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THE DESIGN AND SIMULATION OF MODIFIED IMC-PID CONTROLLER BASED ON PSO AND OS-ELM IN NETWORKED CONTROL SYSTEM

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Abstract. *Networked control system (NCS) for industry process control recently has been paid much attention to. A fact that there exists networked-induced time delay in NCS, and the traditional proportional integral derivative (PID) controllers are still used broadly in industrial sites as their strong adaptability and robustness is well known. Therefore, the control engineers must face an unavoidable problem how to modify PID controller available for the networked-induced time delay in NCS. In this paper, the PID type of internal model control (IMC-PID) is suggested to handle the networked-induced time delay in NCS, where the internal model PID control is combined with PSO to find optimal proportional factor added to the deduced proportional gain, and OS-ELM to adjust the filter factor online. Simulations using Truetime blocks in Simulink/Matlab for the first and second order plants are given, and it is observed that the closed loop system has a well dynamics and adaptive performance.*
Keywords: Networked control system, Time delay, IMC-PID, PSO, OS-ELM, Truetime

1. **Introduction.** Networked control system is a kind of control system to which the spatially distributed control plants, controllers, sensors and actuators are connected via communication network (as shown in Figure 1). The motivations to construct such a kind of control system are the characteristics of low installation and maintenance cost, high reliability, increased system flexibility, and decreased wiring. However, great challenges are also met due to the network-induced imperfections such as time delay. Such network-induced imperfections are handled as various constraints, which should be considered appropriately in the analysis and design of NCS [1].

The design and analysis of NCS are launched from the following aspects mainly. An overview of NCS control methodologies and description of network delay is introduced in [2]. The stability analysis of NCS subject to data loss and time-varying transmission delay are researched in [3,4]. Some other control methods, for instance, gain scheduling [5], feedback control [6] and predictive output feedback control [7], optimal control [8], robust control [9], and filter design scheme [10], are widely applied to NCS as well.

Despite the wide development of the above control methods, the PID control method is still used broadly in industrial sites as their strong adaptability and robustness, and more than 90% of control loops are PID [11]. As the unavoidable problem of the existence of time delay, many modified PID controllers have been used to handle the variable time delay. A structure of NCS based on immune PID controller is designed in [12], which takes the typical one-order inertia plant with time delay and second-order inertia plant in industry process control for an example to simulate. However, the restraining parameter to control the stable effect and initial gain parameters of PID are difficult to set. In [13], a PID controller based on the model predictive control design where the future values of

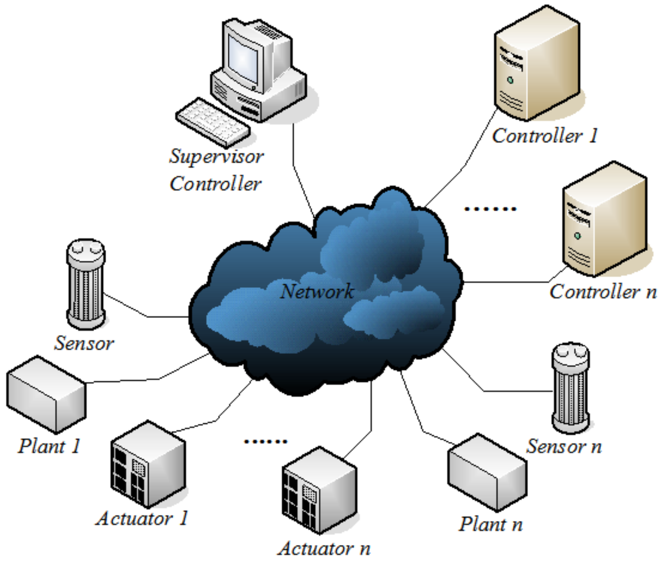

FIGURE 1. Typical structure of NCS

control inputs up to a given control horizon are calculated for NCS is presented. However, only data dropout from the sensor to controller link is considered. A single neuron PID controller that combines with adaptive smith predictor is proposed to compensate the time delay in [14], in which the new adaptive smith predictor can ensure the model error converges to zero. However, the simulation is realized on Simulink/Matlab, which cannot imitate the network environment. A robust H_∞ PID control for NCS such that the load and reference disturbances can be attenuated with a prescribed level is developed in [15]. However, it bases on so many strict preliminaries, such as the time delay on each link which is time varying with equal probability. Besides, in our former work, an adaptive control theory with fuzzy method to adjust the scale factor and learning rate of the neuron neural PID control algorithm is investigated in [16]. However, the set of fuzzy rules is depending on experience completely. An online extreme learning machine PID controller is applied to NCS as well, in which the Jacobin information is identified by online extreme learning machine and then the information is used to adjust the PID parameters online, but the identify accuracy cannot be guaranteed well [17]. The internal model control strategy is introduced to PID control firstly in [18] as its simple structure and less parameter to adjust. Some work about the internal model control and classical IMC-PID control in NCS has been done in [19,20]. However, the structure and parameters are fixed, which cannot compensate to the time delay efficiently, and the robustness and adaptability are not satisfied.

Taking into account of the time delay and the former work about a type of adaptive PID in NCS, an attempt to modify the IMC-PID to handle the networked-induced time delay is made in this paper, where the internal model PID control is combined with the PSO to find optimal proportional factor added to deduced proportional gain, and the OS-ELM to adjust the filter factor online. Simulations using Truetime against the first and second order plants illustrate the effectiveness of the proposed method. Specifically, the proposed method not only integrates the advantage of PID and IMC-PID, but also can overcome the influence of time delay to a large extent.

2. **The Design of PID Type Internal Model Controller for NCS.** The PID type of internal model controller is the improvement of PID. It integrates the advantages of

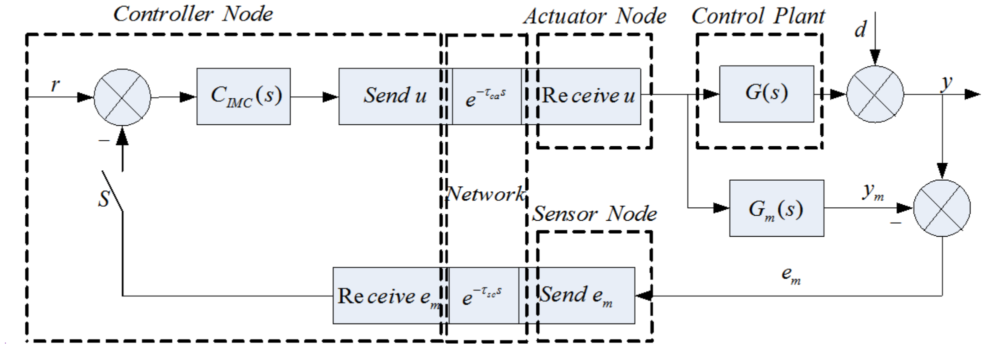

FIGURE 2. The structure of internal model control for NCS

strong robustness and adaptability to the time delay, and there is only one parameter that needs to be set.

2.1. **Problem formulation.** The structure of internal model control for NCS is given in Figure 2. Where, $C_{IMC}(s)$ is the internal model controller; $G(s)$ is the control plant; $G_m(s)$ is the internal model; τ_{ca} and τ_{sc} are the delay from the controller to the actuator and from the sensor to the controller, respectively; and e_m is the difference between the output of the system and the internal model.

The output is presented as the following:

$$\begin{aligned} y(s) = & \frac{C_{IMC}(s)e^{-\tau_{ca}s}G(s)}{1 + C_{IMC}(s)e^{-\tau_{ca}s}[G(s) - G_m(s)]e^{-\tau_{sc}s}} r(s) \\ & + \frac{1 - C_{IMC}(s)e^{-\tau_{ca}s}G_m(s)e^{-\tau_{sc}s}}{1 + C_{IMC}(s)e^{-\tau_{ca}s}[G(s) - G_m(s)]e^{-\tau_{sc}s}} d(s) \end{aligned} \tag{1}$$

The closed loop characteristic equation is:

$$1 + C_{IMC}(s)e^{-\tau_{ca}s}[G(s) - G_m(s)]e^{-\tau_{sc}s} = 0 \tag{2}$$

Exponential time delay terms are contained, which will reduce the stability of NCS and even may lead it to unstable. The internal model control strategy just compensates the time delay by designing the internal model controller $C_{IMC}(s)$ with some methods. However, this strategy has its limitation due to the variable time delay in NCS. Therefore, the IMC-PID control method is developed.

2.2. **The design of IMC-PID controller.** The IMC-PID control is the development of internal model control. The scheme structure is presented in Figure 3. It bases on an equivalent form from the feedback controller $C(s)$ to the traditional PID controller. That is to convert the process of designing IMC controller into the process of solving the parameters of PID, and then design a PID controller from the perspective of IMC.

According to the specific circumstance of NCS and design methods of IMC, two buffers are assumed to be set in the signal input zone of controller and actuator respectively [21], and the total time delay is set to be no more than one sampling period. Then the varied time delay is replaced by the maximum time delay which is equal to one sampling period, that is, $\tau_{sc} + \tau_{ca} = \tau$. This approach method transforms the variable delay to a fixed delay in the process of designing IMC-PID controller, which can compensate the time delay properly.

Consider the generalized plant as first order model plus the time delay (FOPTD) and second order model plus the time delay (SOPTD), respectively. The specific steps of designing the IMC-PID controller against the second order plant for NCS are summarized

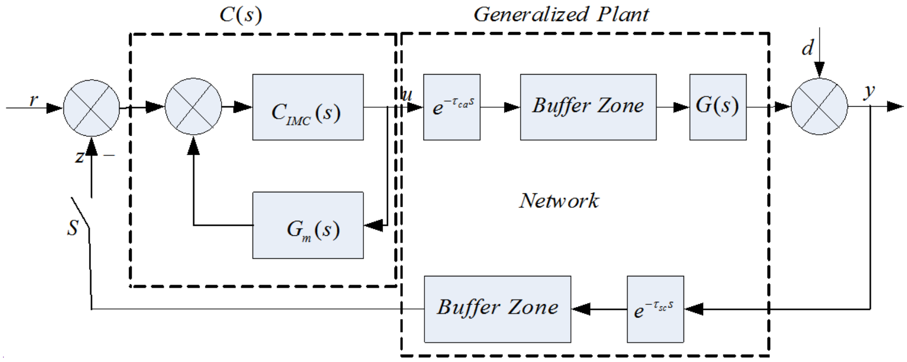

FIGURE 3. The structure of IMC-PID controller in NCS

as the following; the design steps against the first order plant can be done in the similar manner.

Remark 2.1. *The subplots 1 and 2 denote the first and the second general plant in the following equations, respectively.*

$$\begin{cases} G_1(s) = \dfrac{K_1 e^{-\tau s}}{T_1 s + 1} \\ G_2(s) = \dfrac{K_2}{s(T_2 s + 1)} e^{-\tau s} \end{cases} \tag{3}$$

Step 1: Simplify the generalized plant by a first order *Pade* approximation;

$$G_2(s) \approx \frac{\alpha K_2 \left(1 - \frac{\tau}{2} s\right)}{(\alpha s + 1)(T_2 s + 1)\left(1 + \frac{\tau}{2} s\right)} \tag{4}$$

where α is a large number, and τ is the time delay.
Step 2: The design of the internal model controller;
1) Choose the internal model $G_{2m}(s)$ as the following:

$$G_{2m}(s) = G_2(s) = G_{2m^-}(s) G_{2m^+}(s) = \frac{\alpha K_2}{(\alpha s + 1)(T_2 s + 1)\left(1 + \frac{\tau}{2} s\right)} \left(1 - \frac{\tau}{2} s\right) \tag{5}$$

where G_{2m^-} is the minimum phase part of $G_2(s)$, and G_{2m^+} is the all pass part of $G_2(s)$.
2) The design of the filter:
Only the minimum phase part of the G_{2m^+} is chosen when designing the controller. Therefore, it is necessary to design a filter as follows to compensate it.

$$f_2(s) = \frac{1}{\lambda_2 s + 1} \tag{6}$$

3) The design of the internal model controller:
From the above 1) and 2), the internal model controller is expressed as the following:

$$C_{2IMC}(s) = G_{2m^-}^{-1}(s) f_2(s) = \frac{(\alpha s + 1)(T_2 s + 1)\left(1 + \frac{\tau}{2} s\right)}{\alpha K_2 (\lambda_2 s + 1)} \tag{7}$$

Step 3: Design of the PID type of internal model controller;
The feedback controller is denoted as the following:

$$C_2(s) = \frac{C_{2IMC}(s)}{1 - C_{2IMC}(s) G_{2m}(s)} = K_{2p}\left(1 + \frac{1}{T_{2i} s} + T_{2d} s\right) \tag{8}$$

where $K_{2i} = K_{2p}/T_{2i}$, $K_{2d} = K_{2p} * T_{2d}$.

For the SOPTD, the following gains can be deduced.

$$\begin{cases} K_{2p} = \frac{\alpha+T_2}{\alpha K_2(\lambda_2+\tau)} \\ K_{2i} = \frac{1}{\alpha K_2(\lambda_2+\tau)} \\ K_{2d} = \frac{T_2}{K_2(\lambda_2+\tau)} \end{cases} \quad (9)$$

Using the same reasoning method, for the FOPTD, the following gains can be deduced.

$$\begin{cases} K_{1p} = \frac{2T_1+\tau}{K_1(2\lambda_1+\tau)} \\ K_{1i} = \frac{2}{K_1(2\lambda_1+\tau)} \\ K_{1d} = \frac{T_1\tau}{K_1(2\lambda_1+\tau)} \end{cases} \quad (10)$$

It is obvious that only one parameter λ_1 or λ_2 is existed in IMC-PID controller, which is an improvement of PID controller. This kind of method can handle the time delay to some extent. However, as the filter factor is fixed, it is just an equivalent form of a fixed gain PID.

3. The Design of Modified IMC-PID Based on PSO and OS-ELM for NCS.

The IMC-PID controller has the advantage of PID and IMC, which is the strong robustness and compensation effect on time delay. Yet, as the increase and decrease of the proportional gain can decrease the overshoot and the adjust time, and the online tuned PID controller can improve the control performance which has been proved in former work. Therefore, an attempt to modify the internal model PID controller is implemented from the following aspects.

3.1. Add and optimize a proportional factor with PSO.

The overshoot and adjust time have an intimate relationship with the proportional gain; therefore, so as to overcome the insufficient of traditional PID, an effective solution method is adding a weighted value in the part of proportional gain [22]. Some experiments prove that the IMC-PID in NCS shows the same effect, so, a proportional factor is added in the proportional gain. The formation is presented in the following equations.

For the SOPTD general plant,

$$\begin{cases} K_{2p} = K_{2u}\frac{\alpha+T_2}{\alpha K_2(\lambda_2+\tau)} \\ K_{2i} = \frac{1}{\alpha K_2(\lambda_2+\tau)} \\ K_{2d} = \frac{T_2}{K_2(\lambda_2+\tau)} \end{cases} \quad (11)$$

Similarly, for the FOPTD general plant,

$$\begin{cases} K_{1p} = K_{1u}\frac{2T_1+\tau}{K_1(2\lambda_1+\tau)} \\ K_{1i} = \frac{2}{K_1(2\lambda_1+\tau)} \\ K_{1d} = \frac{T_1\tau}{K_1(2\lambda_1+\tau)} \end{cases} \quad (12)$$

Moreover, so as to find a better value of the proportional factor, particle swarm optimization (PSO) algorithm which consists of only two rules for obtaining a new solution from a previous one is adopted. The process of optimizing the proportional factor in NCS is shown in Figure 4.

The fitness function is presented as the following:

$$J = \begin{cases} \int_0^\infty (\omega_1|e(t)| + \omega_2 u^2(t))dt + \omega_3 \cdot t_u, \ e(t) \geq 0. \\ \int_0^\infty (\omega_1|e(t)| + \omega_2 u^2(t) + \omega_4|e(t)|)dt + \omega_3 \cdot t_u, \ e(t) < 0 \end{cases} \quad (13)$$

where $e(t)$ is the error; $u(t)$ is the output of controller; t_u is the rise time; and ω_1, ω_2 and ω_3 are weight value. Therefore, as to avoid too big overshoot, the penalty function is adopted, that is, once the overshoot is generated, it will be used as one item of fitness function, ω_4 is weight value, and $\omega_4 \gg \omega_1$.

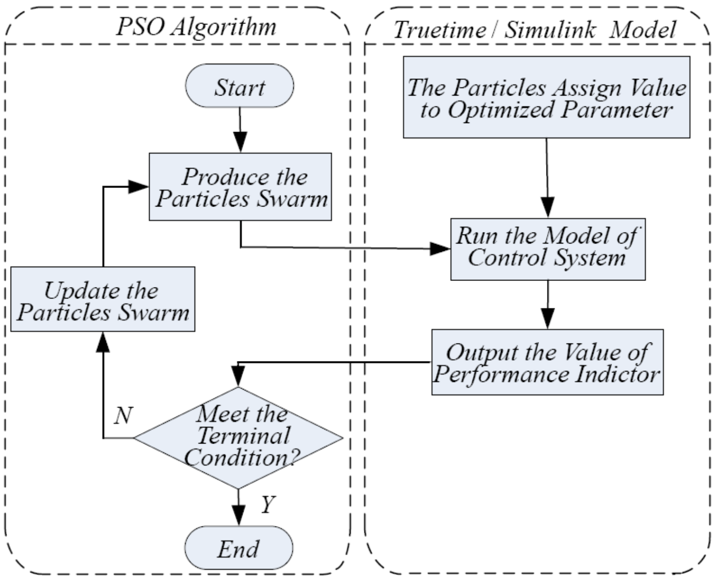

FIGURE 4. The process of optimizing proportional factor with PSO

3.2. **Online adjustment of the filter factor with OS-ELM.** Practice shows that the online tuned PID can decrease the influence of time delay and adapt to the network environment to some extent. On this basis, an attempt that tunes the filter factor λ online by OS-ELM is investigated. Figure 5 shows the schematic diagram of this control strategy.

In Figure 5, r is the reference input, $y_f(k)$ is the adopted output in current sampling time, $u_f(k)$ is the adopted control value, and $e(k)$, $e(k-1)$, $e(k-2)$ are the adopted error in current time and last two sampling time, respectively.

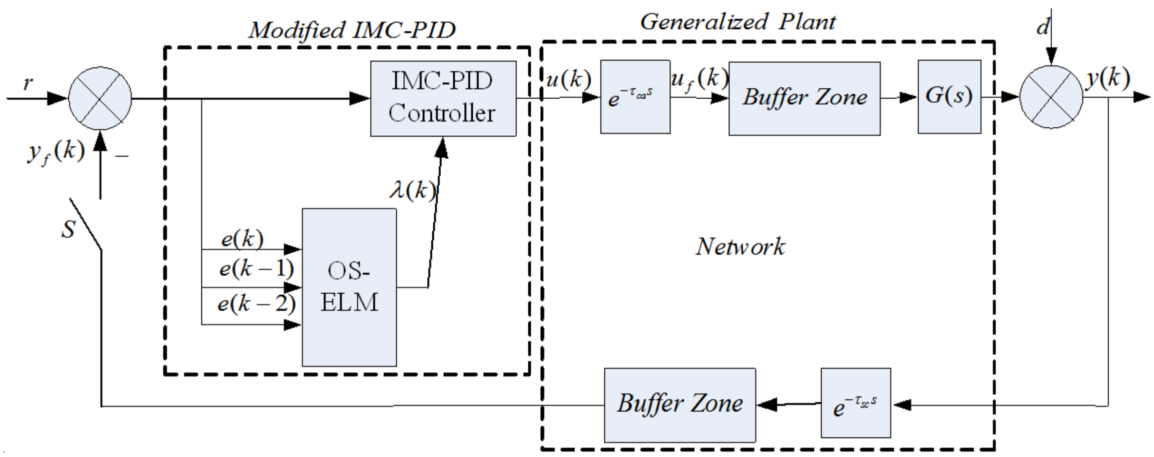

FIGURE 5. Schematic diagram of the online adjustment strategy

For the SOPTD generalized plant, the discrete-time form of PID is shown as the following:

$$\begin{cases} K_{2p}(k) = K_{2u}\frac{\alpha+T_2}{\alpha K_2(\lambda_2(k)+\tau)} \\ K_{2i}(k) = \frac{1}{\alpha K_2(\lambda_2(k)+\tau)} \\ K_{2d}(k) = \frac{\tau}{K_2(\lambda_2(k)+\tau)} \end{cases} \tag{14}$$

Similarly, for the FOPTD generalized plant, the following gains can be achieved.

$$\begin{cases} K_{1p}(k) = K_{1u}\frac{2T_1+\tau}{K_1(2\lambda_1(k)+\tau)} \\ K_{1i}(k) = \frac{2}{K_1(2\lambda_1(k)+\tau)} \\ K_{1d}(k) = \frac{T_1\tau}{K_1(2\lambda_1(k)+\tau)} \end{cases} \tag{15}$$

Moreover, online sequential extreme learning machine is developed based on the essential extreme learning machine [23]. It can learn data one-by-one or chunk-by-chunk (a block of data) with fixed or varying chunk size, which is identical to the data acquisition process in NCS. In this paper, the training set is chosen from the error data in IMC-PID and the reference input, respectively. The algorithm is summarized as the following:

Step 1: Boosting Phase;

Give a small initial training set $N = \{(x_j, y_j)|j = 1, 2, \ldots, \tilde{N}\}$ to boost the learning algorithm first through the following boosting procedure:

1) Assign arbitrarily input weight a_i and bias b_i, $i = 1, \ldots, \tilde{N}$;

2) Calculate the initial hidden layer output matrix $H_0 = [h_1, \ldots, h_{\tilde{N}}]^T$, where

$$h_i = [g(a_1 \cdot x_i + b_1), \ldots, g\left(a_{\tilde{N}} \cdot xi + b_{\tilde{N}}\right)]^T, \quad i = 1, \ldots, \tilde{N} \tag{16}$$

3) Estimate the initial output weight $\beta^0 = M_0 H_0^T T_0$, where $M_0 = (H_0^T H_0)^{-1}$, $T_0 = [y_1, \ldots, y_{\tilde{N}}]^T$, and set $k = 0$.

Step 2: Sequential Learning Phase;

For each further coming observation (x_i, y_i), where $i = \tilde{N}+1, \tilde{N}+2, \tilde{N}+3, \ldots, do$

1) Calculate the hidden layer output vector;

$$h_{k+1} = [g(a_1 \cdot x_i + b_1), \ldots, g\left(a_{\tilde{N}} \cdot x_i + b_{\tilde{N}}\right)]^T \tag{17}$$

2) Calculate the latest output weight β^{k+1} based on recursive least square algorithm;

$$M_{k+1} = M_k - \frac{M_k h_{k+1} h_{k+1}^T M_k}{1 + h_{k+1}^T M_k h_{k+1}} \tag{18}$$

$$\beta^{k+1} = \beta^k + M_{k+1} h_{k+1}\left(y_i^T - h_{k+1}^T \beta^k\right) \tag{19}$$

3) Set $k = k + 1$.

Step 3: Result Output Phase;

When finishing the train process, the output of the OS-ELM is presented as the following:

$$H\beta = \lambda \tag{20}$$

As the filter factor is tuned at each sampling time, then the gains in IMC-PID are realized tuned online. Besides, as the time delay and packet loss problems in NCS, the plant output $y_f(k)$ and input $u_f(k)$ have to be chosen as:

$$y_f(k) = \begin{cases} y(k), & \text{normally.} \\ y(k-1), & \text{otherwise.} \end{cases} \tag{21}$$

$$u_f(k) = \begin{cases} u(k), & \text{normally.} \\ u(k-1), & \text{otherwise.} \end{cases} \tag{22}$$

Above all, the process of the online adjustment of the filter factor in NCS is summarized as the following:
Step 1: Confirm the structure of OS-ELM, that is, the number of input layer node P, the number of hidden layer node L and the activation function of hidden layer;
Step 2: Acquire the error data in IMC-PID to train the OS-ELM;
Step 3: Obtain continuous r and y at sample time, calculate computational error respectively, and then calculate the filter factor in each sampling period;
Step 4: Update the parameters of IMC-PID;
Step 5: Return to Step 3.

4. **Simulations.** To illustrate the control performance of the proposed method, True-time toolbox is used to realize the simulation. The sensor is time-driven, the controller and actuators are event-driven, the sampling period T is 20ms, the time delay is no more than one sampling period, and the network transmission rate is 800,000 bits/s. Choose the IEEE 802.15.4 as the network protocol. Therefore, as to have a clear comparison of the proposed modified IMC-PID, three control loops with the same structure are taken in the simulation, which adopt traditional PID controller, IMC-PID controller, and proposed modified IMC-PID controller, respectively. The reference input adopts the step response. Moreover, the parameters in traditional PID controller and IMC-PID controller are optimized by PSO. The value of integrated absolute error (IAE) and the value of integrated time and absolute error (ITAE) are chosen as objective function.

Example 4.1. *For the first order control plant:*

$$G_1(s) = \frac{2}{4s+1} \tag{23}$$

The K_{1p} is 1.0, K_{1i} is 0.0028 and K_{1d} is 0.7440 in PID controller. The λ_1 is 50 in IMC-PID controller. The K_{1u} is 8.0 in proposed modified IMC-PID controller. The response curves of the three controllers under different network state are demonstrated in Figure 6 and Figure 7, respectively.

The objective function value is shown in Table 1.

Table 1. The objective function value

Type of PID \ State / Indicator	Without Interference		With Interference	
	IAE	ITAE	IAE	ITAE
PID	1.8652	3.5116	3.6416	25.0502
IMC-PID	0.4952	0.2325	0.9903	5.7679
Proposed	0.2460	0.0450	0.4255	2.2309

From the above result, it is clearly indicated that under the control of proposed method, the response curve of the control plant converges to the set value with a shorter steady time and a smaller error than the other two when the time delay varies from zero to one sampling period randomly. Meanwhile, the response curve of plant can reach to the set value quickly when there is interference. The proposed modified control method shows a better control performance and a stronger adaptivity to the time delay and interference. The efficiency of the proposed method is illustrated by the smallest objective function value in Table 1.

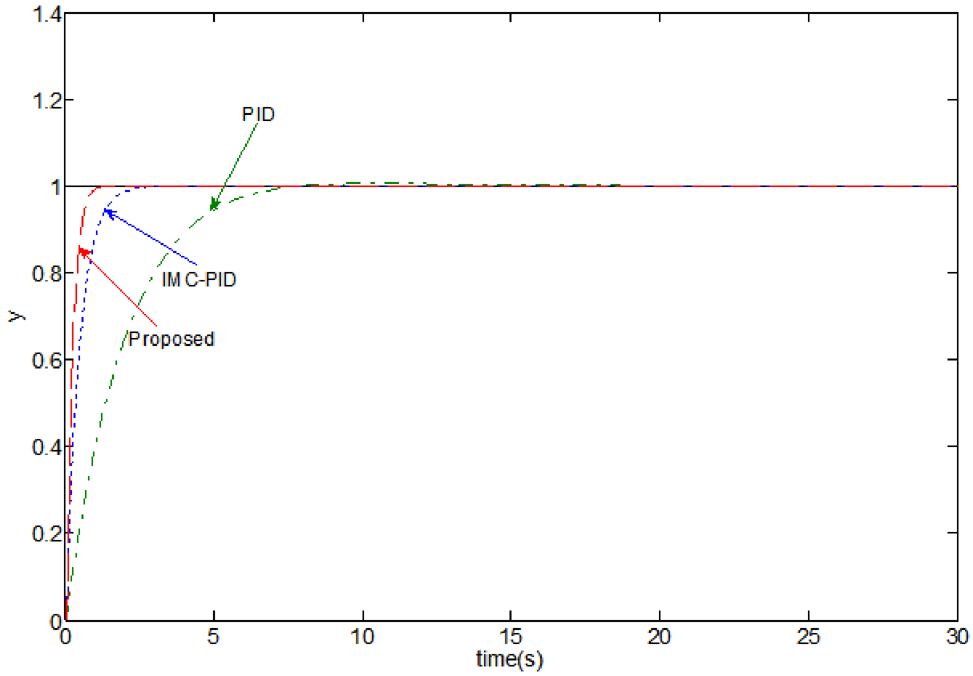

FIGURE 6. Step response curve without interference

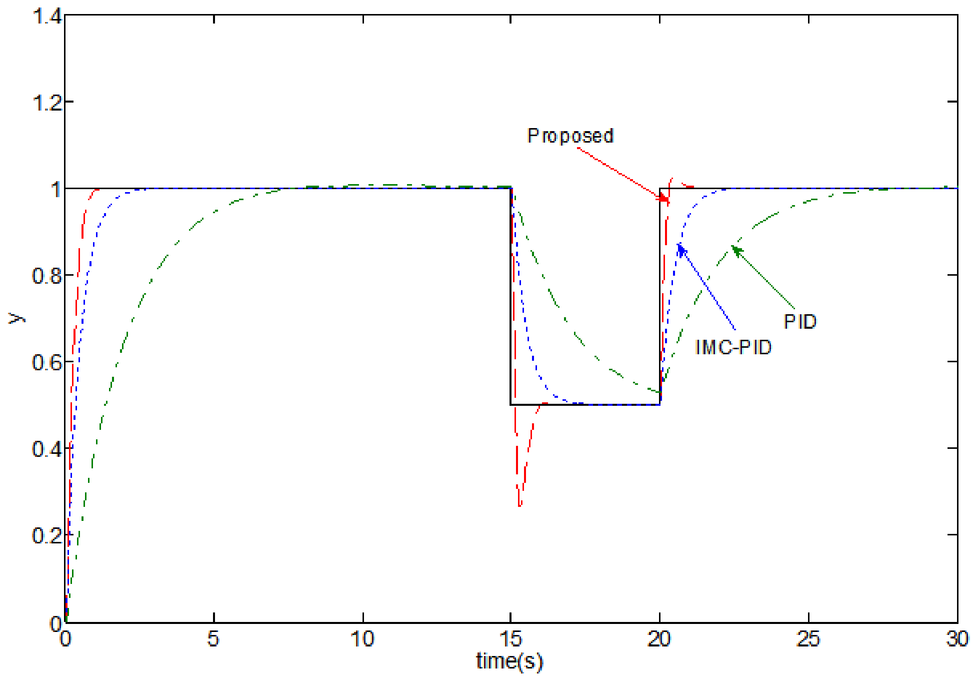

FIGURE 7. Step response curve with interference

Example 4.2. *For the second order control plant:*

$$G_2(s) = \frac{1000}{s^2 + s} \tag{24}$$

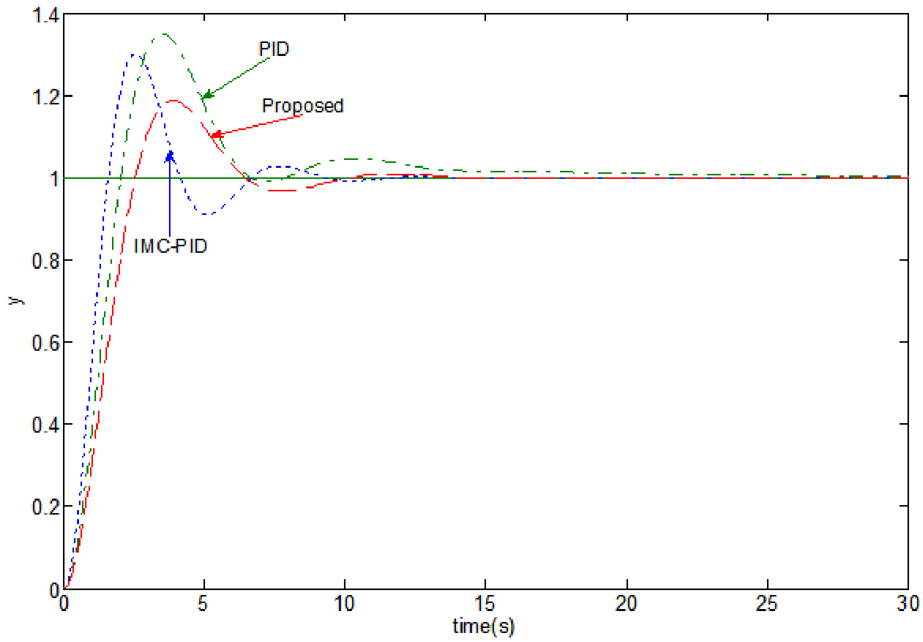

Figure 8. Step response curve without interference

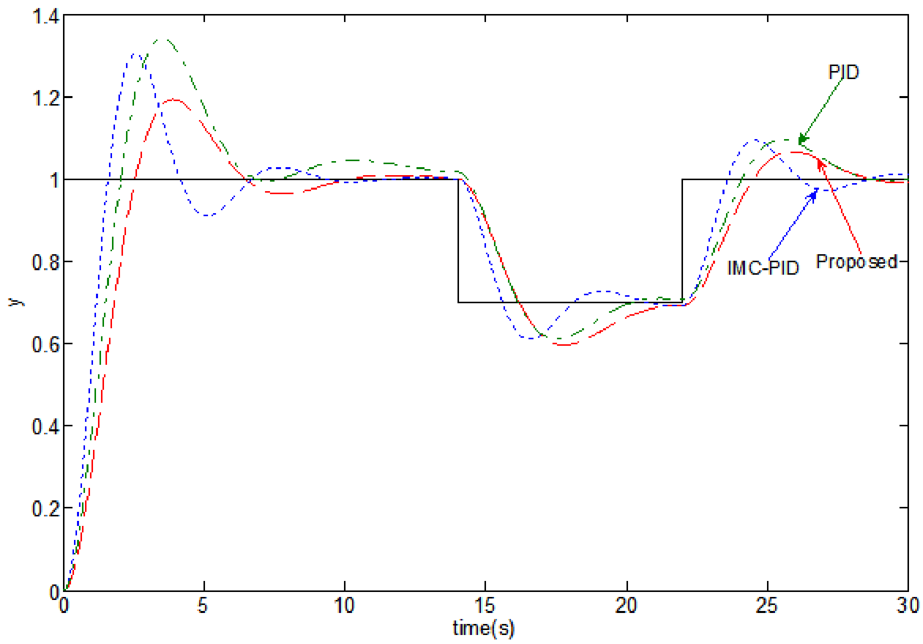

Figure 9. Step response curve with interference

The K_{2p} is 1.0e-03*1.0763, K_{2i} is 1.0e-06*1.3537 and K_{2d} is 1.0e-04*5.0139 in PID controller. The λ_2 is 1.0e+03*2.3601 in IMC-PID controller. The K_{2u} is 0.9487 in proposed modified IMC-PID controller. The response curves of the three controllers with different network state are demonstrated in Figure 8 and Figure 9, respectively.

The objective function value is shown in Table 2.

Table 2. The objective function value

Type of PID \ State Indicator	Without Interference		With Interference	
	IAE	ITAE	IAE	ITAE
PID	2.3624	8.5937	3.4394	30.2870
IMC-PID	1.9607	3.9971	3.2497	29.4782
Proposed	1.6162	3.1361	2.5632	21.9830

Similarly, for the second order control plant, the proposed control method shows a better control performance compared with the other two existence control methods. Specifically, the response curve of control plant reaches to the set value with the least overshoot and shortest steady time under the control of proposed method. It can recover to the set value more accurately when disturbed by interference. Also, the robustness and adaptation to the variable time delay are enhanced to some extent. The smallest objective function value in Table 2 suggests the efficiency of the proposed method.

5. **Conclusions.** In view of the variable time delay in NCS, a modified IMC-PID control method based on particle swarm optimization algorithm and online sequential extreme learning machine is proposed in this paper, where the PSO is employed to find optimal proportional factor that is added to the deduced proportional gain, and the OS-ELM is adopted to adjust the filter factor online. The effectiveness of the proposed control method is illustrated from the simulation results against the first and second order plants. More specifically, the proposed method not only keeps the advantage of original IMC-PID controller, but also can reduce the influence of the variable time delay adaptively and dynamically. Further work towards to the potential use in practice needs to be done in the near future.

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REFERENCES

[1] L. Zhang, H. Gao and O. Kaynak, Network-induced constraints in networked control systems – A survey, *IEEE Trans. on Industry Informatics*, vol.9, no.1, pp.403-416, 2013.
[2] Y. Tipsuwan, M. Y. Chow, Y. Tipsuwan and M. Chow, Control methodologies in networked control systems, *Control Engineering Practice*, vol.11, no.10, pp.1099-1111, 2003.
[3] M. C. F. Donkers, W. Heemels, D. Bernardini and A. Bemporad, Stability analysis of stochastic networked control systems, *Automatica*, vol.48, no.5, pp.917-925, 2012.
[4] X. Luan, P. Shi and F. Liu, Stabilization of networked control systems with random delays, *IEEE Trans. on Industrial Electronics*, vol.58, no.9, pp.4323-4330, 2011.
[5] Z. Tian, X. Gao, M. Shi and K. Li, An improved variable sampling period scheduling method, *Journal of Computational Information Systems*, vol.9, no.2, pp.503-510, 2013.
[6] R. Yang, P. Shi and G. P. Liu, Network-based feedback control for systems with mixed delays based on quantization and dropout compensation, *Automatica*, vol.47, no.12, pp.2805-2809, 2011.
[7] R. Yang, G. Liu and P. Shi, Predictive output feedback control for networked control systems, *IEEE Trans. on Industrial Electronics*, vol.61, no.1, pp.512-520, 2014.
[8] S. H. Hu and Q. X. Zhu, Stochastic optimal control and analysis of stability of networked control systems with long delay, *Automatica*, vol.39, no.11, pp.1877-1884, 2003.

[9] H. Zhang, M. Li, J. Yang and D. Yang, Fuzzy model-based robust networked control for a class of nonlinear systems, *IEEE Trans. on Systems, Man, and Cybernetics – Part A: Systems and Humans*, vol.39, no.2, pp.437-447, 2009.
[10] R. Yang, P. Shi and G. P. Liu, Filtering for discrete-time networked nonlinear systems with mixed random delays and packet dropouts, *IEEE Trans. on Automatic Control*, vol.56, no.11, pp.2655-2660, 2011.
[11] K. J. Aström and T. Hägglund, The future of PID control, *Control Engineering Practice*, vol.9, no.11, pp.1163-1175, 2001.
[12] D. Peng, H. Zhang, C. Huang and J. Lin, Study of immune PID networked control systems based on truetime, *Journal of Networks*, vol.6, no.6, pp.912-915, 2011.
[13] E. Miklovičová and M. Mrosko, PID control strategy for sensor random packet dropouts in networked control system, *International Journal of Systems Applications, Engineering & Development*, vol.6, no.1, pp.154-163, 2012.
[14] X. Zhang, L. Yang and Y. Li, Single neuron PID controller based on adaptive smith predictor for networked control systems, *The 10th IEEE International Conference on Industrial Informatics (INDIN)*, pp.1136-1141, 2012.
[15] H. Zhang, Y. Shi and A. S. Mehr, Robust H_∞ PID control for multivariable networked control systems with disturbance/noise attenuation, *International Journal of Robust and Nonlinear Control*, vol.22, no.2, pp.183-204, 2012.
[16] H. C. Yu, C. Shao and D. S. Zhou, Adaptive single neuron PID control with fuzzy and self-tuning in networked control systems, *Applied Mechanics and Materials*, vol.235, pp.152-157, 2012.
[17] H. C. Yu, C. Shao and D. S. Zhou, The design and simulation of networked control systems with online extreme learning machine PID, *International Journal of Modeling, Identification and Control*, 2013.
[18] D. E. Rivera, M. Morari and S. Skogestad, Internal model control: PID controller design, *Industrial & Engineering Chemistry Process Design and Development*, vol.25, no.1, pp.252-265, 1986.
[19] J. Li, F. Du and Y. Zhang, Two-degree-of-freedom internal model controller for NCS, *World Automation Congress IEEE*, pp.1-4, 2012.
[20] G. C. Zhao and H. Y. Wang, Stability design of delay network control system based on internal model control -PID controller, *The Application of Computer System*, vol.19, no.8, pp.104-107, 2010.
[21] R. Luck and A. Ray, Experimental verification of a delay compensation algorithm for integrated communication and control systems, *International Journal of Control*, vol.59, no.6, pp.1357-1372, 1994.
[22] K. J. Astrom, PID controllers: Theory, design and tuning, *Instrument Society of America*, 1995.
[23] G. B. Huang, N. Y. Liang and H. J. Rong, On-line sequential extreme learning machine, *IASTED International Conference on Computational Intelligence*, pp.232-237, 2005.