IJCTA, 9(23), 2016, pp. 119-124
© International Science Press

An Effective Controller Design for Networked Control System

Richa Sharma* Deepak Nagaria and Purushottam Sharma*****

Abstract : The networked control system plays an important role in industrial applications. In industrial application, communication network is introduced between plant and controller and communication networks introduce a new problem into feedback control loop. The study is mainly focused on the efficient controller design. Controller is the main part of the networked control system. The basic components of NCS are sensors, actuators, and controllers. Sensors are used to sense the control signal from the plant and send this control signal to the controller, then controller process this signal and transmit it to the actuator, actuator retransmits this signal to the plant. The stability and performance of the system can be improved by a suitable controller design. In the networked control system design process, time delay and stability are a major concern. The time delay and performance of the system can be improved by a suitable controller design. Experimental results showed that the proposed controller can supersede the existing controller if proper design is used.

Keywords : Networked control system, networked induced time delay, MATLAB/True Time Tool.

1. INTRODUCTION

During past two decades, point to point communication architectures has been successfully used in industry for control system. But this type of communication control system is no longer suitable to meet new requirements of technologies and availability of network connectivity. If a feedback control system is closed through a real-time network or a communication channel is called as networked control system (NCS). The basic components of NCS are sensors, actuator, and controller. Sensor is used to sense the control signal from the plant and send this control signal to the controller, then controller process this signal and transmit it to the actuator, actuator retransmits this signal to the plant as shown in figure 1. In this type of system, data are transmitted in the form of packets through the network. The main purpose to introduce communication network in control system is to minimize the wiring of the system, maintenance, and system flexibility and suppleness

Due to these advantages, NCS became more popular in practical applications. The networked control system is widely used in manufacturing automation, electronics factories, robots, advanced aircraft and electric vehicles [1]. The introduction of a communication network in the control closed loops makes the analysis of NCS complex. The major issues that occur in NCS are time delays, packet losses and limited bandwidth [2]. There are two types of time delay, variable time delay, and constant time delay. These parameters degrade the system performance. Many researchers have paid attention in these parameters. They designed many controllers to improve the performance of the system. Dong Yue [3] presented a delay dependent approach for a controller design. They considered both networked induced delay and data packet dropout. Vojtech Vesely [4] proposed a LMI based algorithm to resolve the problem of the robust output feedback controller design. M.B.G. Cloosterman et.al [5] derived a LMI conditions for robust stability of NCS under the condition of uncertainty, time varying and bounded time delay. L. Zhang et.al [6] designed a linear quadratic regulator (LQR) for a state variable model of the networked

---

* Research Scholar, Department of Electronics Engineering AKTU, Lucknow, U.P., India s.richa.sharma@gmail.com
** Reader, Department of Electrical Engineering B.I.E.T, AKTU, Lucknow, U.P., India deepaknagaria@gmail.com
*** Amity University Uttar Pradesh, Noida, U.P, India. Psharma5@amity.edu

control system.Saba Salehi et. al [7] proposed a Lyapunov-Krasovskii function to design a mode dependent static output feedback controller. They considered both sensors to controller and controller to actuator delay. A BMI (bilinear matrix inequality) approach is used for stability of NCS. Yugang Niu et. al [8] designed a sliding mode controller. To design sliding controller they firstly introduced estimation method to compensate packet dropout. Xiao-Ming Tang et.al [9] proposed a novel model for NCS with networked induced time delay and packet disorder. An augmented state space model was obtained using novel model of NCS. In this paper, we focused on controller design for compensating different delays of the networked control system which are introduced when data are transmitted through the network. The network which is used in this system is Ethernet [10].

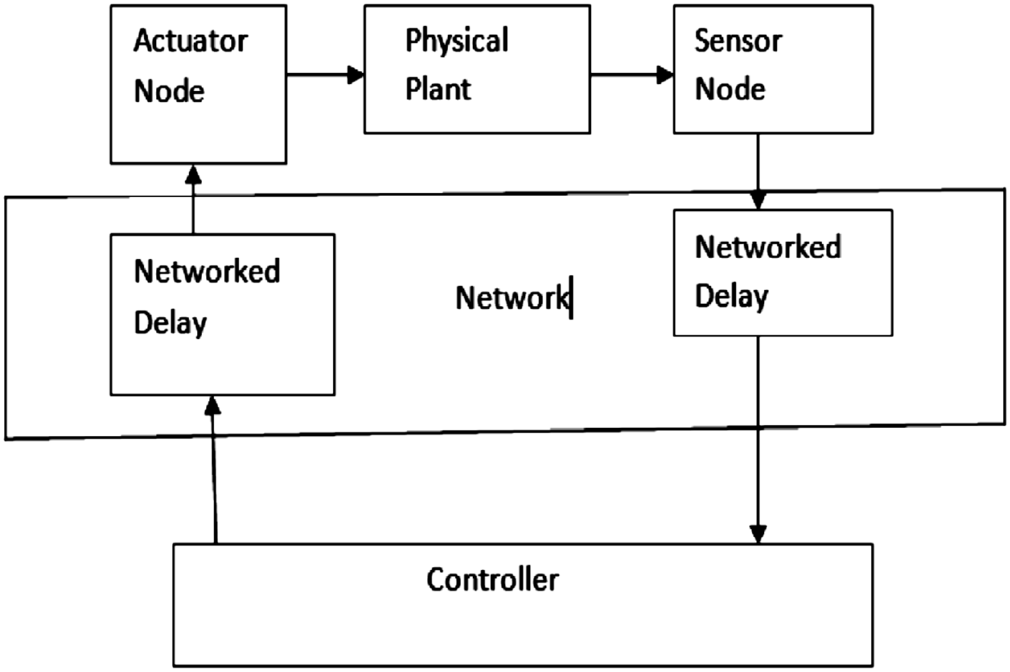

Fig. 1. Networked control system.

The controller design basically depends on the available information. The proposed controller is designed by considering the effect of time delay within the network. The paper is organized as follows: NCS model is detailed in section-(*ii*). The proposed controller design is presented in section-(*iii*). Simulation and results discussion are discussed in section-(*iv*). Section –(*v*) conclude this paper.

2. NCS MODEL

In a complex feedback control system if system components sensor, actuator and controller are connected via communication channel is known as a networked control system. There are two types of networked structure: Hierarchical Structure and Direct Structure. The hierarchical structure system has many subsystems. Every subsystem has its own sets of sensor, controller, and actuator. The controller of the subsystem is connected to the main controller through the network. The function of the main controller is to calculate the reference signal and send it to the plant in the form of packets. But in direct structure data is traveled directly from the controller to plant through the network. The communication channel forms the direct connection between controller and plant. For successful implementation of networked control system, different protocols are available. Data networks are different from the control networks. Some properties of the network are responsible for system performance. The system performance will be degraded due to response time, access delay, transmission time, packet size etc. In this paper, we use a direct structure where sensor, actuator, and plant directly connected to the controller through a communication network. The main motive of this research paper to analyze the effect of proposed controller in the presence of delay in the networked system. Time delay maximum and minimum limit of delay can be decided by the controller. The presence of delay degrades the performance of the system.

The total time delay present in networked control system [11, 15]

1. Data transfer delay from sensor to controller (τ_{sc})
2. Controller processing time delay (τ_c)
3. Data transfer delay from controller to actuator (τ_{ca})

Total communication delay of networked control system

$$\tau_k = \tau_{sc} + \tau_c + \tau_{ca} \tag{1}$$

3. PROPOSED CONTROLLER DESIGN

This paper aim is to investigate the suitable controller for the networked control system. The structure of controller paid an important role to control several processes of the plant. The plant poses some guidelines to the controller. The selection of controller depends on the best possible performance that can be achieved by the well-tuned controller. In this paper, we are designing digital PID controller to control the plant performance in the presence of constant time delay. From the literature of time delay analysis, it is proved that PID controller [12] are stable when time delay exists in input and output.

PID controller in continuous time

$$u(t) = \mathrm{K}p\,(e\,(t) + \frac{1}{\mathrm{Ti}}\int_0^t e(\tau)d\tau + \mathrm{T}_d \frac{de(\mathrm{T})}{dt} \tag{2}$$

Where $e(t)$ is the error signal which is defined as

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

Here $r(t)$ is the reference signal and $y(t)$ is the controller output**.**

PID controller transfers function $\quad \mathrm{G}(s) = \mathrm{K}_p\left(1 + \frac{1}{\mathrm{sTi}} + s\mathrm{T}_d\right) \qquad (4)$

Then the relation between P, I, D and coefficients are Proportional (P) = K_p Integral (I) = $\mathrm{K}_p / s\mathrm{T}_i$ Derivative (D) = $\mathrm{K}_p / \mathrm{T}_d$

The controller performance can be controlled by these three parameters. These parameters can be tuned using auto tuning.

The discretization is done at discrete time-instants, $tk = kh$,

Discrete PID controller at time step k

$$\mathrm{G}(k) = \mathrm{K}p\; e(k) + \left(ui\,[k-1] + \frac{\mathrm{Kph}}{\mathrm{Ti}} e[k\right) + \left(\frac{\mathrm{Td}}{\mathrm{Td + Nh}}\mathrm{U}_d\,[k-1] + \frac{\mathrm{Kp\;Td\;N}}{\mathrm{Td + Nh}}[e(k) - e(k-1)\right) \tag{5}$$

Here h = sampling time and N = filtering factor

4. SIMULATION AND RESULT DISCUSSION

To verify the performance of proposed controller design let us consider plant transfer function

$$\mathrm{G}_p(s) = \frac{1.32}{(s + 0.4621)\,(s + 0.1799)} \tag{6}$$

As discussed above the PID controller consist of three tuning parameters. By proper tuning the values of PID controller parameters comes out to be K_p= 0.121, K_i= 0.0231, K_d = 0.0347.

Discrete form of PID controller with sampling period h = 0.1 sec

$$\mathrm{G}_c(z) = \frac{0.8162\,z^2 - 1.386z\;0.5742}{z^2 - 1} \tag{7}$$

The model is simulated in MATLAB/True Time tool. In following simulations we assume Ethernet-type network where transmission of simultaneous messages is decided based on package priorities. In turetime tool, we select an Ethernet network for communication. At first, the performance of NCS can be analyzed in the presence of total delay in Ethernet. The reference signal is stepped signal. The control system performance is evaluated with respect to the reference signal. In figure 2 network schedule gives the proper values for each of the transmitted signals through the network. The controller schedule for signal transmission is shown in figure 3. The actuator and sensor scheduling is represented by figure 4. Figure 5, 6 and 7 shows the measured signal performance with a reference signal in different sampling periods and control performance.

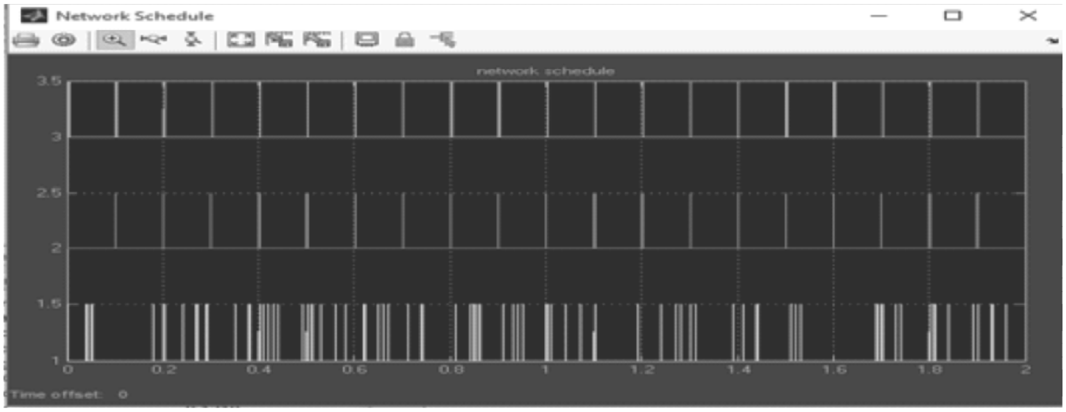

Fig. 2. Network schedules.

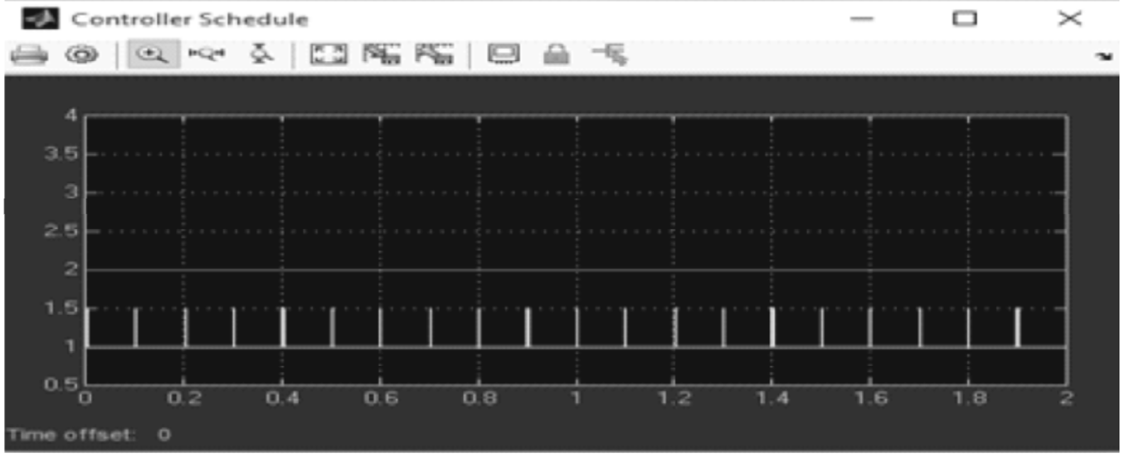

Fig. 3. Controller schedule

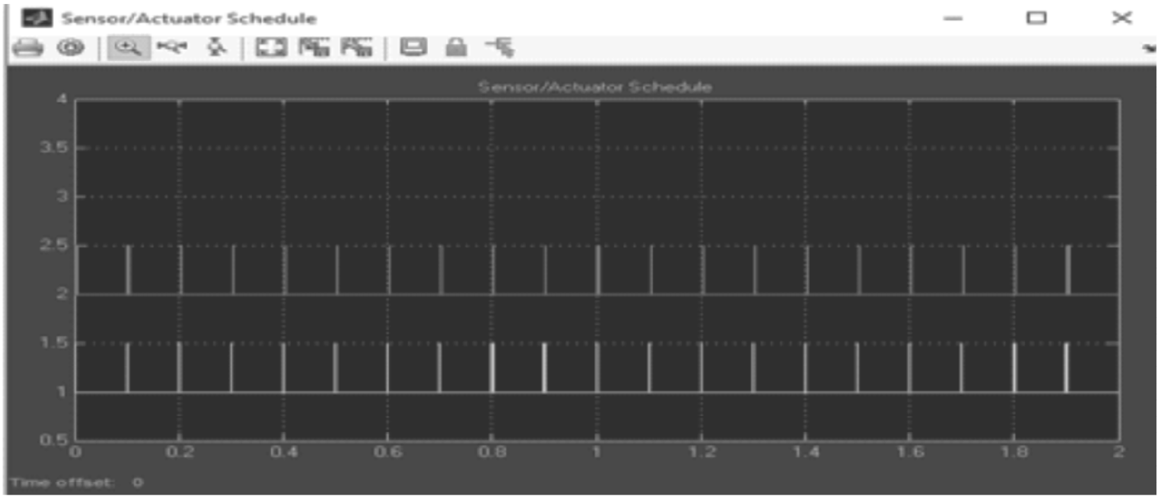

Fig. 4. Sensor /Actuator Schedule

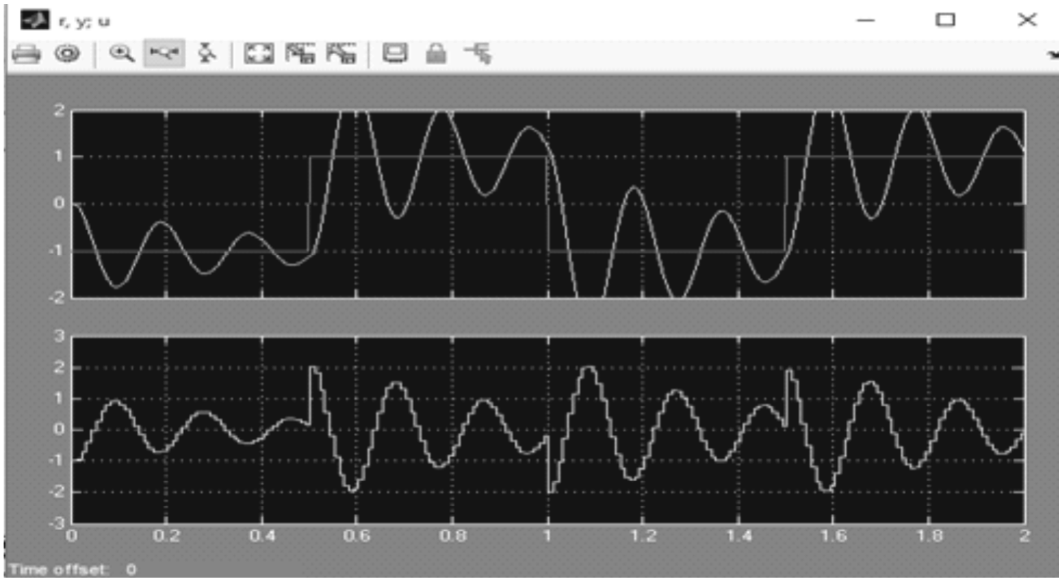

Fig. 5. Control performance of system with sampling 0.030 sec

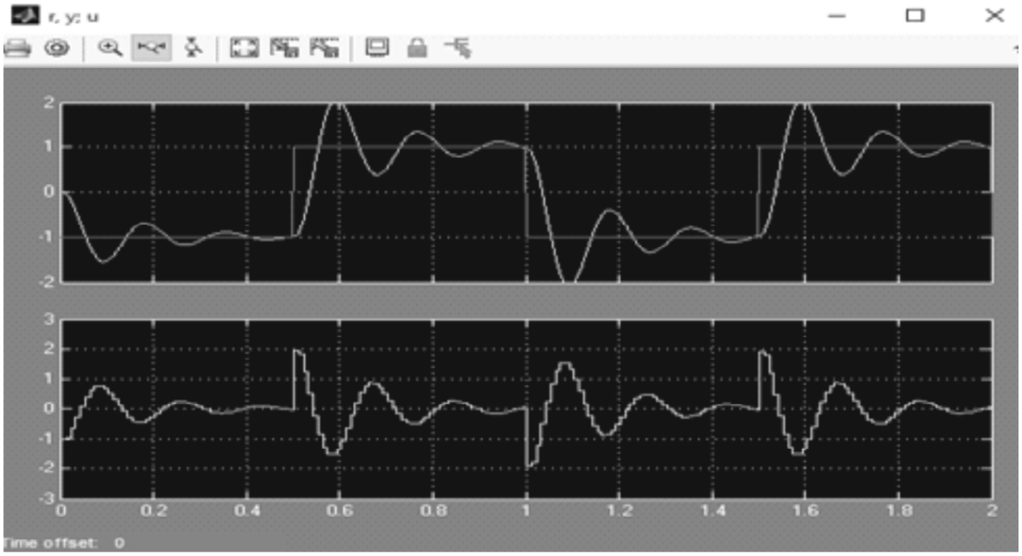

Fig. 6. Control performance of system with sampling 0.020 sec

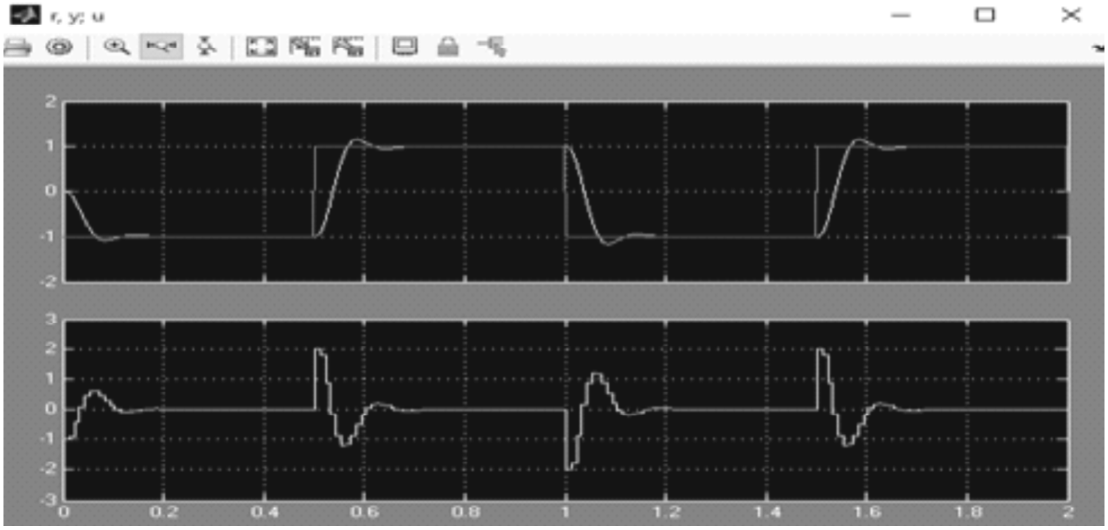

Fig. 7. Control performance of system with sampling 0.010 sec

In our simulation we change the sampling period from 0.010sec to 0.030 sec. From simulation it is clear that communication is overloaded and performance of the system decreases. As we can see from simulation results that control system performance degraded if we are increasing the sampling period. PID controller parameters are good enough for overall system performance.

5. CONCLUSION

Integrating communication networks into control systems replace point-to-point communication architecture but on the other hand NCSs bring several issues like network-induced delays or packet dropouts. For designing better control system it is mandatory to know the behavior and characteristics of NCSs. In this study a digital PID controller is designed for networked control system. It is assumed that the time delay induced in networked system is constant. The parameters of PID are tuned via proper tuning process which is based on process model and desired closed loop responses. The simulated result proves that the designed controller can make the system stable. True time tool is used for network simulation.

6. REFERENCES

1. L. Zhang, H. Gao, O. Kaynak, “Network-Induced Constraints in Networked Control Systems—A Survey”, IEEE Transactions on Industrial Informatics, Vol. 9, No. 1, pp. 403-416, 2012.
2. WEI Ling, XUE Ding-yu, E Da-zhi “Some Basic Issues in Networked Control Systems”, Second IEEE Conference on Industrial Electronics and Applications, 2007, pp. 2098-2102
3. Dong Yue, Qing-Long Han, and Chen Peng, “State Feedback Controller Design of Networked Control Systems”, IEEE Transactions on Circiuts and Systems-II, vol. 51, no. 11, November 2004.
4. Vojtech Vesely, “Static Output Feedback Robust Controller Design via LMI Approach”, Journal of Electrical Engineering, vol. 56, no. 1-2, 2005.
5. M.B.G. Cloosterman, N. van de Wouw, W.P.M.H. Heemels, and H. Nijmeijer, “Robust stability of networked control systems with timevarying network-induced delays”, in Proceedings of the 45th IEEE Conference on Decision and Control, San Diego, CA, USA, pp. 4980- 4985, Dec. 2006.
6. L. Zhang and F. Hua-Jing, “A novel controller design and evaluation for networked control systems with time-variant delays”, Journal of the Franklin Institute, vol.343, no.2, pp.161–167, 2006.
7. Saba Salehi, Lihua Xie, Wenjian Cai “Robust Controller Design for Networked Control Systems with Uncertain Time Delays”, 10th Intl. Conf. on Control, Automation, Robotics and Vision Hanoi, Vietnam, 17–20 December 2008.
8. Yugang Niu and Daniel W. C. Ho, “Design of Sliding Mode Control Subject to Packet Losses”, IEEE Transactions on Automatic Control, vol. 55, no. 11, November 2010.
9. Xiao-Ming Tang and Bao-Cang Ding, “Design of Networked Control Systems with Bounded Arbitrary Time Delays”, International Journal of Automation and Computing April 2012.
10. Kun Ji and Won-jong Kim, “Real-Time Control of Networked Control Systems via Ethernet”, International Journal of Control, Automation, and Systems, vol. 3, no. 4, pp. 591-600, December 2005
11. Amira Sarayati Ahmad Dahalan, Abdul Rashid Husain, Mohd Badril Nor Shah and Muhammad Iqbal Zakaria, “Time Delay Analysis in Networked Control System Based Controller Area Network”, Proc. of the International Conference on Advances in Computer and Information Technology - ACIT 2012.
12. Kiam Heong Ang and Gregory Chong, “PID Control System Analysis, Design, and Technology”, IEEE Transactions on Control Systems Technology, vol. 13, no. 4, July 2005.
13. Mikael Pohjola, Lasse Eriksson and Heikki Koivo, “Tuning of PID Controllers for Networked Control Systems”, IECON 2006 - 32nd Annual Conference on IEEE Industrial Electronics, 2006.
14. Tran, Q.N.; Özkan, L.; Backx, A. Generalized predictive control tuning by controller matching. J. Process Control 2015, 25, 1–18.
15. Tian, Z.-D.; Gao, X.-W.; Li, K. A Hybrid Time-delay Prediction Method for Networked Control System. Int. J. Autom. Comput. 2014, 11, 19–24.