Adaptive Retuning PID to Overcome Effect of Delay Change in Networked Control Systems

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ABSTRACT

Several issues in Networked Control Systems (NCSs) such as networked delay, sampling, transmitting methods and data dropout make the system response goes unstable. This paper deals with networked delay problem and proposes Adaptive Retuning PID Controller to overcome effect of time delay change by adaptively changing its two parameters, T_i and T_d. The results show that, with delay 0.03 - 0.07 second, where these are bigger than nominal delay of networked system (<1ms), the proposed controller can enhance the system response as close as its original designed controller.

Keywords
Networked Control Systems, NCSs, networked induced delays, Adaptive PID

1. INTRODUCTION

Tele-operated robot, satellite, and large scale industrial systems such power generation plants and petrochemical processing facilities, are examples of NCSs' application. For more than last two decade, digital data communication has been a main issue in computer based control system. In another side, for one last decade, communication medium has also changed from RS-232 and RS-485 to Ethernet or RJ-45. These conditions have consequently caused communication topology and protocol become more complex [1-4]. In control system point of view, kind of network topologies and communication protocols fall to new problems in synchronization, sampling time, transient response performance, and stability [5-11]. These problems give all control engineers a challenge to find appropriate method and good control strategies.

Fig.1 and 2 describe the general structure of NCSs [11,12]. Kind of topology and communication protocol are decided by users themselves. Choosing of communication protocol is generally difficult due to sensor specification, actuator, and used computer system. Controller is lied in central processing unit in central controller. Sensor sends the data for controlling, logging, or monitoring purposes. Actuator will execute commands sent from controller to manipulate plant so that the set point can be reached. Fortunately, vendors of sensor and actuator have designed their products in order to support with generally used protocols, such as Modbus TCP, Ethernet/IP-Profinet in Programmable Logic Control, and Fieldbus Foundation - Profibus in Distributed Control Systems. Those protocols are open but unable to be directly used. There are two approaches to overcome these problems: by using software and hardware [13]. First method is by using OPC software and another by buying communication module needed the protocol to communicate.

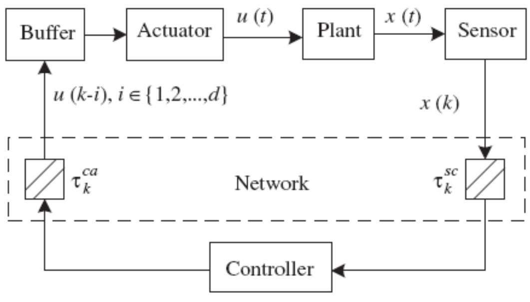


Figure 1: Structure of NCSs with time varying delay

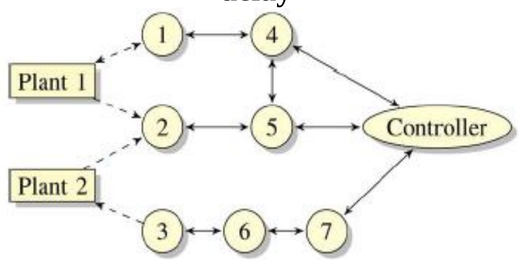


Figure 2: Example of multi-hop control network

This paper is preliminary report of our research in NCSs. In this paper, several control strategies are overviewed to get appropriate control scheme for our NCSs plant. From two main problems of NCSs (delay time and packet drop), control strategies for overcoming random delays are discussed. To enhance system response due to change of delay, Adaptive Retuning PID controller is applied. The simulation results are presented to see that this method is able to overcome the effect of time delay change.

Experiment being conducted is also explained to get feedback or new idea from other researchers.

2. EXPERIMENT SETUP

Fig. 3 and 4 are the experiment setup of our research. Main controller is in computer, where input output module (RTU) is TCP/IP version of Advantech Technology (6017 series). The set point is level of tank with differential sensor as feedback to controller. Communication between I/O module and computer is bridged by Ethernet switch. Preliminary experiment has been conducted by author's former student [14].

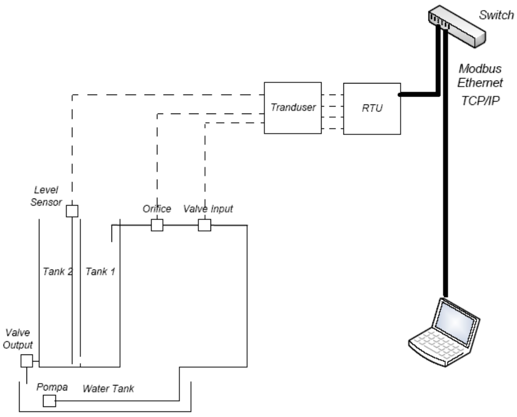


Figure 3: Experiment design

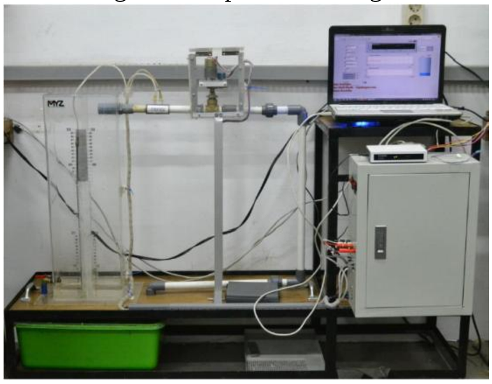


Figure 4: Realization of experiment design

3. CONTROL SYSTEM OVERVIEW

With modern communication technology (e.g., Ethernet), it becomes convenience to control large distributed systems on wide area. An array of distributed sensors, actuators, and controllers can be interconnected through common network medium. This condition brings advantage in low installation cost, ease of maintenance & installation, and flexible & fast to reconfigure [15]. Although there are advantages, there also several issues in control system such as networked delay, sampling, transmitting methods and data dropout [16]. In this paper, discussing is bounded for control strategies applied to enhance system response due to change of time delays. Several control strategies will be discussed in following subsections.

3.1 Robust Control

Robustness in control scheme is considered due to difficulties to get ideal mathematical model of the controlled system. To deal with robust system, bode plot of the system must be well known since it provides information about phase and frequency response. The advantages of control design based on bode plot are that it provides exact results for time delay systems and finds relative stability [13].

Simple definition of stability system based on bode plot is stated as follow:

"A negative feedback closed loop system is unstable if the frequency response of the open loop has an amplitude ratio greater than 1 at the crossover frequency".

First step is solving for frequency crossover in the open loop transfer function at the phase -180^0, Eq. (1), so that

$$\arg\left(G_{\text{openLoop}}\ (j\omega)\right) = -180 \qquad (1)$$

Where G is denoted as transfer function of the system (multiplication of controller and plant transfer function). Amplitude Ratio (AR) is then calculated by Eq. (2).

$$AR = \left|G_{\text{openLoop}}\ (j\omega)\right| \qquad (2)$$

If AR >1, the closed loop system is unstable.
Bode plot analysis, by find phase & gain margin, is then used to assess the stability of a feedback systems. As gain margin (GM) is defined as change in open loop gain required to make the system unstable so find greater gain margin, Eq. (3), can withstand greater changes in system parameters before becoming unstable in closed-loop [13,17].

$$GM > 1 \qquad (3)$$

Where $GM = \frac{1}{AR_{co}}$, AR_{co} is amplitude of open loop transfer function of the system at crossover frequency (ω_{co} where $\emptyset = -180^0$). Based on bode stability criterion, stability can be reached when $\emptyset = -180^0$, AR=1.

Another part of bode plot analysis is phase margin (PM) which is defined as the amount of phase angle that can be decreased before the system become unstable. The stability can be derived based on Eq. (4) and (5).

$$PM > 0 \qquad (4)$$

$$\text{Where } PM = \emptyset_{pm} + 180^0 \qquad (5)$$

$\emptyset_{pm}$ is phase angle when amplitude of G(s) = 1 which occurs at a frequency ω_{pm} .

By using this method, robust control system can be designed to overcome time delay problem.

3.2 Smith Predictor

This method, proposed in the 1950's and usually used in factory processes, is used to control systems that experience large but fixed delays in signal propagation [1]. This method is effective for system that experience large but fixed delays. Poor disturbance rejection is considered as the weakness of the method.

3.3 Middleware (Gain Scheduling)

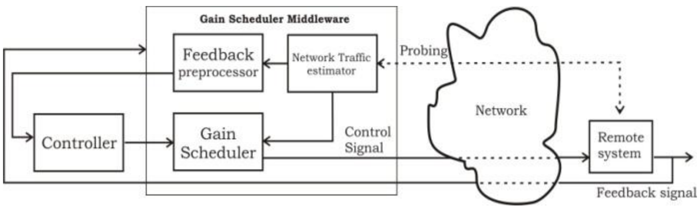
This method was proposed by [18] and modeled the delays as shifted exponential probability densities. The mean delay time is calculated from experimental results and then used as nominal value to design their gain scheduling middleware approach. This method has been applied to enable a PI-Controller, Eq. (6), in DC motor in networked condition.

$$G_c(s) = \frac{K_p\left(s+\left(\frac{K_i}{K_p}\right)\right)}{s} = \frac{K_p(s+Z_c)}{s} \qquad (6)$$

Where Z_c is constant. The middleware measures the delay in the system and uses that information to adjust an additional outer loop gain parameter β. When time delay is small, the loop gain is increased. If delay times increase, the gain is lowered to maintain system stability and performance. The value of β for given time delay is known *a priori*. A lookup table is generated offline using an optimal design based on cost functions. Structure of control strategy is depicted in Fig. 5.

Figure 5: Gain scheduler Middleware Design[18].

3.4 Adaptive Retuning PID



This method was proposed by [1] as extended work of [18]. PID controller was used due to inherently more robust against time delay and distinct advantage over PI controller in the sense that phase lead (phase advance) is possible. The algorithm consist of three main steps: (1). Measuring present time delay of system; (2). Calculating corresponding phase margin lost due to the delay; (3). Updating PID parameters to recover lost phase margin and return the closed-loop system nominal conditions. Detail of the algorithm will be discussed in next section.

4. PROPOSED CONTROL ALGORITHM

4.1 Review of PID controller

Eq. (7) is form of PID controller where zero locations are dependent on two parameters, T_i and T_d.

$$G_c(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \qquad (7)$$

Based on Eq. (8) and (9), the relationship among T_i, T_d, magnitude and phase can be described in Fig. 6 and 7. In Fig. 6, it can be clearly seen that by modifying T_i and T_d, controller phase can be modified. In same time, modification of T_i and T_d does not vary controller gain, see Fig 7.

$$|G_c(T_i, T_d)| = \sqrt{1 + \left(\frac{1-\omega^2 T_i T_d}{\omega T_i}\right)^2} \qquad (8)$$

$$\angle\emptyset_c(T_i, T_d) = \arctan\left(\frac{1-\omega^2 T_i T_d}{\omega T_i}\right) \qquad (9)$$

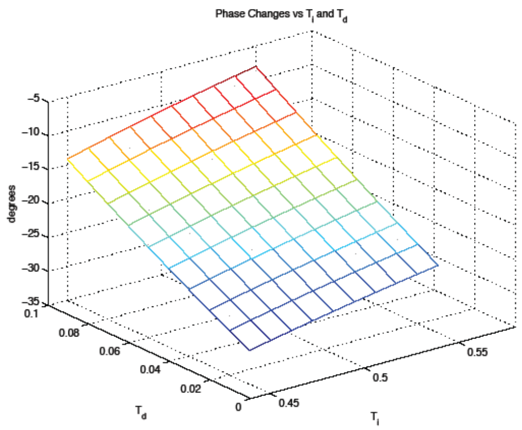


Figure 6: Phase change due to T_i T_d variation

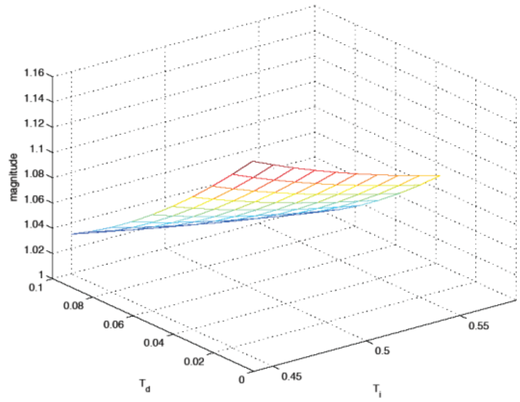


Figure 7: Gain change due to T_i T_d variation

4.2 Control algorithm

The control algorithm is aimed to recover phase margin that was lost from the changing delay (problem always appears in NCSs). The recovering strategy is by adjusting parameters T_i and T_d so that the new controller phase compensates for the change in phase delay. Detail of algorithm is described as follows:

a. Find delay change in network system, δt. In network technology, it can be found by typing 'ping' command.

b. Calculate phase delay change as stated in Eq. (10)

$$\delta\emptyset_m = \omega\ x\ \delta t\ x \frac{180^0}{\pi} \quad (10)$$

c. Based on Taylor series expansion, Eq. (9) can be set as Eq. (11)

$$\emptyset_c(T_i, T_d) = \emptyset_c(T_{i0}, T_{d0}) + \nabla\emptyset_c \begin{bmatrix} \delta T_i \\ \delta T_d \end{bmatrix} \quad (11)$$

Where $\nabla\emptyset_c$ is the gradient of the compensator phase with respect to compensator parameters. Substracting the nominal phase $\emptyset_c(T_{i0}, T_{d0})$ from both sides yields the change in controller phase due to adjusting controller gains so that the equation become Eq. (12).

$$\delta\emptyset_m = \nabla\emptyset_c \begin{bmatrix} \delta T_i \\ \delta T_d \end{bmatrix} \quad (12)$$

By finding $\delta\emptyset_m$ and $\nabla\emptyset_c$, incremental change in controller parameters $(\delta T_i, \delta T_d)$ can be derived.

d. Based on value of δT_i and δT_d, PID controller parameters are finally updated.

4.3 Result and Discussion

MATLAB 2011 was used to simulate model plant in [18], Eq. (13), and to examine control algorithm effectiveness.

$$G_p(s) = \frac{2029.826}{(s+26.29)(s+2.296)} \quad (13)$$

The original PID design is with parameter $Kp = 0.1724766$, $Ki = 0.38332136$, $Kd = -0.0001247099450$. Fig. 8 show the response of original controller design against input step. The response has overshoot 4.31 %, peak amplitude 1.04, and rise time at 0.114 second.

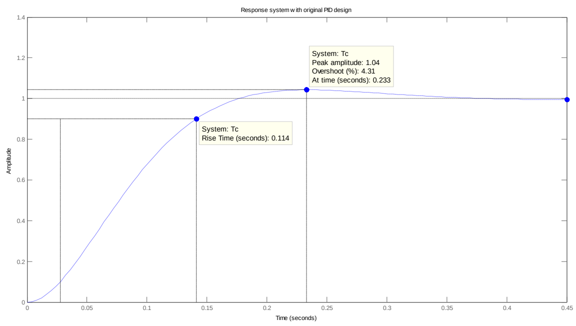


Figure 8: Response with original PID design

As NCSs has problem due to change of time delays, the presence of them is depicted in Fig. 9. It can be clearly seen that the variation of delay change influence the stability of system responses. Detail of the effects are also described in Table 1.

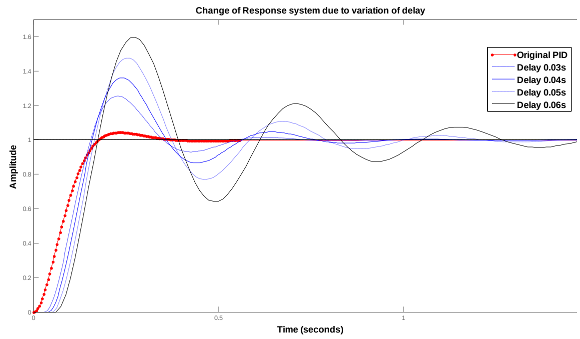


Figure 9: The effect of time delay changes

Table 1: Time delay changes vs response system

	Overshoot (%)	Peak response
Original PID	4.31	1.04
Delay 0.03s	25.4	1.25
Delay 0.04s	36	1.36
Delay 0.05s	47.6	1.48
Delay 0.06s	59.8	1.6

The proposed control is now applied to enhance lack of system responses due to variation of delays. Fig. 10 and 11 show the response of systems controlled by the proposed algorithm. With the algorithm, response of system that goes to unstable can be returned back to original control design. Table 2 depicts comparison of proposed control, original PID, and delay changes.

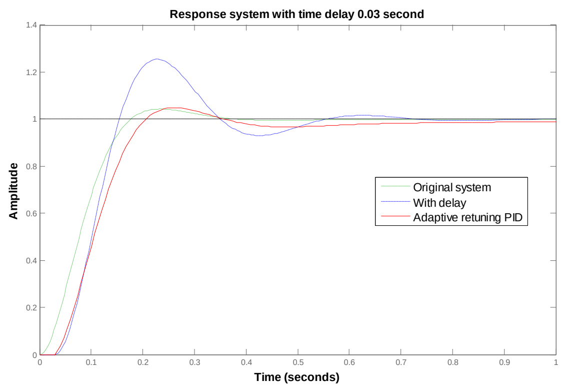


Figure 10: Response system with time delay 0.03 second

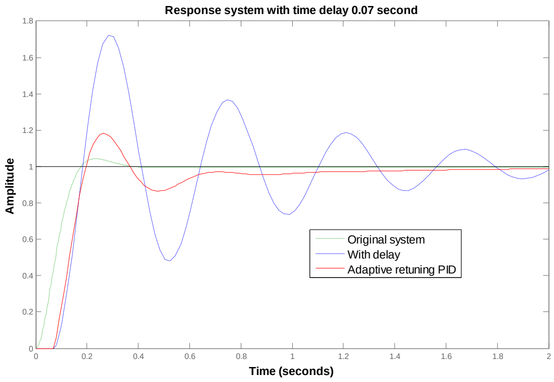


Figure 11: Response system with time delay 0.07 second

Table 2: Response system with and without proposed control

	Overshoot (%)		Peak response	
	without	with	without	with
Delay 0.03s	25.4	4.88	1.25	1.05
Delay 0.04s	36	6.8	1.36	1.07
Delay 0.05s	47.6	9.65	1.48	1.1
Delay 0.06s	59.8	13.5	1.6	1.14

5. CONCLUSION

In this paper, Networked Control Systems (NCSs) was reviewed to show trend in modern control method in relationship with modern communication technology widely used. Although NCSs brings advantage in low installation cost, ease of maintenance & installation, and flexible & fast to reconfigure, there also several issues in control system such as networked delay, sampling, transmitting methods and data dropout. In this paper, the effect of variations in delay changes provided to show that this problem can change stability of the system response. The Adaptive Retuning PID method was thus applied to overcome the problem. the presence of several delays was also presented to show the effectiveness of the proposed control. The results show that the method is able to enhance the system response as close as original controller.

6. ACKNOWLEDGMENT

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