]C[z^{-1}]\right)u(t) \\ = C[z^{-1}]T[z^{-1}]R[z^{-1}]w(t) \\ - \left(F[z^{-1}]T[z^{-1}] + U(1)A[z^{-1}]C[z^{-1}]\right)y(t)\end{aligned} \quad (36)$$

To calculate this control law, the polynomial operating on $u(t)$ in the left-hand side of Eq. (36) is divided by the leading term g_0 and the remaining term.

$$\begin{aligned}G[z^{-1}]T[z^{-1}] - U(1)z^{-k_m}B[z^{-1}]C[z^{-1}] \\ = g_0 + z^{-1}G'[z^{-1}]\end{aligned} \quad (37)$$

Then the control law (Eq. (36)) is calculated by

$$\begin{aligned}u(t) = \frac{1}{g_0}\{C[z^{-1}]T[z^{-1}]R[z^{-1}]w(t) \\ - (F[z^{-1}]T[z^{-1}] + U(1)A[z^{-1}]C[z^{-1}])y(t) \\ -G'[z^{-1}]u(t-1)\}.\end{aligned} \quad (38)$$

From Eq. (23) it is noticed that the closed-loop transfer function from reference signal to output is independent of $U(z^{-1})$. And the controller poles can be given by the following equation.

$$G[z^{-1}]T[z^{-1}] - U(1)z^{-k_m}B[z^{-1}]C[z^{-1}] = 0 \quad (39)$$

3.3. Self-Tuning Controller

In the case that the plant parameters are unknown, GMVC based on on-demand type feedback controller should be designed as self-tuning controller, by applying the parameter identification law. That is, conventional GMVC is designed by using the nominal values of plant parameters so that the closed-loop characteristic becomes the desired characteristic $T[z^{-1}]$ through $P[z^{-1}]$, $Q[z^{-1}]$ and $R[z^{-1}]$. Moreover on-demand type feedback controller can be designed by coprime factorization and using $U(1)$ in the previous subsection. It is noticed that the proposed controller can maintain the conventional GMVC's closed-loop characteristic because of $y(t) = N(z^{-1})K(z^{-1})w(t)$, when the identified parameters converge on true values. In this paper the following parameter identification law is used. In order to make identified parameters converge on true values, persistently exciting (PE) signal should be added to the control system [17, 18].

$$\begin{aligned}\hat{\theta}(t) = \hat{\theta}(t-1) \\ + \frac{\Gamma(t-1)\psi(t-1)}{1+\psi^T(t-1)\Gamma(t-1)\psi(t-1)}\varepsilon(t)\end{aligned} \quad (40)$$

$$\begin{aligned}\Gamma(t) = \Gamma(t-1) \\ - \frac{\Gamma(t-1)\psi(t-1)\psi^T(t-1)\Gamma(t-1)}{1+\psi^T(t-1)\Gamma(t-1)\psi(t-1)} \\ \Gamma(0) > \alpha I,\ 0 < \alpha < \infty\end{aligned} \quad (41)$$

$$\varepsilon(t) = y(t) - \hat{\theta}^T(t-1)\psi(t-1) \quad (42)$$

$$\hat{\theta}(t) = [\hat{a}_1(t), \dots, \hat{a}_n(t), \hat{b}_0(t), \dots, \hat{b}_m(t)]$$

$$\psi(t-1) = [-y(t-1), \dots, -y(t-n), u(t-k_m), \dots, u(t-k_m-m)]$$

$\hat{a}_1(t), \dots, \hat{b}_m(t)$ are the identified parameters, $\Gamma(t)$ is error covariance matrix, $\varepsilon(t)$ is identification error, α is initial factor of $\Gamma(t)$.

4. Numerical Example

In this section, the numerical example is shown to check the behavior of the proposed controller. The following controlled system described in Eq. (1) is given.

$$A[z^{-1}] = 1 + 0.6z^{-1} + 0.7z^{-2}$$

$$B[z^{-1}] = 0.5 - 1.5z^{-1}$$

$$C[z^{-1}] = 1, \quad k_m = 1$$

Simulation steps are 200, the initial values of output and input are assumed to be zero. The variance of white Gaussian noise $\xi(t)$ is $\sigma^2 = 0.04$. In order to design the closed-loop characteristic to be stable, the generalized output is given so as to make the controlled output $y(t)$ follow the reference signal $w(t)$.

$$\Phi(t+1) = y(t+1) + 0.8u(t) - 0.84z^{-2}w(t)$$

The reference signal $w(t)$ is rectangular wave with the amplitude 1 and the period of 80 steps. When the identified parameters converge on true values, the closed-loop poles are $0.3923 \pm 0.5262i$ and its absolute value is 0.6563. Therefore the derived closed-loop system for true values of plant parameters is designed to be stable. In this case, the new design parameter $U(1) = -D^{-1}(1)X(1)$ is calculated to 0.4748. The controller's poles are $0.7736 \pm 0.58i$ and 0.5317 and their absolute values are 0.9669 and 0.5317. That is, the strong stability system can be obtained. If the parameter is selected as $U(1) = 0$, the controller becomes the conventional GMVC in Eq. (14). Then the absolute value of controller's pole is 1.1538. On the other hand, the closed-loop poles are equal to the proposed ones. It means that the conventional GMVC for this example does not make strong stability system. Therefore it finds that the new design parameter $U(1) = -D^{-1}(1)X(1)$ has the characteristic to construct a strong

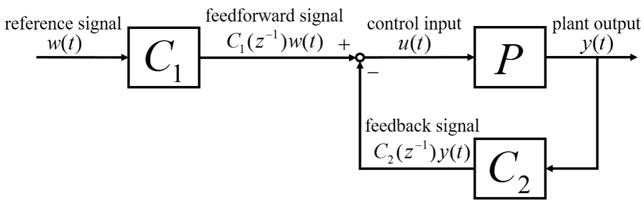

Fig. 1. Block diagram of the proposed system.

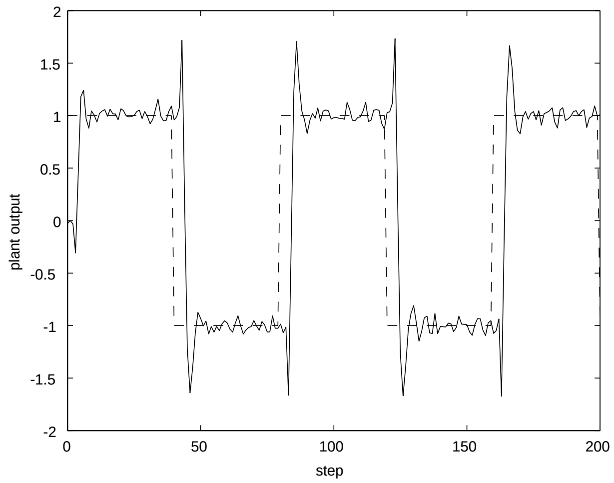

Fig. 2. Conventional method (output response).

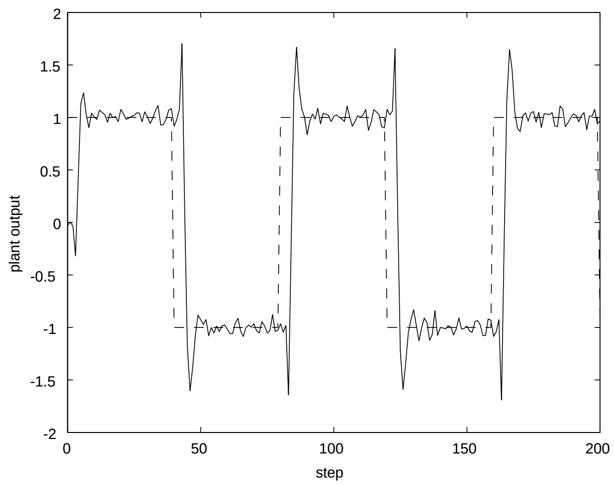

Fig. 3. Proposed method (output response).

stability system. But it is noticed that the new design parameter does not always supply strong stability system because it depends on the given system in Eq. (1) and the conventional controller. **Fig. 1** shows the block diagram of the proposed system. P, C_1 and C_2 mean controlled plant, feedforward and feedback part of the proposed controller in Eq. (19).

The nominal values of plant parameters and the parameter identification law's parameter α are set to be $0.9\times$true values and 1. **Figs. 2** and **3** show the output responses by the conventional method and the proposed method respectively. The dashed lines of their figures mean the reference signals $w(t)$ and the solid lines of them show the output re-

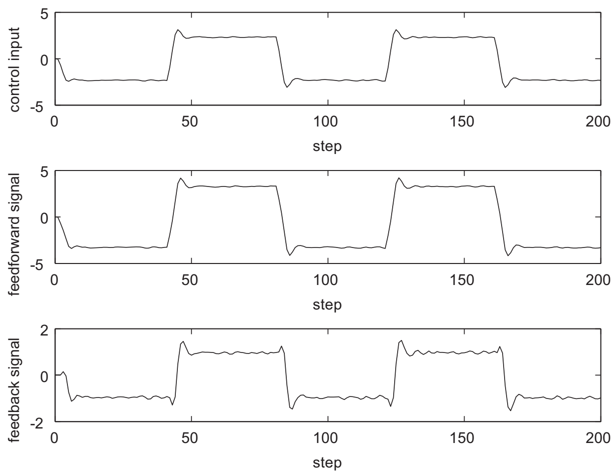

Fig. 4. Conventional method (control input).

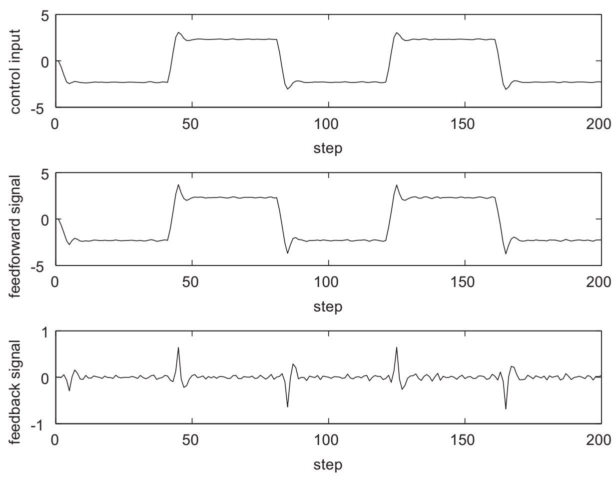

Fig. 5. Proposed method (control input).

sponses $y(t)$. From these figures it can find that their outputs are almost the same (the difference comes from the noise), although their controllers are different (Eqs. (14) and (36)). Moreover, **Figs. 4** and **5** show the control inputs $u(t)$ (upper part), the feedforward signals (middle one), which are expressed as $C_1(z^{-1})w(t)$ described in Eq. (19), and the feedback signals $C_2(z^{-1})y(t)$ (lower one). These figures show that the control inputs are almost the same. On the other hand, it can find that the feedforward and the feedback signals are different. In **Fig. 5**, the proposed controller shows that the feedback signal emerges in order to follow the reference signal and tries to become zero when the output tries to become equal to the reference signal. When the reference signal is switched from 1 to -1, the feedback signal emerges again, in order to follow new reference signal. And it tries to become zero again when the control objective is achieved. If there is no disturbance and the control objective is achieved, the feedback signal becomes equal to zero in the case that the plant parameters are true values [15]. Therefore it can find that the proposed controller has a characteristic whose feedback signal emerges based on demand of achieving the control

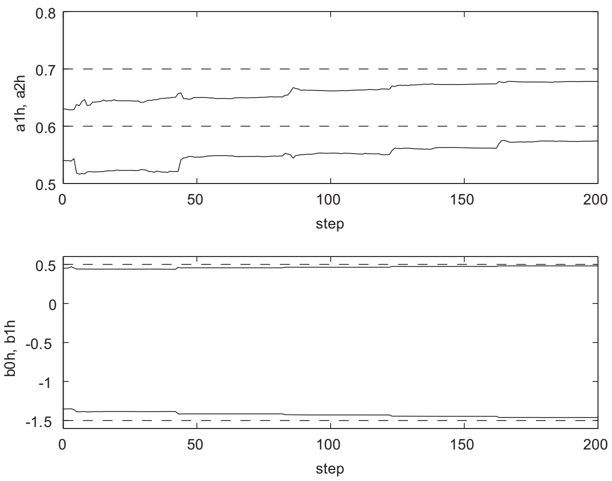

Fig. 6. Identified parameters (conventional method).

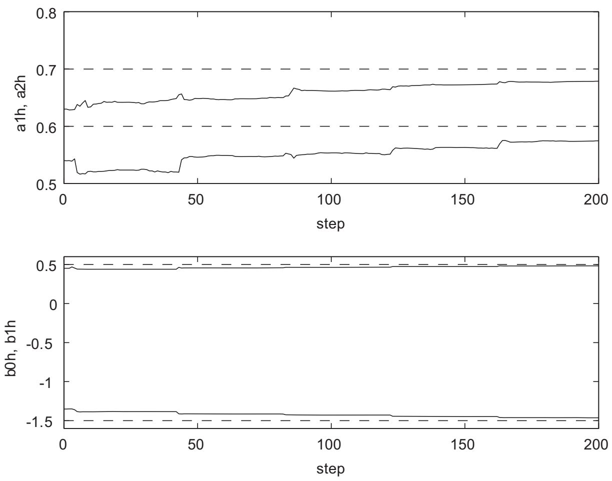

Fig. 7. Identified parameters (proposed method).

objective and tries to become zero when the control objective is achieved. This means that the proposed controller is on-demand type feedback controller. **Figs. 6** and **7** show the results of identified parameters. In these figures the dashed lines mean the true values of plant parameters and the solid lines mean the identified parameters. From each figure, it can find that the identified parameters are going to converge on true values.

5. Conclusion

This paper proposed a design method of self-tuning GMVC based on on-demand type feedback controller using coprime factorization. The numerical example showed the behavior of the proposed controller, whose feedback signal emerges based on demand to have controlled output follow the reference signal and tries to become zero if controlled output tries to become equal to the reference signal in a noisy environment. As future works, there is an extension to multi-input multi-output systems using the proposed method.

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Name:
Akira Yanou

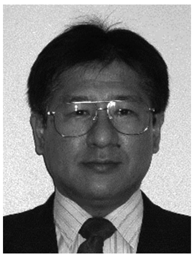
Affiliation:
Kawasaki College of Allied Health Professions

Address:
316 Matsushima, Kurashiki 701-0194, Japan

Brief Biographical History:
2001 Received Ph.D. in Engineering from Okayama University
2002- Assistant Professor, Faculty of Engineering, Kinki University
2004- Lecturer, Faculty of Engineering, Kinki University
2009- Assistant Professor, Graduate School of Natural Science and Technology, Okayama University
2016- Associate Professor, Department of Radiological Technology, Kawasaki College of Allied Health Professions

Main Works:
• adaptive learning, control and estimation

Membership in Academic Societies:
• The Society of Instrument and Control Engineers (SICE)
• The Institute of Systems, Control and Information Engineers (ISCIE)
• The Japan Society of Mechanical Engineers (JSME)
• Japanese Society of Radiological Technology (JSRT)
• The Institute of Electrical and Electronics Engineers (IEEE)



Name:
Mamoru Minami

Affiliation:
Okayama University

Address:
3-1-1 Tsushimanaka, Kita-ku, Okayama 700-8530, Japan

Brief Biographical History:
1978/1980 Received B.S. and M.S. degrees in Aeronautical Engineering from Osaka Prefecture University, respectively
1992 Received Ph.D. degree in Faculty of Engineering from Kanazawa University
1994- Associate Professor, Department of Mechanical Engineering, University of Fukui
1999- Associate Professor, Department of Human and Artificial Intelligence Systems, University of Fukui
2002- Professor, Department of Human and Artificial Intelligence Systems, University of Fukui
2010- Professor, Graduate School of Natural Science and Technology, Okayama University

Main Works:
• robotics and automation in dynamics, kinematics and control of robots including mobile manipulators, intelligent motion control, intelligent robot, machine vision for real-time adaptive operation

Membership in Academic Societies:
• The Japan Society of Mechanical Engineers (JSME)
• The Robotics Society of Japan (RSJ)
• The Society of Instrument and Control Engineers (SICE)
• The Institute of Electrical and Electronics Engineers (IEEE)

Name:
Takayuki Matsuno

Affiliation:
Okayama University

Address:
3-1-1 Tsushimanaka, Kita-ku, Okayama 700-8530, Japan

Brief Biographical History:
2000 Received M.E. degree from Nagoya University
2005 Received Dr.Eng. from Nagoya University
2004- Nagoya University
2006- Toyama Prefectural University
2011- Okayama University

Main Works:
• "Manipulation of Deformable Linear Objects using Knot Invariants to Classify the Object Condition Based on Image Sensor Information," IEEE/ASME Trans. on Mechatronics, Vol.11, Issue 4, pp. 401-408, 2006.
• "GPR Signal Processing with Geography Adaptive Scanning using Vector Radar for Antipersonal Landmine Detection," Int. J of Advanced Robotic Systems, Vol.4, No.2, pp. 199-206, 2007.

Membership in Academic Societies:
• The Institute of Electrical and Electronics Engineers (IEEE) Robotics and Automation Society (RAS)
• The Japan Society of Mechanical Engineers (JSME)
• The Robotics Society of Japan (RSJ)
• The Society of Instrument and Control Engineers (SICE)