Model-Driven PID Control System, its properties and multivariable application

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Abstract

PID control systems are widely used as a basic control technology in the industrial control system today. However, tuning of PID control systems is not always easy, because of its simple control structure to wide classes of industrial control processes. In order to improve the issues, we developed a Model-Driven PID control system, named MD PID Control system, by extending the "model driven control" concept proposed by Kimura(2000).

Properties of the MD PID Control system are as follows; a). Two degrees of freedom property, that is, both good set-point tracking and good disturbance regulation. b). Wide applicability to various kind of industrial control processes. c). Compatibility to conventional PID Control systems by setting only control parameters. We have already successful applications in industry of Japan.

Multivariable model predictive control systems are used for many industries, especially petrochemical industry, however, conventional multivariable model predictive control systems have several issues, such as slow regulating property for unexpected disturbance and hard works to maintain the multivariable process model.

In this paper, we suggest a simple multivariable control system by extending Model-Driven PID control system for interacting processes and show a numerical example, after introducing the structure and properties of the MD PID control system.

1.**Introduction**

PID control systems [1], [2] are widely used as a basic control technologies in today's industries, as in Control Technology Survey Report 1996 in Japan [3], [4] at SICE and a Paper by Desborough and Miller [5] at Chemical Process Control 6, 2001. However, tuning of PID control systems is not always easy, because of its control limitations based on its simple control structure to wide classes of industrial control processes, such as long dead-time processes, oscillatory processes, unstable processes and processes with zero. In order to improve the issues, several advanced PID control technologies, such as, I-PD control systems by Kitamori[6,7] and Two degrees of freedom PID control systems by Araki[8], Hiroi[9] and Shigemasa[10], have been proposed since the early 1980s. However, these control systems have the same issue for long dead-time processes. Recently, "From Model-based Control to Model-Driven Control"[11] was proposed by Kimura at the International Conference on Decision and Control (CDC) 2000 Sydney. He defined a Model-Driven Control (MDC) concept as " a control system architecture which uses a model of the plant as a principal component of controller". The advantages of the MDC are simple and easy to understand the control architecture, good tenability and its proved robustness. PID τ_d control systems by Shinskey [12],[13], PPI (Predictive PI) control systems by Hagglund and Astrom[1] and Internal Model Control (IMC) systems by Morari and Zafiriou [14] can be considered to belong to the same class as the MDC. However, it is difficult to realize the MDC structure for unstable processes and oscillatory processes. In order to improve these issues, we proposed a Model-Driven(MD) PID control system, which is combined with PD feedback, Q filter, model and set point filter at the first ISA/ JEMIMA/SICE Joint Technical Conference 2001 Tokyo [15], the CCA/CACSD2002 Glasgow[16], the 46th JACC2003 Okayama[17].

In this paper, we suggest a simple multivariable control system by extending application of the MD PID control system for interacting processes and show a numerical example, after introducing the structure and properties of the MD-PID control system.

2. Model Driven PID Control System

Fig.1 shows a block diagram of a MD PID control system, the control system consists of the following three blocks as;

(a) PD feedback compensator ,

(b) Main controller blocks consist of a gain block, a second order Q filter with tuning parameters λ and α , and a normalized first order delay model with dead time ,

(c) Set-point filter ,

where r, v, u, y, d are set-point, internal input for local loop, an input for the process P(s), output and disturbance, respectively.

A Design procedure

In this section, a design procedure is discussed from an identified controlled process P(s).

Step1:PD feedback compensator

A role of the PD feedback compensator is to stabilize even unstable process P(s) and to compensate the dynamical characteristics from v to y, that is, the process with the local PD feedback, into a first order delay system with dead time, as shown in Eqn. (1). The total controlled process G(s) including the controlled process P(s) with a local PD feedback F(s) can be designed or tuned to a first order delay system with dead time as shown in Eqn. (1).

$$G(s) = [1 - P(s)F(s)]^{1} P(s) \cong \frac{K\exp(-Ls)}{1+Ts} \quad (1)$$

$$F(s) = \frac{K_f(1+T_f s)}{1+\kappa T_f s} \quad (2)$$

The PD feedback F(s) can be designed from the controlled process P(s), by using several methods, such as model matching method by Kitamori (1979,2001), frequency region methods, simulation and optimisation. Simulation method is simple and user friendly approach for real process control fields.

A simple example, in the case of a process model with integral and dead time in Eqn (3), is illustrated in Fig. 2.

$$P(s) = \frac{\exp(-10s)}{10s} \quad (3)$$

The exact total controlled process can be expressed as in Eqn (4) by using a gain feedback compensator K_f=0.25.

$$G(s) = \frac{4\exp(-10s)}{\exp(-10s)+40s} \quad (4)$$

After some simulations, the first order delay process with dead time $\hat{G}(s)$ in Eqn.(5) is approximated from $G(s)$ in Eqn.(4) especially low frequency region.

$$\hat{G}(s) = \frac{4\exp(-11.8s)}{1+28.4s} \quad (5)$$

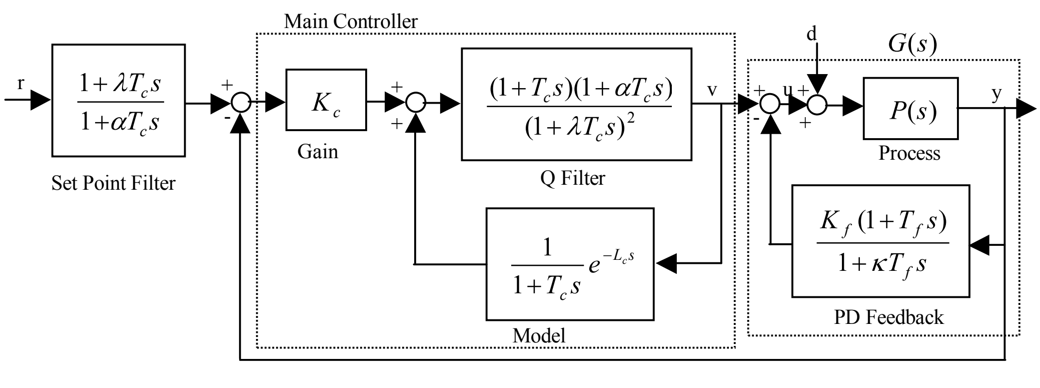

Fig.1 Model Driven Two Degrees of Freedom PID Control System

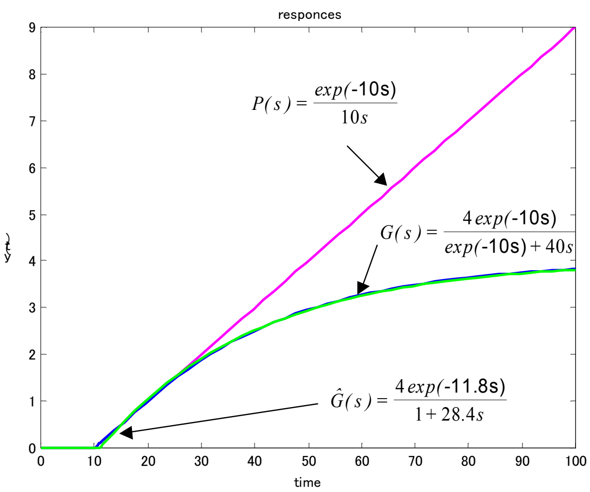

Fig.2 Step response curves pf a PD feedback loop

Step2: Main Controller and set-point filter

If the overall controlled process G(s) is approximated as a first order delay system with dead time as in Eqn. (1), the tuning approaches are as the same as a PID τ_d control system and a PPI control system as follows;

1). Kc=1/K : Gain
2). Tc=T : Integral time constant
3). Lc=L :Dead time

Step3: Adjusting tuning parameters

By using a second order Q filter

$$Q(s) = \frac{(1+T_c s)(1+\alpha T_c s)}{(1+\lambda T_c s)^2} \quad (6),$$

and the set-point filter

$$\frac{1+\lambda T_c s}{1+\alpha T_c s} \quad (7),$$

the output y can be expressed as Eqn. (8)

$$y = \frac{\exp(-L_c s)}{1+\lambda T_c s} r + \frac{\exp(-L_c s)}{K_c(1+T_c s)} [1 - \frac{(1+\alpha T_c s)(1+T_c s)}{(1+\lambda T_c s)^2}] d \quad (8)$$

where λ is concerning response speed of control system and α is concerning disturbance regulating property due to a cancelling zero for slow pole of the total controlled process. Fig.3 shows simulation results of the MD PID control system for step response in reference signal r and a response under step disturbance d in the case of $\alpha = 1$, λ=0.5, 1.0, 1.5 and the total controlled process as Eqn.(9).

$$G(s) = \frac{\exp(-10s)}{1+5s} \quad (9)$$

As in Fig,3, response speed of the MD PID control system is varying according to λ. Fig.4 shows simulation results of the MD PID control system for step response in reference signal r and a response under step disturbance d in the case of $\alpha = 1.0, 1.75, 3.0$, λ=1.0 for a total controlled process as Eqn. (9). As in Fig,4, disturbance regulating characteristics of the MD PID control system is varying according to α without change of reference tracking property.

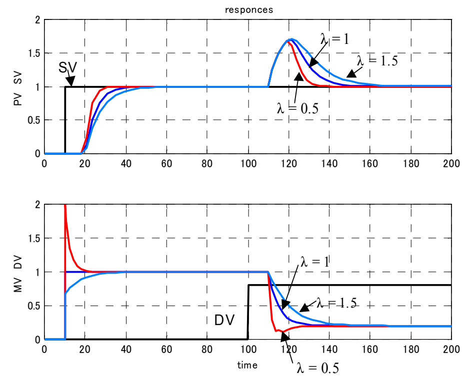

Fig.3 Response curves of MD PID system with fixed $\alpha = 1$ and different λ.

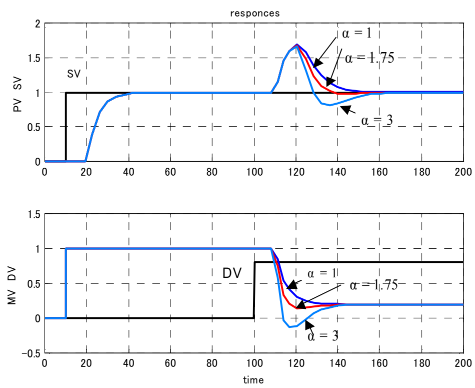

Fig.4 Response curves of MD PID system with fixed $\lambda = 1$ and different α.

Special Features

1) *Widely applicable process controller*

As the MD PID control system has the following structures, such as a PD local feedback, a 2^{nd} order Q filter, a first order delay model with dead time and a set point filter, the control system can be applied to not only long dead time processes, but also integral processes, oscillatory processes, small dead-time processes and even unstable processes. The overall controlled process G(s) can be approximated to a first order delay system with dead-time as in Eqn. (1), by suitable PD feedback compensator.

2) Two degrees of Freedom characteristics

By using a second order Q filter with a cancelling zero concerning parameter α for slow pole of the controlled process, the MD PID Control system shows quick disturbance regulating property by adjusting the parameter α. And by using the set-point filter, transfer characteristics from the reference r to the output y becomes a first order delay with dead-time. So the MD PID Control system shows quick set-point tracking property without overshooting. As described, the MD PID control system has strong two degrees of freedom property.

3) Upper compatibility from conventional PID control systems

By simple calculations, various type of conventional PID control systems can be realized smoothly from the MD PID control system with the following conditions;

$$\begin{aligned} &\textit{PID Control: } K_f = 0, L_c = 0, \alpha = \lambda = 1 \\ &\textit{PI} \quad \textit{PD Control: } \quad L_c = 0, \alpha = \lambda = 1 \qquad (10) \\ &\textit{PID}\tau_d \textit{ Control: } K_f = 0, \quad \alpha = \lambda = 1 \\ &\textit{IMC Control: } K_f = 0, \quad , \alpha = \lambda \\ &\textit{MD PID Control: } \alpha = \lambda \end{aligned}$$

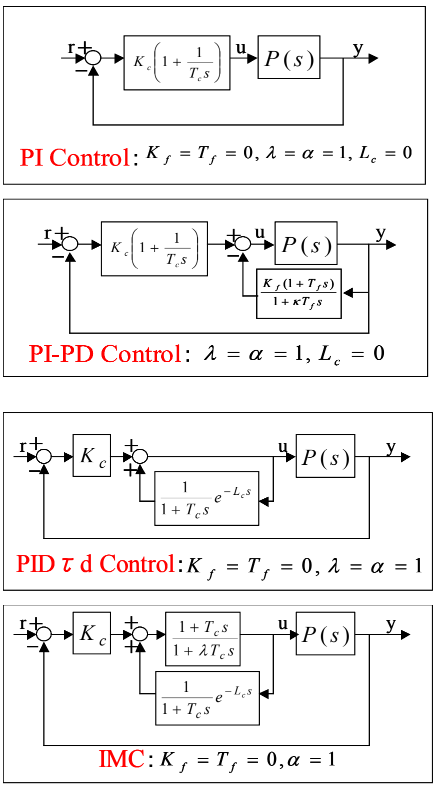

Fig.5 Conventional PID control systems

3) Robustness

Practical robust stability of the MD PID control system can be evaluated by using well-known stability measures, such as a Nyquist plot of the MD PID control system, gain margin, phase margin and the maximum sensitivity Ms as shown in Fig.6. Astrom recommended reasonable values of Ms are 1.2 and 2 in [1].

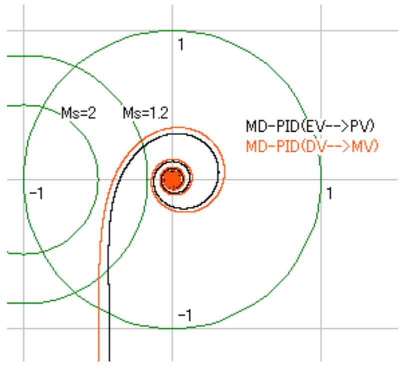

Fig.6 A nyquist plot of a MD PID control system

3. Decoupling design of Model Driven PID control system

Several successful applications of MD PID control system are reported in real petrochemical processes and paper making processes in Japan, however, we attempt to extend applicability of the MD-PID control system to internally interacting MIMO system.

A decoupler K_d as a new block element is introduced as in Fig.7. As well known decoupling design method, K_d can be designed to satisfy the Eqn. (11).

$$\lim_{s \to 0} P(s) K_d = I \qquad (11)$$

So the simplest K_d can be expressed as in Eqn.(12).

$$K_d = P(0)^{-1} \qquad (12)$$

Both Q filters, models and set-point filters are designed from the daigonal elements of $P(s)K_d$ in the conventional MD PID design procedure.

4. Numerical example

Consider the following two input two output process P(s) shown in Eqn.(13)

$$P(s)=\begin{bmatrix} \frac{4.05}{1+50s}e^{-27s} & \frac{1.77}{1+60s}e^{-28s} \\ \frac{5.39}{1+50s}e^{-18s} & \frac{5.27}{1+60s}e^{-14s} \end{bmatrix} \quad (13).$$

The simple decoupler K_d can be designed as in Eqn.(14)

$$K_d=\begin{bmatrix} 4.05 & 1.77 \\ 5.39 & 5.27 \end{bmatrix}^{-1}=\begin{bmatrix} 0.45 & -0.15 \\ -0.46 & 0.34 \end{bmatrix} \quad (14),$$

and decoupled models G_M are obtained by considering $diagP(s)K_d$ shown as in Eqn.(15)

$$G_M=\begin{bmatrix} \frac{1}{1+50s}e^{-27s} & - \\ - & \frac{1}{1+60s}e^{-14s} \end{bmatrix} \quad (15)$$

Fig.8 shows response curves of the MD decoupling PID control system and conventional decoupling PID control system designed by using the model matching method by Kitamori[7], for step references and step

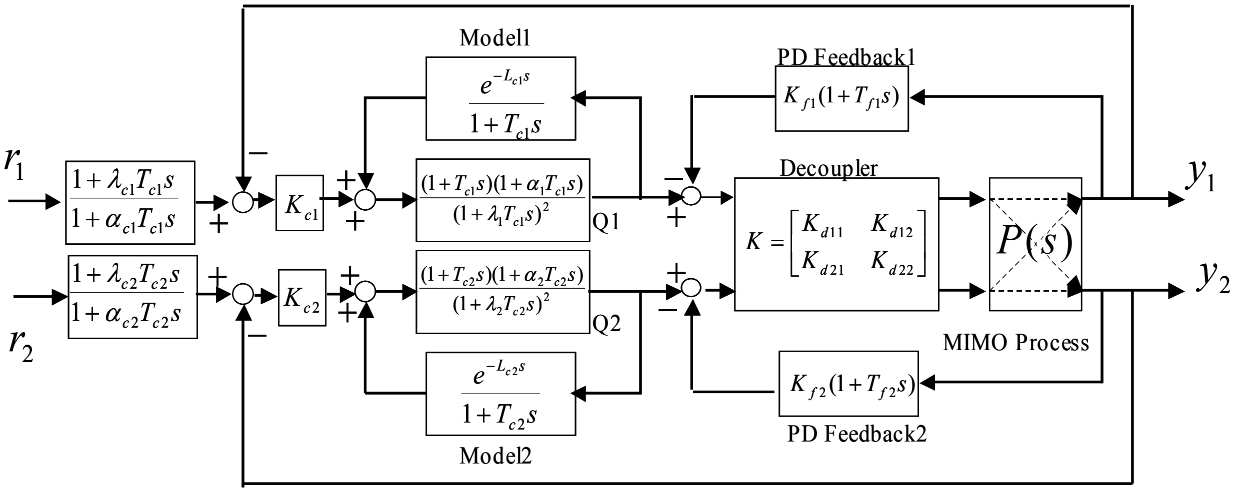

Fig.7 Model-Driven Decoupling PID control system for MIUMO controlled system

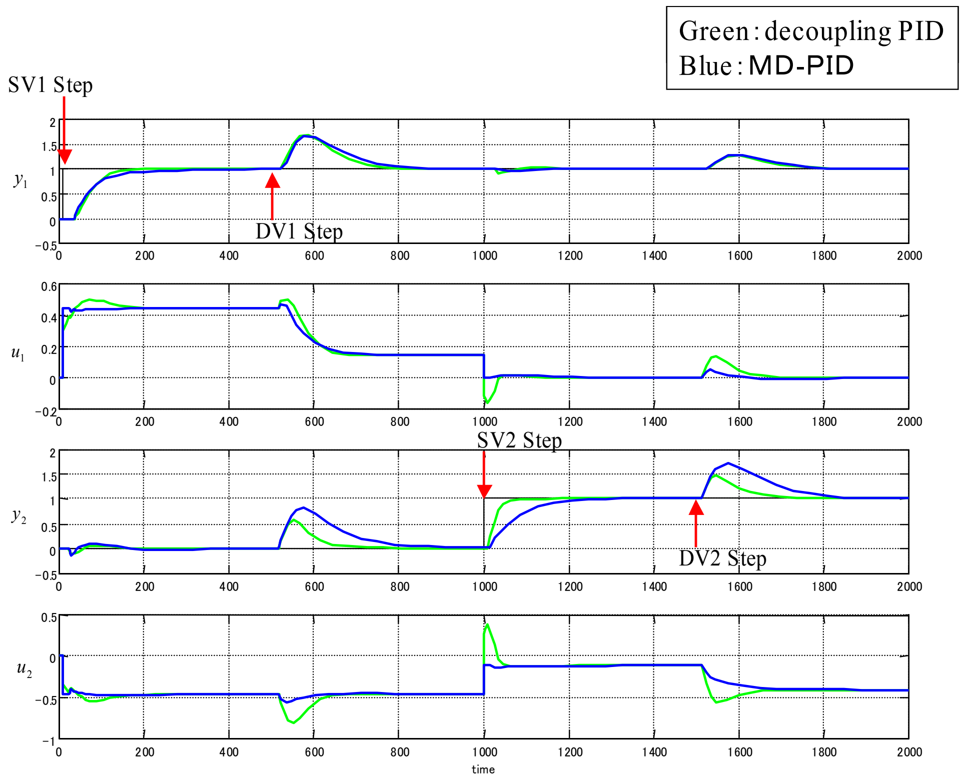

Fig.8 Comparing responses of the MD decoupling PID control system and conventional decoupling PID control system designed by model matching method

disturbances. As in Fig.8, the MD decoupling PID control system shows sufficiently good control in spite of using simple gain decoupler K_d.

4. Conclusions

Firstly, we introduced a Model Driven PID control system, named as MD PID control system, which was developed by using a Model-Driven Control concept proposed by Kimura. The MD PID control system has several features, such as wide applicability with easy tuning steps, strong two degrees of freedom property, upper compatibility from conventional PID control systems and robustness.

In this paper, we suggested Model Driven Decoupling PID control system extending an applicability of MD PID control system to interacting MIMO system. Through simulation study, sufficiently good control performances are obtained in spite of only using simple gain decoupler K_d. This method can be implemented to conventional DCS system easily

Nomenclature

r: Reference or Set point Variable(SV)
e: Deviation
u: Input or Manipulated Variable(MV)
y: Output or Process Variable(PV)
v: Internal Manipulated Variable
s: Laplace operator
P(s): Transfer function of the process
Q(s):Internal model controller or Q parameter
G(s):Overall controlled process with PD feedback
K: Gain of overall process with PD feedback
T: Time constant of overall controlled process
L: Dead-time of overall controlled process
Kc: Proportional gain
Ti: Integral time constant
Lc: Dead-time in model
λ :Tuning parameter for response speed
α : Tuning parameter for disturbance regulation
Kf: PD feedback gain
Tf: PD feedback time constant
κ : Derivative gain parameter of PD feedback
K_d: Decoupler

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