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Data-Driven Design of Predictive Functional Control Based Feed-Forward Disturbance Rejection Controller

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Abstract: Many large-scale multi-input multi-output systems are treated as a combination of single-input single-output systems in reality. At such times, interference from input signals not focused is regarded as observable disturbances. For observable disturbances, feed-forward controllers are effective in rejecting the influence. A simple feed-forward controller construction is a combination of transfer functions of controlled and disturbance systems. This paper proposes an extension of the simple feed-forward controller and its parameter-tuning method. The controller is designed based on a Predictive Functional Controller (PFC), one of the Model Predictive Control (MPC). The effectiveness of the proposed scheme is verified by some simulation examples.

Keywords: process control, predictive control, disturbance rejection, data-driven control, model predictive and optimization-based control.

1. INTRODUCTION

Large-scale processes are mostly multi-input, multi-output (MIMO) systems. However, the processes are often treated as a couple of single-input, single-output (SISO) systems. This is because it is difficult to design suitable controllers for a MIMO system. By focusing on each SISO system, interference from other inputs can be regarded as a measurable disturbance. Therefore, disturbance rejection is very important in large-scale process control and is actively researched, like Guzmán and Hägglund (2021) and Zotică et al. (2022).

For measurable disturbances, a feed-forward controller is effective in reducing its influence (see, e.g., Elso et al. (2013)). Among many feed-forward controllers, a controller constructed by a disturbance system and the inverse function of a controlled system can remove the influence of disturbance perfectly. The controller is a simple controller similar to a PID controller, and it has room to extend for a high-performance controller. Although Model Predictive Controller (MPC) is a typical advanced controller in process control (see, e.g., Morari and Lee (1999); Drgoňa et al. (2020)), the large computation cost is needed and it is difficult to use conventional MPC for replacing it without changing Distributed Control System. Especially, because the simple controllers are utilized in lower layered control loops, controllers which keep low complexity but high performance are required in order to replace that. Among MPCs, Predictive Functional Control (PFC) is one of the simplest MPCs proposed by Richalet and O'Donovan (2009). PFC simplifies MPC by making several assumptions, and at every step, it calculates the input by performing small-scale least squares rather than nonlinear optimization. In particular, the control law of PFC is the same as a normal PI controller under specific control parameters. Therefore, PFC is suitable for replacing conventional PID controllers to obtain better control results.

Whether on simple controllers or PFCs, it is important to determine the parameters because control parameters strongly affect control performance. On Ashida and Obika (2022), the authors have proposed a data-driven controller design method for the simple feed-forward controllers based on Fictitious Reference Iterative Tuning (FRIT) proposed by Kaneko et al. (2005). FRIT can tune the controller without system parameters, and effectiveness is verified for experiments. For instance, Ikeda et al. (2015) apply FRIT methods to a vibration suppression controller.

The objective of this paper is to propose a PFC-based feed-forward controller for disturbance rejection and a data-driven design method of the controller. Normal PFC is designed as a feed-back controller, but we eliminate feedback elements from PFC and only feed-forward controllers in this paper. As a result, the proposed controller can be employed when operators want to add only a feed-forward controller without changing the existing feedback controller. Additionally, the proposed PFC-based controller includes the conventional controller as a special case the same as a normal PFC includes a PI controller. Hence it is also easy to use for extending the existing feed-forward controllers. In addition, the FRIT method is employed to determine controller parameters. In the FRIT method, an evaluation function to be minimized is derived directly from the tracking error signal. Thus, the evaluation function of FRIT and tracking error have a close connection.

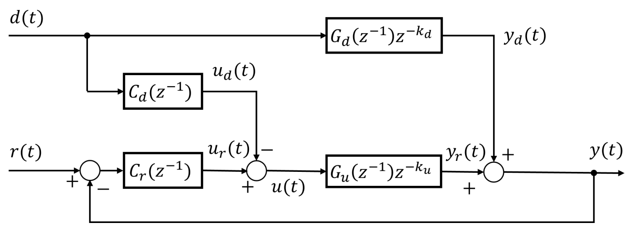

Fig. 1. Block diagram of a conventional controller

The effectiveness of the proposed scheme is verified by some simulation examples.

2. CONTROLLED SYSTEM

This paper assumes that a controlled system can be written as the following linear system:

$$y(t) = G_u(z^{-1})z^{-k_u}u(t) + G_d(z^{-1})z^{-k_d}d(t), \tag{1}$$

where $u(t), y(t)$, and $d(t)$ are input, output, and disturbance signals respectively. $G_u(z^{-1})$ and $G_d(z^{-1})$ are discrete transfer functions of input and disturbance, where z^{-1} is a delay-operator as $z^{-1}y(t) = y(t-1)$. k_u and k_d are time-delays between input-output and disturbance-output. Under the condition that k_u is the same or less than k_d, influence of disturbance can be removed from the output perfectly. In this paper, time-delays k_u and k_d are assumed to be known.

3. CONVENTIONAL CONTROL SCHEME

A well-known control system with feedback and feedforward controllers is shown as Fig. 1. $r(t)$ is reference signal, and $C_r(z^{-1})$, and $C_d(z^{-1})$ are transfer functions of feedback, feedforward controllers. PID controllers, particularly in chemical processes, are often used as $C_r(z^{-1})$. Therefore, the PID controller is also used in this paper as $C_r(z^{-1})$. Equation of the PID controller is as follows:

$$\Delta u(t) = k_i e(t) + k_p \Delta e(t) + k_d \Delta^2 e(t), \tag{2}$$

$$e(t) := r(t) - y(t), \tag{3}$$

where Δ denotes differensing operator as $\Delta = 1 - z^{-1}$. On the other hand, a simple form of feedforward controller $C_d(z^{-1})$ is

$$C_d(z^{-1}) = G_d(z^{-1})G_u(z^{-1})^{-1}z^{-(k_d-k_u)}. \tag{4}$$

From Fig. 1, $y(t)$ can be written as

$$y(t) = \frac{G_u(z^{-1})C_r(z^{-1})z^{-k_u}}{1+G_u(z^{-1})C_r(z^{-1})z^{-k_u}}r(t) + \frac{G_d(z^{-1})z^{-k_d} - G_u(z^{-1})C_d(z^{-1})z^{-k_u}}{1+G_u(z^{-1})C_r(z^{-1})z^{-k_u}}d(t). \tag{5}$$

By substituting Eq. (4), Eq. (5) becomes

$$y(t) = \frac{G_u(z^{-1})C_r(z^{-1})z^{-k_u}}{1+G_u(z^{-1})C_r(z^{-1})z^{-k_u}}r(t). \tag{6}$$

This result shows that influence of disturbance $d(t)$ is removed from output $y(t)$ by using Eq. (4) as a feedforward controller.

4. PROPOSED CONTROL SCHEME

PFC based feedforward controller and FRIT, a data-driven controller design method consist the proposed control scheme. Below is an explanation of each.

4.1 PFC based feedforward controller

Eq. (4) is a simple controller for rejecting measurable disturbance. For improving performance, this paper extends the controller to PFC based controller. The following internal model of PFC is used in this paper:

$$\hat{y}(t) = -\sum_{i=1}^{f_u} y_{ui}(t) + \sum_{i=1}^{f_d} y_{di}(t) \tag{7}$$

$$y_{ui}(t) = G_{ui}(z^{-1})u_d(t) \tag{8}$$

$$y_{di}(t) = G_{di}(z^{-1})z^{-k}d(t) \tag{9}$$

$$G_{ui}(z^{-1}) = \frac{b_i z^{-1}}{1+a_i z^{-1}} \tag{10}$$

$$G_{di}(z^{-1}) = \frac{b_{di} z^{-1}}{1+a_{di} z^{-1}} \tag{11}$$

This model only describes influence of disturbance and input by a feedforward controller. Because only difference of time-delay $z^{-(k_d-k_u)}$ is required to remove influence of disturbance as is clear from Eq. (4), $k = k_d - k_u$ is in the model, and relationship between $u_d(t)$ and $y_{ui}(t)$ has no time-delay. Because the majority of process systems have no any resonance elements, the model is likely sufficient to represent the processes. From Eq. (8), a h-step ahead prediction value of $y_{ui}(t)$ at the current time t represents

$$y_{ui}(t+h|t) = -a_i y_{ui}(t+h-1|t) + b_i u(t+h-1) \tag{12}$$

$$= (-a_i)^h y_{ui}(t) + b_i[1, -a_i, \ldots, (-a_i)^{h-1}][u(t+h-1|t), \ldots, u(t)]^T. \tag{13}$$

In PFC, future input values are supposed by some basis functions. Because most reference signals in process control are constant or step-wise, this paper uses the following constant-type basis function:

$$u(t+h-1|t) = u(t+h-2|t) = \cdots = u(t). \tag{14}$$

By using this relation, Eq. (13) becomes

$$y_{ui}(t+h|t) = (-a_i)^h y_{ui}(t) + b_i\{1 + (-a_i) + \cdots + (-a_i)^{h-1}\}u(t) \tag{15}$$

$$= (-a_i)^h y_{ui}(t) + b_i \frac{1-(-a_i)^h}{1-(-a_i)}u(t). \tag{16}$$

Time difference between t and $t+h$ is

$$\delta y_{ui}(t+h|t) = (-a_i)^h y_{ui}(t) + b_i \frac{1-(-a_i)^h}{1-(-a_i)}u(t) - y_{ui}(t) \tag{17}$$

$$= -\{1-(-a_i)^h\}y_{ui}(t) + b_i \frac{1-(-a_i)^h}{1-(-a_i)}u(t). \tag{18}$$

Next, from Eq. (9), $y_{di}(t+h|t)$ represents

$$y_{di}(t+h|t) = (-a_{di})^h y_{di}(t) + b_{di}[1, -a_{di}, \ldots, (-a_{di})^{h-1}] \cdot [d(t+h-k-1|t), \ldots, d(t-k)]^T. \tag{19}$$

Time difference between t and $t+h$ is

$$\delta y_{di}(t+h|t) = (-a_{di})^h y_{di}(t) + b_{di}[1, -a_{di}, \ldots, (-a_{di})^{h-1}] [d(t+h-k-1|t), \ldots, d(t-k)]^T - y_{di}(t) \tag{20}$$

$$= -\{1-(-a_{di})^h\}y_{di}(t) + b_{di}[1, -a_{di}, \ldots, (-a_{di})^{h-1}] [d(t+h-k-1|t), \ldots, d(t-k)]^T. \tag{21}$$

Table 1. Control parameters of PFC

f_u	Order of the controlled system
a_i, b_i	Coefficients of the controlled system
f_d	Order of the disturbance system
a_{di}, b_{di}	Coefficients of the disturbance system
k	Difference of time-delays
h	Prediction step (scholar or vector)

When $h <= k_d + 1$ holds, Eq. (21) can be calculated without using future values of disturbance signal $d(t)$.

When $\hat{y}(t + h|t)$ always reaches zero, the following condition holds:

$$\sum_{i=1}^{f_u} \delta y_{ui}(t+h|t) = \sum_{i=1}^{f_d} \delta y_{di}(t+h|t). \tag{22}$$

By setting prediction point as not single point h but multi-point $[h_1, h_2, \ldots, h_g]$, Eq. (22) becomes

$$\begin{bmatrix} \sum_{i=1}^{f_u} \delta y_{ui}(t+h_1|t) \\ \vdots \\ \sum_{i=1}^{f_u} \delta y_{ui}(t+h_g|t) \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{f_d} \delta y_{di}(t+h_1|t) \\ \vdots \\ \sum_{i=1}^{f_d} \delta y_{di}(t+h_g|t) \end{bmatrix}, \tag{23}$$

and from Eqs. (18) and (21), this is rewritten to

$$\begin{bmatrix} \sum_{i=1}^{f_u} b_i \frac{1-(-a_i)^{h_1}}{1-(-a_i)} \\ \vdots \\ \sum_{i=1}^{f_u} b_i \frac{1-(-a_i)^{h_g}}{1-(-a_i)} \end{bmatrix} u(t) = \begin{bmatrix} x_1(t) \\ \vdots \\ x_g(t) \end{bmatrix}, \tag{24}$$

$$x_j(t) = \sum_{i=1}^{f_d} \delta y_{di}(t+h_j|t) + \sum_{i=1}^{f_u} \{1-(-a_i)^{h_j}\} y_{ui}(t). \tag{25}$$

PFC calculates $u(t)$ by applying least squares method to Eq. (24) on each control steps. Control parameters are shown as Table 1.

4.2 Relationship between PFC based and the conventional controller

Considering first order model, PFC controller is

$$b_1 \frac{1-(-a_1)^h}{1-(-a_i)} u(t) = \delta y_{d1}(t+h|t) + \{1-(-a_1)^h\} y_{u1}(t). \tag{26}$$

Additionally, by setting prediction step h as 1, the controller becomes

$$\begin{aligned} b_1 u(t) =& \delta y_{d1}(t+1|t) + \{1-(-a_1)\} y_{u1}(t) && (27) \\ =& -\{1-(-a_{d1})\} y_{d1}(t) + b_{d1} d(t-k) \\ &+ \{1-(-a_1)\} y_{u1}(t). && (28) \end{aligned}$$

By substituting Eqs. (8)-(11), Eq. (28) is

$$b_1 \left\{1 - \frac{1-(-a_1)}{1+a_1 z^{-1}}\right\} u(t) = b_{d1} \left\{1 - \frac{1-(-a_{d1})}{1+a_{d1} z^{-1}}\right\} z^{-k} d(t), \tag{29}$$

$$\frac{b_1 \Delta z^{-1}}{1+a_1 z^{-1}} u(t) = \frac{b_{d1} \Delta z^{-1}}{1+a_{d1} z^{-1}} z^{-k} d(t). \tag{30}$$

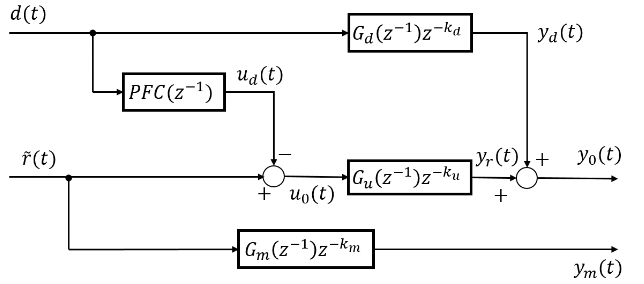

Fig. 2. Schematic of the FRIT for the proposed controller

Therefore,

$$u(t) = G_{d1}(z^{-1}) G_{u1}(z^{-1})^{-1} z^{-k} d(t) \tag{31}$$

holds. This result indicates that the PFC based feedforward controller is an extension of the first order conventional controller. Especially when the controlled system do not have any resonance points and the internal model can express the controlled system exactly, the PFC based controller becomes the extension of the conventional one at any order systems.

4.3 FRIT based tuning of the proposed controller

FRIT is one of data-driven controller tuning methods. The authors have already proposed a method of applying FRIT to the simple feedforward controller, and the method is used to tune PFC based controller in this paper. FRIT determines control parameters directly from operating data without any system models. Although most of the control parameters of PFC (Table 1) are the same as system parameters, FRIT determines them as not system models but the control parameters.

Schematic diagram of FRIT for the proposed controller is shown as Fig. 2. $\tilde{r}(t)$ is called fictitious reference signal in FRIT. Although $\tilde{r}(t)$ is not a reference signal clearly in this case, this paper still calls $\tilde{r}(t)$ as fictitious reference signal the same as normal FRIT. Because FRIT adjusts the control parameters as if the controllers could be represented by a transfer function, h is set to 1 while FRIT, and $PFC(z^{-1})$ is based on Eq. (26). When actually controlling after the FRIT, the operators choose h for robustness, and Eq. (24) is used for control. FRIT assumes that initial operating data $u_0(t), y_0(t)$, and $d_0(t)$ have been already obtained. According to Fig. 2, $u_0(t)$ is

$$u_0(t) = -PFC(z^{-1}) d(t) + \tilde{r}(t). \tag{32}$$

Therefore, $\tilde{r}(t)$ can be shown as

$$\tilde{r}(t) = u_0(t) + PFC(z^{-1}) d(t), \tag{33}$$

and

$$y_m(t) = G_m(z^{-1}) z^{-k_m} \tilde{r}(t). \tag{34}$$

Here, we define evaluation function J as

$$J = \sum_{t=1}^{N} \varepsilon(t)^2, \tag{35}$$

$$\varepsilon(t) = y_0(t) - y_m(t), \tag{36}$$

where N is a length of the initial data. Clearly as $PFC(z^{-1})$ changes, so does J. When $J = 0$ and $\varepsilon(t) = 0$ hold, $y_0(t) = y_m(t)$ also holds. Considering

$$y_0(t) = G_d(z^{-1})z^{-k_d}d(t) + G_u(z^{-1})z^{-k_u}[\tilde{r}(t) - PFC(z^{-1})d(t)] \quad (37)$$

and Eq. (34), $y_0(t) = y_m(t)$ is rewritten as the follows:

$$[G_d(z^{-1})z^{-k_d} - G_u(z^{-1})z^{-k_u}PFC(z^{-1})]d(t) + [G_u(z^{-1})z^{-k_u} - G_m(z^{-1})z^{-k_m}]\tilde{r}(t) = 0. \quad (38)$$

This implies

$$G_d(z^{-1})z^{-k_d} = G_u(z^{-1})z^{-k_u}PFC(z^{-1}), \quad (39)$$

$$G_u(z^{-1})z^{-k_u} = G_m(z^{-1})z^{-k_m}, \quad (40)$$

thus, $PFC(z^{-1})$ becomes the same as $C_d(z^{-1})$ of Eq. (4) and influence of disturbance is perfectly removed if $J = 0$ achieves. By some optimization methods, FRIT finds parameters of $PFC(z^{-1})$ which minimize J. In optimization, $G_m(z^{-1})$ is set as

$$G_m(z^{-1}) = z^{-k_u}\sum_{i=1}^{f_u} G_{ui}(z^{-1}) \quad (41)$$

because Eq. (40) indicates that the ideal $G_m(z^{-1})$ is the same as $G_u(z^{-1})z^{-k_u}$. In this paper, we assume that the controller orders f_u, f_d are set by operators, and FRIT tunes a_i, b_i, a_{di}, b_{di}.

4.4 Procedures of the proposed scheme

(1) Obtain operating data $u_0(t), y_0(t)$ and $d_0(t)$.
(2) Determine f_u and f_d.
(3) Calculate a_i, b_i, a_{di} and b_{di} using FRIT.
(4) Determine h.
(5) Control the system using Eq. (24).

5. NUMERICAL EXAMPLES

In these simulations, reference signals were unitary zero on all steps.

5.1 Second order system

This simulation uses the following system:

$$G_u(s)e^{-L_u s} = \frac{1}{(1000s+1)(100s+1)}e^{-500s}, \quad (42)$$

$$G_d(s)e^{-L_d s} = \frac{10}{(2000s+1)(50s+1)}e^{-1000s}. \quad (43)$$

By discretizing these using 10 seconds sampling-time, $G(z^{-1})$ and $G_d(z^{-1})$ are

$$G_u(z^{-1})z^{-k_u} = \frac{4.821\times 10^{-4}z^{-1} + 4.647\times 10^{-4}z^{-2}}{1 - 1.895z^{-1} + 0.896z^{-2}}z^{-50}, \quad (44)$$

$$G_d(z^{-1})z^{-k_d} = \frac{4.675\times 10^{-3}z^{-1} + 4.366\times 10^{-3}z^{-2}}{1 - 1.814z^{-1} + 0.815z^{-2}}z^{-100}. \quad (45)$$

Random noise was added to the output and $y_0(t)$ is calculated as

$$y_0(t) = G_u(z^{-1})z^{-k_u}u_0(t) + G_d(z^{-1})z^{-k_d}d(t) + G_\xi(z^{-1})\xi(t), \quad (46)$$

where $\xi(t)$ was a Gaussian white noise and $G_\xi(z^{-1})$ is

$$G_\xi(z^{-1}) = \frac{0.004988z^{-1}}{1 - 0.9950z^{-1}}. \quad (47)$$

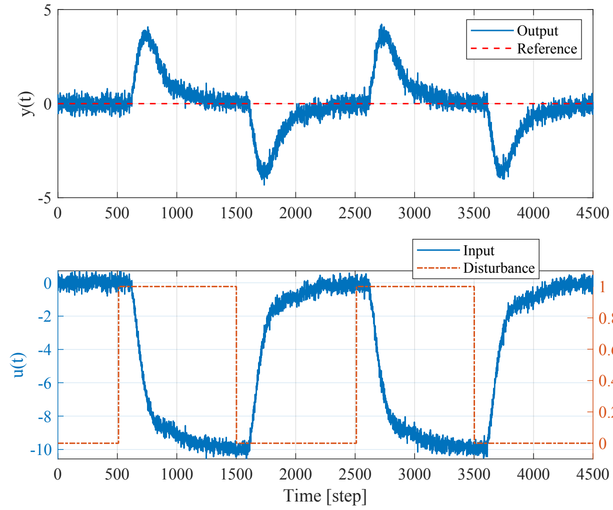

Fig. 3. Initial data of the second order system

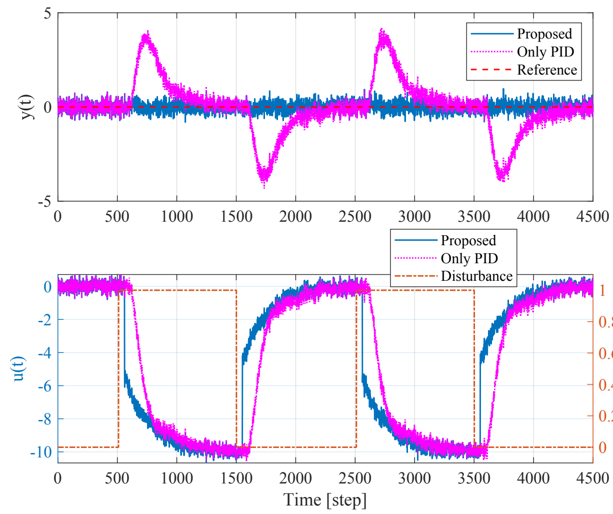

Fig. 4. Control result using the proposed scheme for the second order system

Firstly, an initial data shown as Fig. 3 was obtained using the following $C_r(z^{-1})$:

$$C_r(z^{-1}) = \frac{0.01}{\Delta} + 1. \quad (48)$$

Upper figure shows output and reference signals, and lower figure shows input and disturbance signals. Because only feedback controller was used and controlled system has a time-delay, influence of the disturbance is indicated on the output. Based on these initial data, design parameters $f_u = f_d = 1$ and with known time-delays, we applied FRIT and obtained the following parameters:

$$G_{u1}(z^{-1}) = \frac{0.0090z^{-1}}{1 - 0.9916z^{-1}}, \quad (49)$$

$$G_{d1}(z^{-1}) = \frac{0.0485z^{-1}}{1 - 0.995z^{-1}}. \quad (50)$$

With $h = 1$ and the obtained parameters, control result shown in Fig. 4 was obtained. The proposed result employed the same $C_r(z^{-1})$ as the initial result as a feedback controller. Blue lines are the signals using the proposed scheme, and the initial data is also shown for comparison. Clearly, influence of disturbance was mostly negated from the output signal in the proposed result.

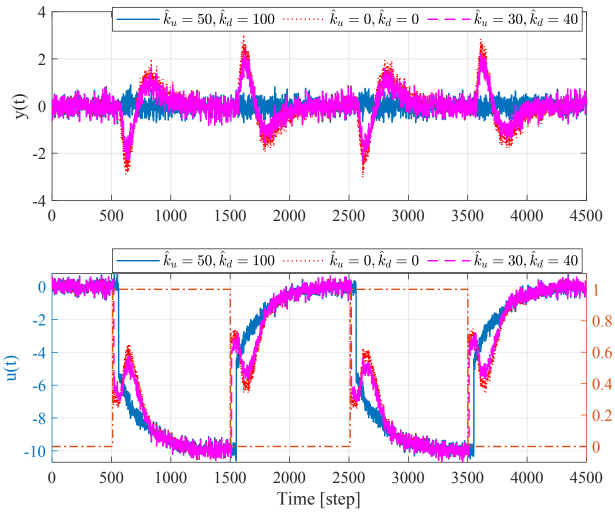

Fig. 5. Control result using the proposed scheme for the unstable system

Above discussions are assumed that the time-delay of the internal model are known. Control results of proposed controller when the time-delays were not the same as the actual values are shown as Fig. 5. $\hat{k}_u$ and $\hat{k}_d$ denote estimated time-delays of PFC and FRIT. The results of $\hat{k}_u = 0, \hat{k}_d = 0$ and $\hat{k}_u = 30, \hat{k}_d = 40$ are similar. Comparing to $\hat{k}_u = 50, \hat{k}_d = 100$, influence of disturbance appeared clearly, but the influence was smaller than only PID controller.

5.2 System with unstable pole and zero.

Next, the following system with an unstable pole was utilized:

$$G_u(s)e^{-L_u s} = \frac{1}{(11.7s-1)(11.9s+1)}e^{-2s}, \tag{51}$$

$$G_d(s)e^{-L_d s} = \frac{1}{(15.8s+1)(10.2s+1)}e^{-5s}. \tag{52}$$

This unstable system is sometimes used as a temperature control model of a polymerization process (e.g. Kano et al. (2011)). An input is a reference of coolant temperature, and an output is a polymerization temperature. Coolant temperature is assumed to be controlled adequately to follow the reference temperature. By discretizing these transfer functions using 1 second sampling-time,

$$G_u(z^{-1})z^{-k_u} = \frac{0.0036z^{-1}(1+1.0005z^{-1})}{(1-1.089z^{-1})(1-0.9194z^{-1})}z^{-2}, \tag{53}$$

$$G_d(z^{-1})z^{-k_d} = \frac{0.0029z^{-1}(1+0.9476z^{-1})}{(1-0.9387z^{-1})(1-0.9066z^{-1})}z^{-5}. \tag{54}$$

was obtained, and controlled system has not only the unstable pole but also an unstable zero. This is because zero-order hold affected in the process of discretization. Gaussian white noise with zero mean, 0.1^2 variance was added to the output, and $G_\xi(z^{-1})$ is

$$G_\xi(z^{-1}) = \frac{0.04183^{-1}}{1-0.9582z^{-1}}. \tag{55}$$

Firstly, an initial data shown as Fig. 3 was obtained using the following $C_r(z^{-1})$:

$$C_r(z^{-1}) = \frac{30.84 - 53.11z^{-1} + 27.97z^{-2}}{\Delta}, \tag{56}$$

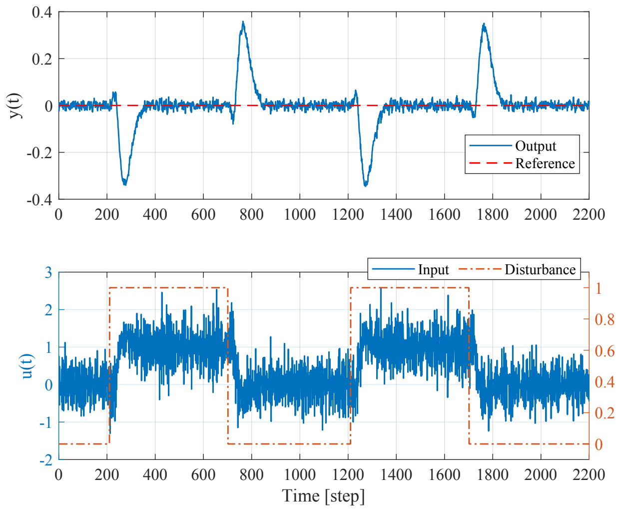

Fig. 6. Initial data of the unstable process

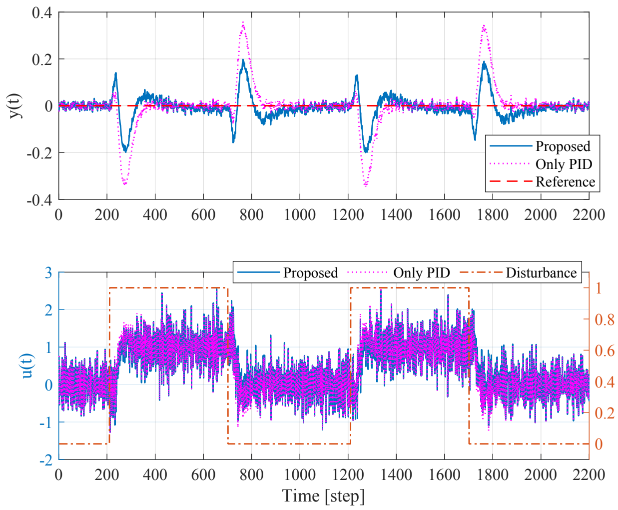

Fig. 7. Control result using the proposed scheme for the unstable system

and this is the same as the PID controller as:

$$C_r(z^{-1}) = 2.821 + \frac{0.05411}{\Delta} + 27.97\Delta. \tag{57}$$

This controller was designed by MATLAB Toolbox to stabilize the control-loop. Using the operating data, FRIT calculated the following object by $f_u = f_d = 1$:

$$G_{u1}(z^{-1}) = \frac{-0.09752z^{-1}}{1+0.0228z^{-1}}, \tag{58}$$

$$G_{d1}(z^{-1}) = \frac{0.0005952z^{-1}}{1-0.9951z^{-1}}. \tag{59}$$

With $h = [1, 2]$, the control result shown as Fig. 7 was obtained. The result shows that although control performance is worse than the previous example, the proposed method obtained better performance than only PID controller. This result indicates that the proposed controller could apply some system with unstable poles and zeros. However, control result of Fig. 7 is not enough good for application, and the proposed method might make large oscillation. Therefore, we would like to extend the system for higher performance and stability.

Table 2. MAE corresponding to h

h	MAE
1	0.0306
2	0.0339
3	0.0387
1,2	0.0333
1,3	0.0371
2,3	0.0367

Table 2 shows a Mean Absolute Error (MAE) between reference signal and output corresponding to some h. Table 2 shows that MAE tends to increase with h. In the normal PFC, the larger h is, the more stable the output signal is, although it deviates from the reference trajectory. Hence, it is possible to realize more stable control instead of large MAE.

6. CONCLUSIONS

This paper has proposed a PFC-based disturbance rejection feed-forward controller. Compared with the conventional simple controller, the proposed controller is one of the model predictive controllers and includes the conventional controller as a special case. In addition, the FRIT-based data-driven design of the feed-forward controller has been proposed. It can determine the parameters of PFC using only one set of operating data.

The effectiveness of the proposed scheme has been verified by the second-order system and the unstable, non-minimum phase system. For the second system, the influence of noise was removed clearly, and it disappeared to some extent when the time-delay of the controller was not the same as the actual value. For the unstable system, the proposed method could reduce the influence of noise, and IAE corresponding to h was considered.

In the future, we intend to research how to make the proposed controller more robust, and the influence of h in more detail. Additionally, we plan to employ the proposed method in some actual systems.

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