Journal of Information Engineering and Applications
ISSN 2224-5782 (print) ISSN 2225-0506 (online)
Vol.7, No.5, 2017
www.iiste.org

Evaluating a ZigBee Network with SMC for Hard and Concurrent Parameter Variations

Mais M. Salman* O. A. Awad
Al-Nahrain University, College of Information Engineering, Iraq

Abstract

One of the main issues concerning a wireless networked control system is the variable delay associated with the communicating network used to join its dispersed components. This paper presents a variable structured Sliding Mode Controller (SMC) designed for a ZigBee wireless networked control system (WNCS) in addition to the design of a standard PID controller. WNCS can improve the reliability and the effectiveness of the control system by eliminating time and costs of installation and maintenance. Presence of time delays between sensors, actuators and controllers of the controlled system can degrade the performance and destabilize the whole system. To reduce the effect of the network delay, simulation tools for WNCS are developed to help designers in studying the influence of network on performance of the control system. The TrueTime toolbox is used to analyze the effects of network delays and to evaluate the effects of ZigBee parameters on control systems such as packet loss, ACK. Timeout limit, and traffic load. It is clear from the results that SMC is superior to PID control.

Keywords: NCS, SMC, PID, ZigBee, TrueTime

1. Introduction

Networked control systems (NCSs) [1] are known as feedback control loops with dispersed components such as sensors and/or actuators with controllers, which are closed via communication networks. The features of NCSs which represent the information (reference input, plant result, control signal) are transmitted over a network among control system components (sensor, controller, and actuator). The great advantages in applications of NCSs are: reduced system wiring, ease of system maintenance, high reliability, and increased system lightness, etc.

In spite of the advantages, the insertions of communication networks in control loops make the NCSs analysis and synthesis complex. In network transmission, data packets suffer from not only packet losses, but also from the network induced time delays, the latter is one of the main issues which affect the performance and stability of the closed loop system [2].

In [3] the simulation of a networked control system for a DC servo motor is controlled by a PD controller over a shared ZigBee network. Simulations are done for different scenarios regarding time delay and data loss probability until the system becomes unstable and PD controller can no longer work.

In [4] the sliding mode control (SMC) which is a special case of VSC techniques. It is used to control the speed of DC motor. The simulation result shows that the sliding mode controller (SMC) is better than the PI controller for speed controlling the DC motor.

In [5] the ZigBee wireless networked control system was simulated using Truetime. Truetime is a network MATLAB/Simulink-based on simulation toolbox, which was used in this work to design a PID controller for DC motor system. Wireless network simulations are designed, and focusing on the major three problems in NCSs which are sampling period and packet dropout.

In this paper, the ZigBee network is to be evaluated for controlling a dc motor. A SMC is designed and implemented using TrueTime simulator under MATLAB. The contribution of this work are

- The ZigBee network is heavily tested under different conditions and evaluated for different Network values of delay and packet loss.
- The sliding mode controller is proved to be very efficient and compensate for a wide range of time delays, bounded by less than 0.0928 sec which is almost 9 folds the sampling time.
- The SMC is successfully designed and proved its robustness with the ZigBee network under hard and concurrent parameter variations.

1. Time Delay

Network packet delay can degrade the NCS performance significantly and even destabilize the entire system. The overall delay τ shown by the system due to the network insertion between its components is the effect of three components: the delay between the sensor and the controller τ_{sc}; the delay between the controller and actuator τ_{ca} and the delay due to the computation time τ_c of processing the control algorithm. The total delay is given in equation (1).

$$\tau = \tau_{sc} + \tau_{ca} + \tau_c \qquad (1)$$

The controller computation time τc is fixed and comparatively negligible in comparison to the other two components. It is related to the hardware processing power of the controller and on the use of efficient code in implementing the control algorithm. The sensor to controller τsc delay and controller to actuator delay are random variable delays by nature. They are related to network quality of service QoS. Control mechanisms depending on constant time delay are not suitable for NCS, since network delay is usually time varying. When τ is less than the sampling period Ts, the delay is considered a short delay and stability of the NCS can be easily maintained [6]. On the other hand, when τ is larger than the sampling period, some delay compensation technique must be employed [7].

2. ZigBee Network

ZigBee [8] is a specification for a cost effective, low rate and low power wireless communication protocol for home automation and monitoring. Although it exists since late 2004, ZigBee still has to fully prove its success, at least in the industrial domain where reliability and security are uttermost important.

ZigBee is a specification for the higher protocol layer, and builds upon the physical (PHY) and medium-access control (MAC) layers in the 802.15.4 specification [9].

ZigBee has been designed to provide the following features:

1- The range is about 70m indoors and 400m outdoors [10].

2- Low device cost, low installation cost and low maintenance. ZigBee devices allow batteries to last up to years without any chargers (low cost and easy installation).

3- Low power consumption with ranging of battery life from months to years.

4- Maximum data rates allowed for each of the frequency bands are fixed as 250 kbps for 2.4 GHz, 40 kbps for 915 MHz, and 20 kbps for 868 MHz [11]

3. Network Security

Sending and receiving control, actuator and sensor commands in the network bring a necessary point of security over the network. Any network medium especially wireless medium is susceptible to easy intercepting because of the data over the network can be available to everyone connected to the network.

It is a highly critical point to protect transmitted data from unauthorized access and modification in wireless systems. Malicious users can intercept, eavesdrop the data and transmit via shared and broadcast medium. Network security includes essential elements in Internet security devices that provide integrity, confidentiality, and authentication [12, 13].

4. Sliding Mode Control (SMC)

Sliding mode control (SMC) is one of the popular strategies to deal with uncertain control systems.
The main feature of SMC is the robustness against parameter variations and external disturbances and is widely used to obtain good dynamic performance of control systems. There are various applications of SMC such as: robotic manipulators, aircrafts, DC motors etc.

A Sliding Mode Controller is a Variable Structure Controller (VSC). Basically, a VSC includes several different continuous functions that can map plant state to a control. Surface and the switching among different functions are determined by plant state that is represented by a switching function [14, 15]. The basic control law of SMC [16] is given by:

$$s=\dot{e}+ce \tag{2}$$

Differentiating (2) and making the derivative of sliding surface equal to zero produces (3)

$$\dot{s}=\ddot{e}+c\dot{e} \tag{3}$$

$$\dot{s}=\ddot{e}+c\dot{e}=0 \tag{4}$$

Where:

s is sliding surface, e is error, ė is derivative error, c is positive scalar, r is reference and y is output response.
If the sliding surface is positive, the switching control signal is positive. If the sliding surface is negative, the switching control signal is negative.

$$u=\begin{cases} +u_o & if \quad s>0 \\ -u_o & if \quad s<0 \end{cases} \tag{5}$$

The switching control can be written as (6). In (6), sgn (s) is a sign function that switches between 1 and -1 at high frequency.

$$u=u_o\,\mathrm{sgn}(s) \tag{6}$$

For Boundary layer, using switching function (sign) as a part of the control law for the sliding surface $s(x)=0$, which is the main reason of the chattering in the control effort. In order to reduce the chattering phenomenon, a boundary layer approximation of discontinuous control must be applied around the sliding surface [17].

5. Proportional-Integral-Derivative (PID)

Proportional-Integral Derivative (PID) control is the most widely used control in the industry. The reasons for its popularity are it is simple usage and effectiveness. The control signal u(t) of the standard PID controller is given by (7). Figure 1 shows a typical closed loop feedback system controlled by a PID controller. Several PID tuning methods have been proposed such as manual method and Zeigler Nichols method etc., Ziegler and Nichols is most common tuning method to find its parameters: proportional gain k_p, integral gain k_i and the derivative gain k_d [18, 19].

$$u(t)=k_p e(t)+k_i\int_0^t e(t)dt+k_d\frac{de}{dt} \tag{7}$$

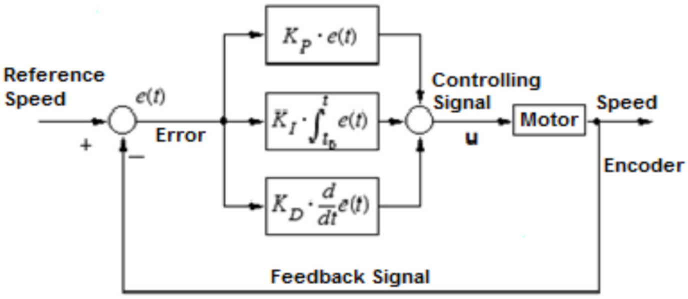


Figure 1. Block diagram of PID controlled system [20]

6. DC motor

DC motors are widely used in robotic and industrial equipment where high accuracy is needed. In some cases the uncertain conditions encounter the DC motor control to some difficulties. Hence, DC motor control has been stimulated a great deal of interest from several decades ago up to now. DC motors are identified as adjustable speed machines for many years and a wide range of options have evolved for this purpose. The model for a speed controlled DC motor is given by the following second ordered transfer function [21].

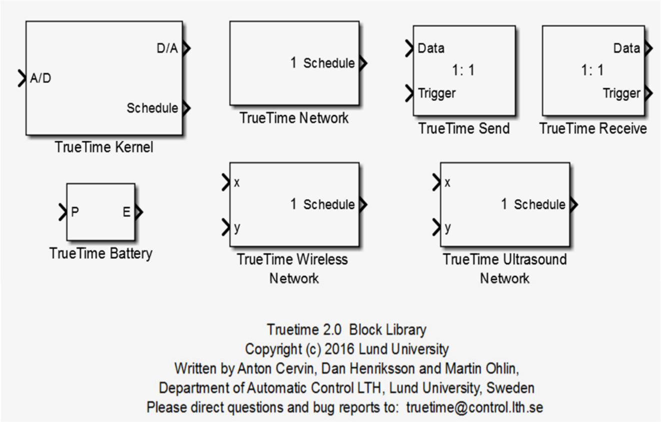
$$\frac{W(s)}{U(s)}=\frac{\frac{k_m}{JL}}{s^2+\left(\frac{R}{L}+\frac{b}{J}\right)s+\left(\frac{Rb+k_e k_m}{JL}\right)} \tag{8}$$

Where W is the motor speed, U is the controlled voltage, J is the moment of inertia, k_m is the motor constant, k_e is the backemf- speed constant, L is the armature inductance, R is the armature resistance, and b is the viscous damping coefficient.

7. TrueTime Toolbox

Truetime [22] is a MATLAB based simulator that has been developed at the Department of Automatic Control, Lund University, Sweden since 1999, for the design and simulation of embedded control systems and distributed control systems. TrueTime toolbox consists of a library of blocks and a collection of MEX files (MATLAB external interface) [23].

TrueTime blocks library version 2, consists of TrueTime Kernel, TrueTime Network for wire network, TrueTime Send, TrueTime Receive, TrueTime Battery, TrueTime wireless network, and TrueTime Ultrasound Network as shown in figure 2.



Truetime 2.0 Block Library
Copyright (c) 2016 Lund University
Written by Anton Cervin, Dan Henriksson and Martin Ohlin,
Department of Automatic Control LTH, Lund University, Sweden
Please direct questions and bug reports to: truetime@control.lth.se

Figure 2.TrueTime library

8. Simulation Case Studies

The sampling period is 0.01s for all simulation case studies, packet dropout is chosen equal to 1% and 25% for two controllers.

The parameters of Zigbee network [24] as appeared in table 1

Table 1.Parameters of ZigBee network

Parameters	**Value**	**Unit**
Network type	802.15.4(ZigBee)	-
Network number	1	-
Number of nodes	3	-
Data rate	250000	Bps
Minimum frame size	248	Bit
Transmit power	-3	dBm
Receiver signal threshold	-48	dBm
Pathloss exponent	3.5	1/distance^x
ACK timeout	0.000864	S
Retry limit	5	-
Error coding threshold	0.03	-
Data	80	bit

The parameters of DC motor [21] as appeared in table 2.

Table 2. Parameters of DC motor

symbol	**NAME**	**Values**	**Unit**
R	armature resistance	7.17	Ω
L	armature inductance	0.953×10^{-3}	H
K_e	back emf coefficient	0.29	Vs
K_m	Torque coefficient	$46\times10_{-3}$	NmA^{-1}
J	inertia moment	4.42×10^{-6}	kgm^2
b	viscous friction	2.99×10^{-4}	Nms
W(s)	Motor angular speed	-	Rad/s
U(s)	Armature voltage	-	V

Using parameters of DC motor which are given in Table II the transfer function of DC motor with angular velocity as controlled variable and input terminal voltage as manipulating variable is obtained as given in equation 9:

$$\frac{W(s)}{U(s)} = \frac{10.92\times10^{6}}{s^{2}+7.6\times10^{3}s+3.67\times10^{6}} \tag{9}$$

The parameters of PID controller is shown in equation 10, figure 3 shows the speed of DC motor and control action with optimum PID , figure 4 show the speed response of DC motor and control action of SMC

$$k_{p=}3.2704e\text{-}3 \tag{10}$$
$$T_{i=}1.935e\text{-}4$$
$$T_d=4.85e\text{-}5$$

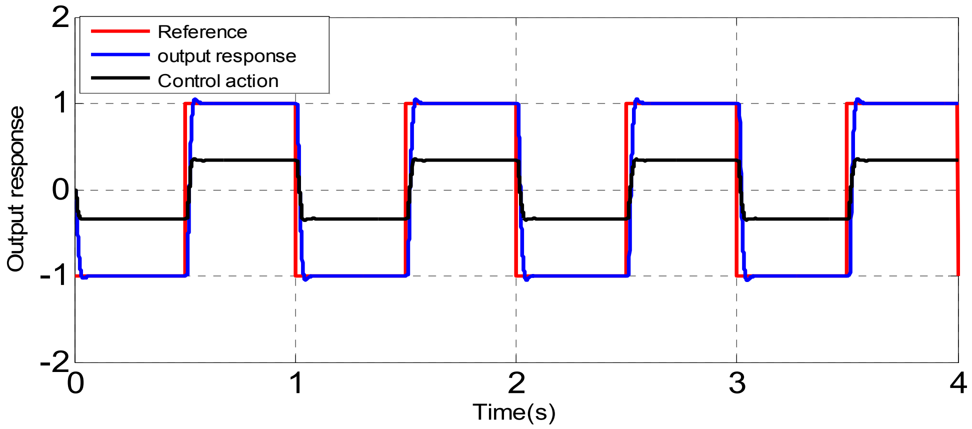


Figure 3.The speed response of DC motor and control action with optimum PID

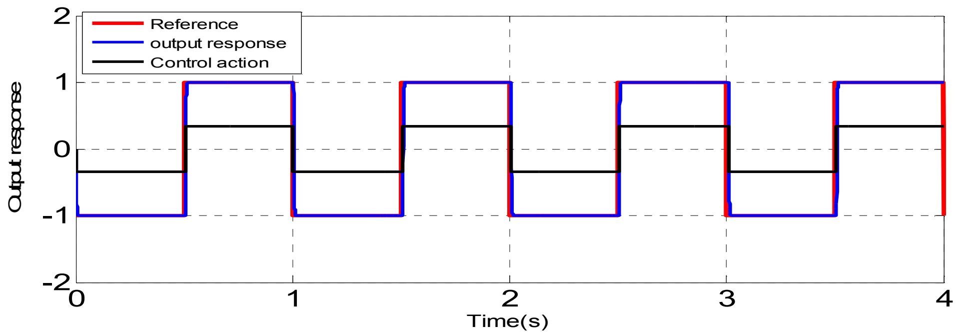


Figure 4.The speed response of DC motor and control action with optimum SMC

9. Time Delay Control Loop

The insertion of network communication in control systems imposes time delay that effects on the system performance.

Variable time delay is imposed on control system model in feed forward and feed backward, the figure 5 shows the system control model with variable time delay block, and output system response for both two controllers is checked.

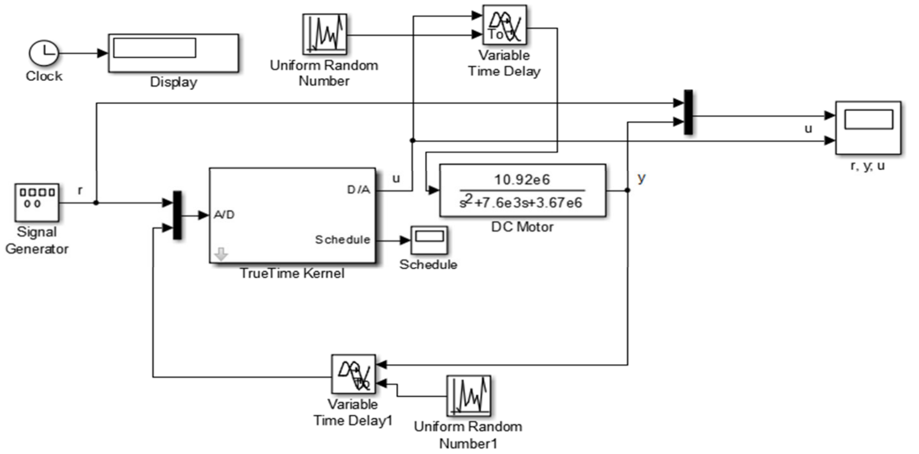


Figure 5.The speed response of DC motor and control action of SMC

11.1 Time Delay in PID Control Loop

Testing the system with the PID controller for randomly variable time delays is shown in Figures 6-12. Test are conducted on the cases of max random delays of 0.0001s,

0.000505s, 0.006s, 0.0241 and 0.0928s in the feed forward and feed backward paths. The results are good for short delays less than 0.000505s, acceptable for time delay 0.006s and bad delays greater than 0.0241 (long delay).

Applying a time delay of 0.0928s, the output system response shows high overshoot and it is the worst case that made the system unstable.

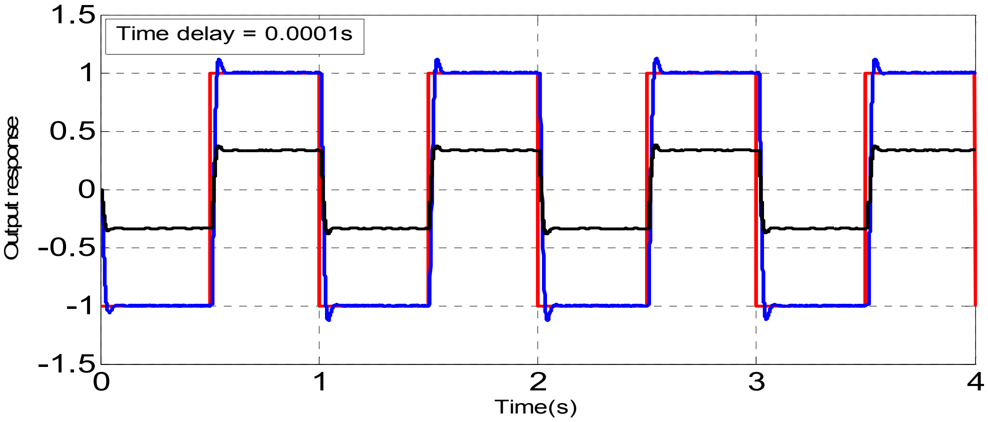


Figure 6.The speed response of DC motor and control action with PID controller and time delay 0.0001s

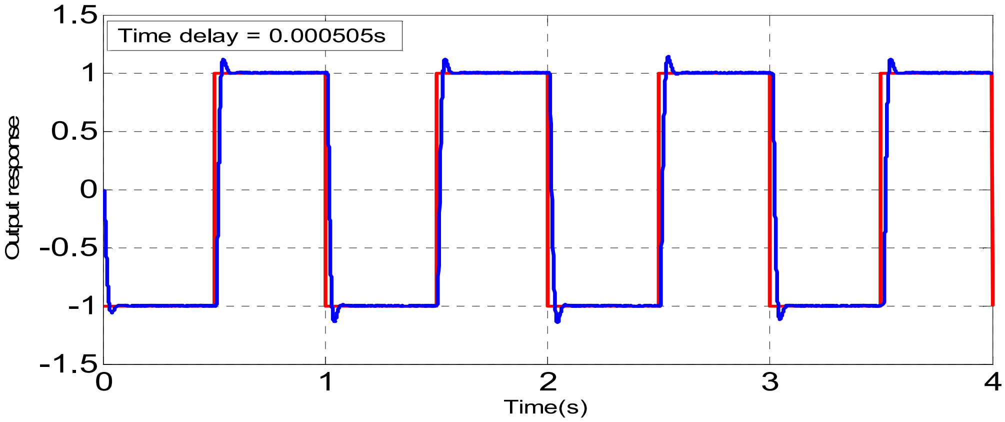


Figure 7.The system response for PID with time delay= 0.000505s

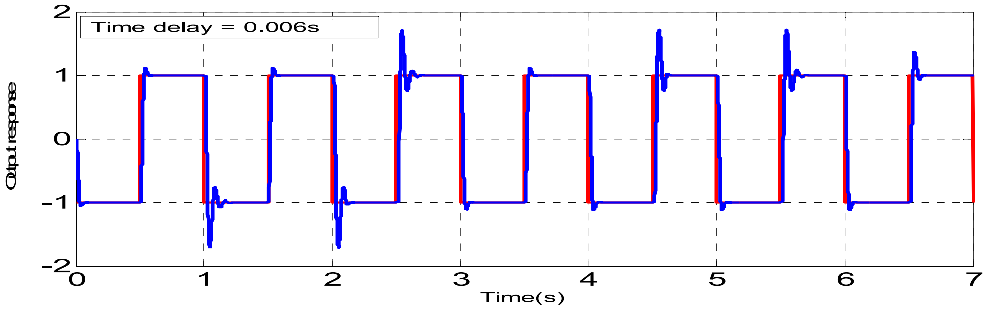


Figure 8.The system response for PID with time delay= 0.006s

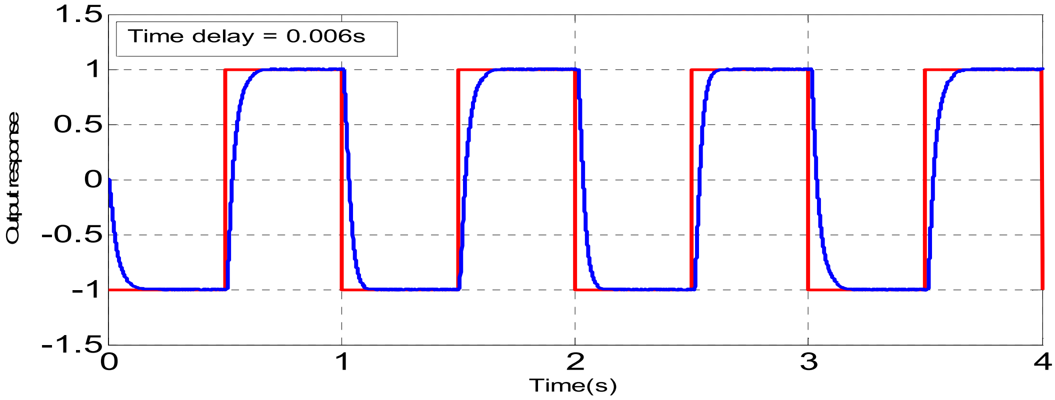


Figure 9.The system response for PID with time delay= 0.006s after refinement

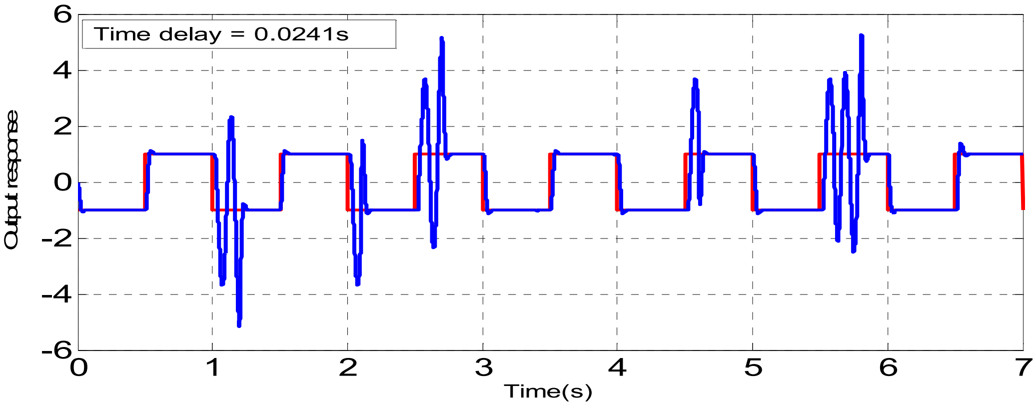


Figure 10. The system response for PID with time delay= 0.0241s

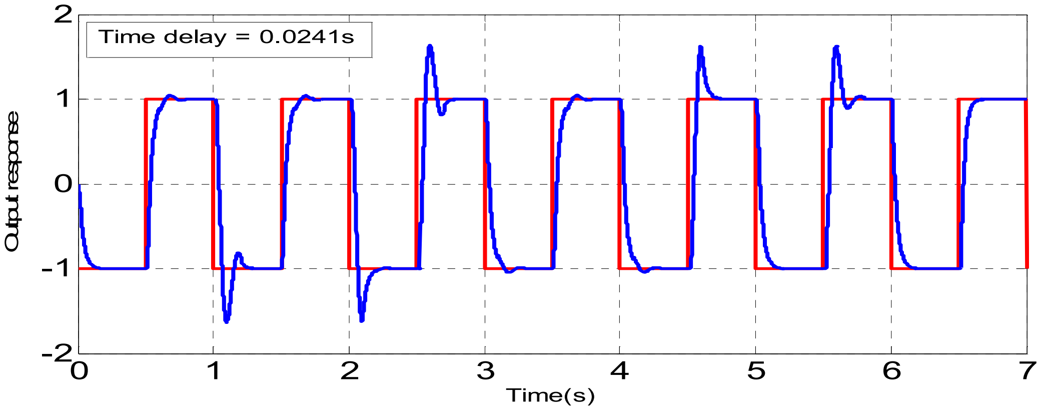


Figure 11. The system response for PID with time delay= 0.0241s after refinement

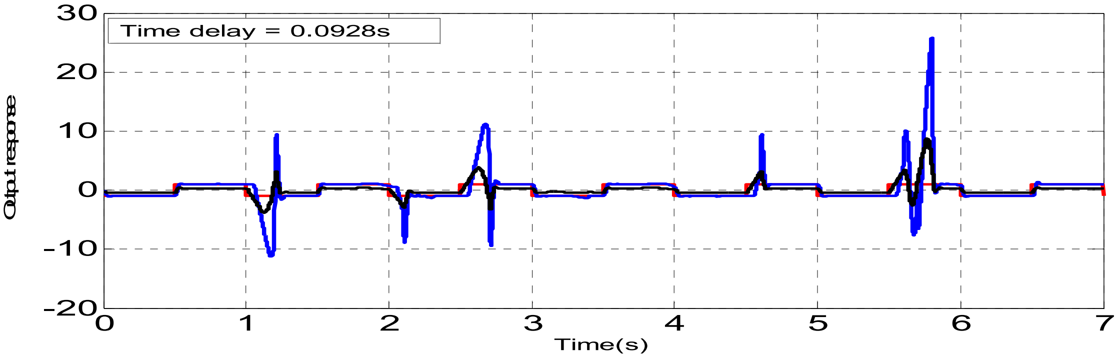


Figure 12.The system response and control action for PID with time delay= 0.0928s

9.2 Time Delay in SMC Loop

The same imposed random time delays that are applied to the system in the previous test with the PID controller are applied.

Using SMC, to show the difference between it and PID controller for such delays.

The output response of system for SMC is obtained as shown in figures 13-17. It shows perfect results with delays of 0.0001s, 0.000505s, 0.006s, and 0.421. For the final value of 0.0928s time delay, the output response shows less stability than previous results as shown in figure 17.

SMC still has good capability in controlling the speed of the DC-motor, all results show that SMC is better than PID controller.

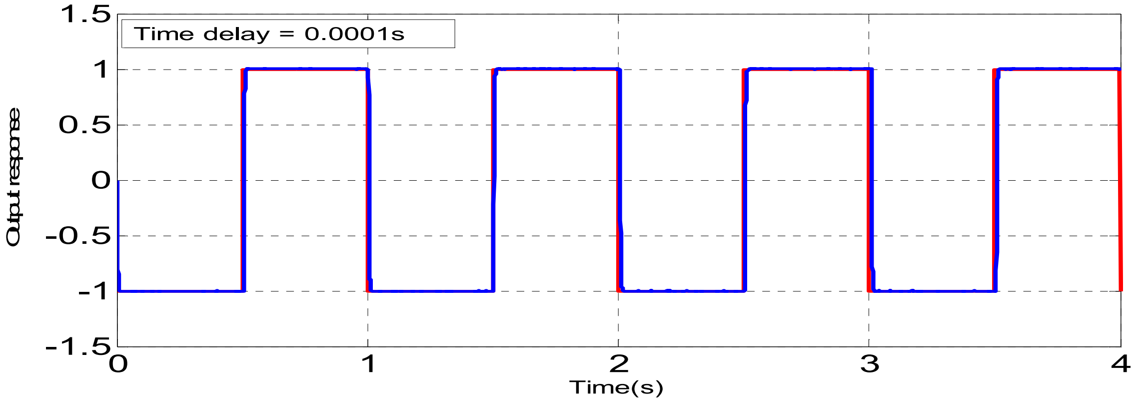


Figure 13.The system response for SMC with time delay= 0.0001s

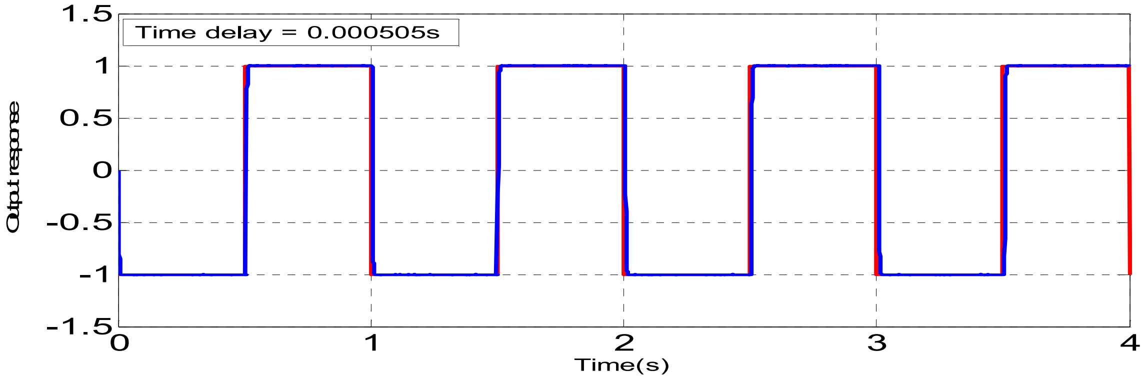


Figure 14. The system response for SMC with time delay= 0.000505s

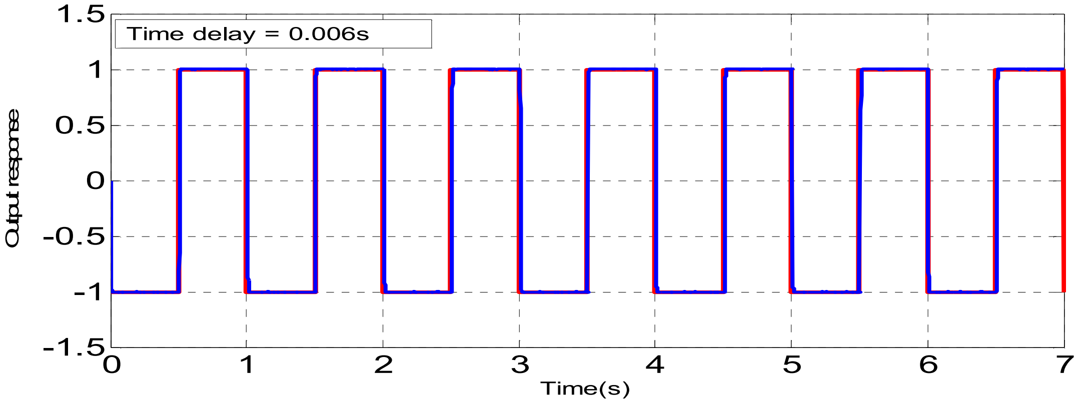


Figure 15. The system response for SMC with time delay= 0.006s

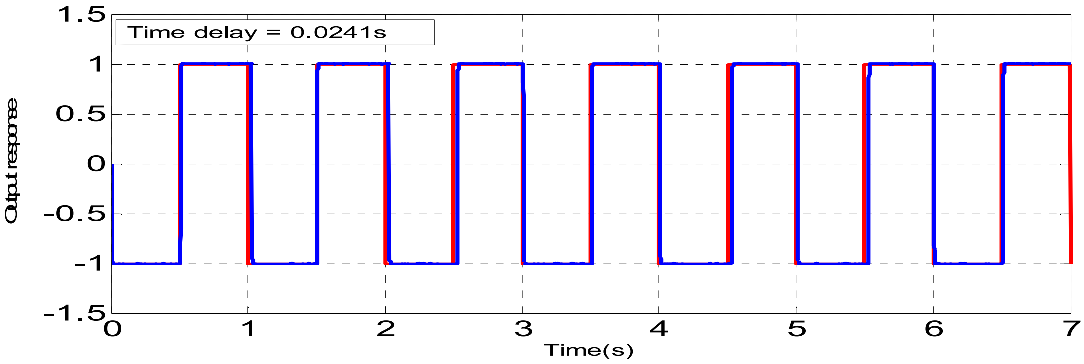


Figure 16.The system response for SMC with time delay= 0.0421s

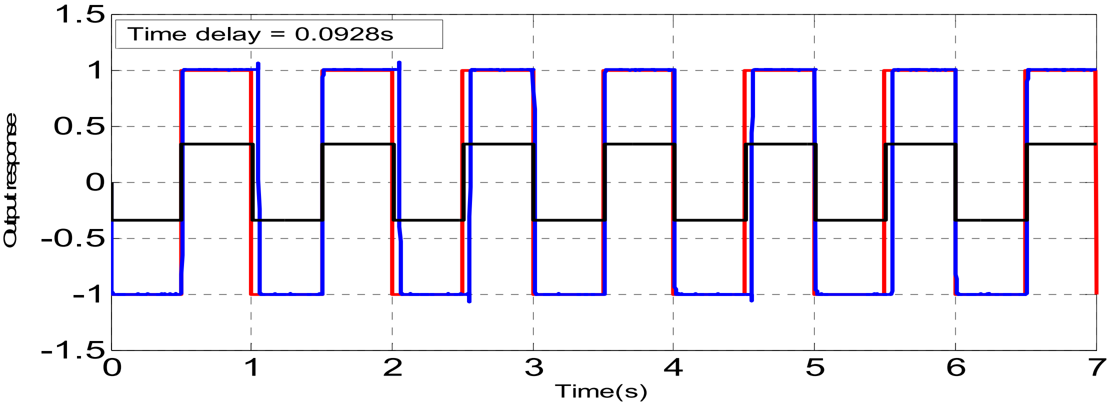


Figure 17.The system response and control action for SMC with time delay= 0.0928s

10. Variable Load Test

By adding variable time delay block between actuator and plant as shown in figure 18, the performance of both PID controller and SMC is tested for different values of delays representing the traffic load in the network; the results are obtained in figures 19-34 below.

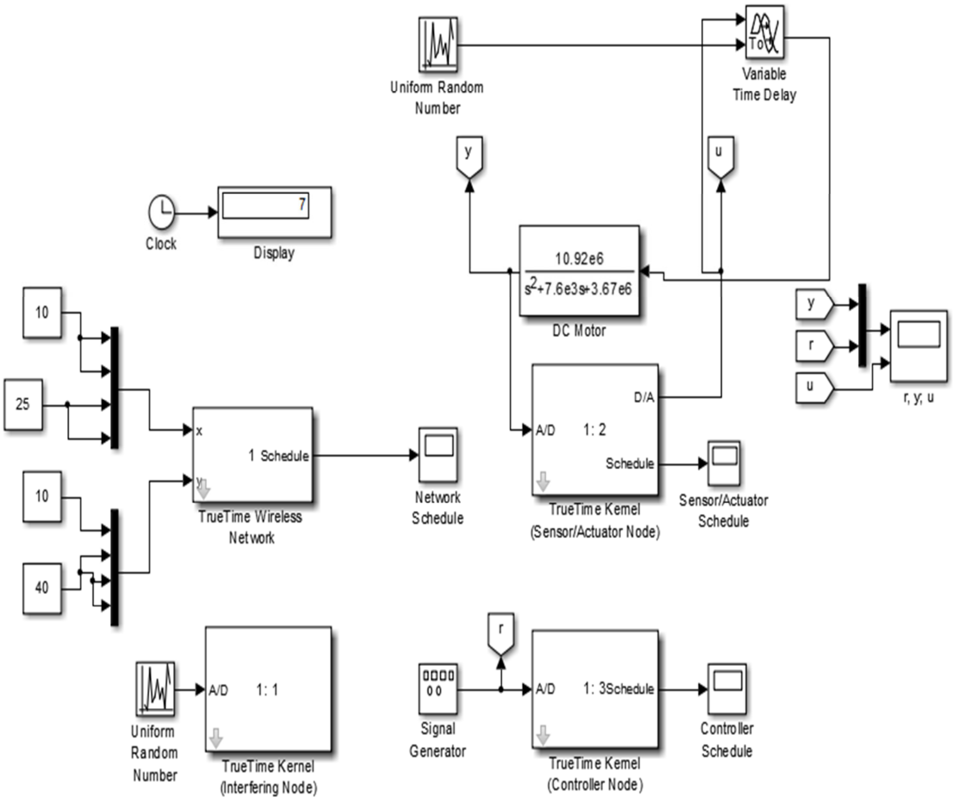


Figure 18.The model of WNCS with time delay block

12.1Variable Load for PID

Testing the system with the PID controller for randomly variable time delays and packet loss probability are shown in Figures 19-27. Tests are applied on the cases of random delays of 0.0001s, 0.006s, 0.0241 and 0.0928s between actuator and plant with packet loss 1% and 25%. The results are good for short delays less than 0.0001s, acceptable for time delay 0.006s and bad delays greater than 0.0241 (long delay).

Applying a time delay of 0.0928s, the output system response shows high overshoot and it is the worst case that made the system unstable.

Refinement is made for cases 0.006s and 0.0241s and results are shown in figure 22, figure 24 and figure 26.

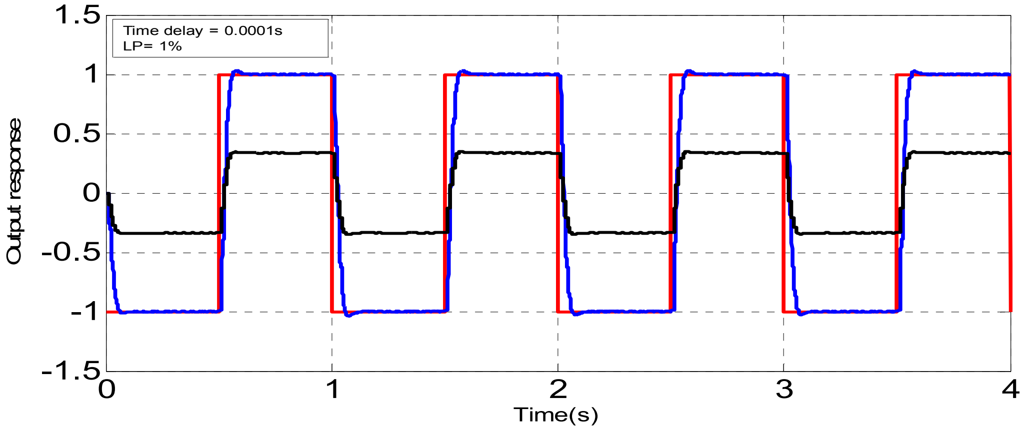


Figure 19.The system response for PID with time delay= 0.0001s and LP=1%

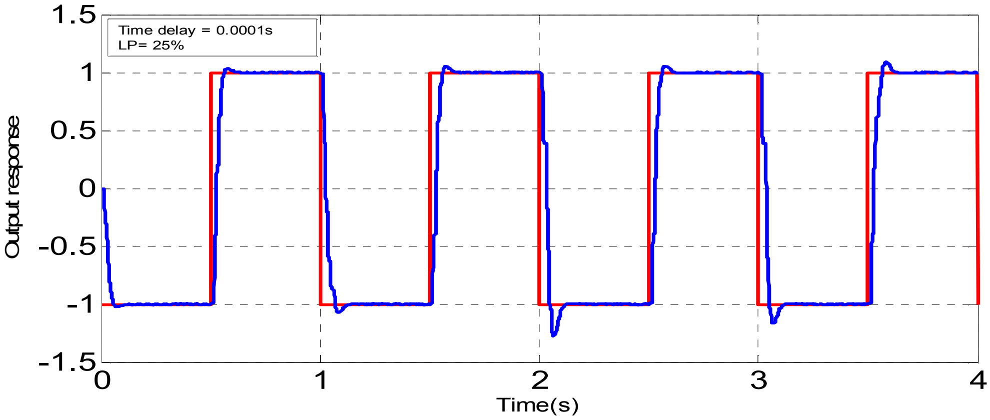


Figure 20. The system response for PID with time delay= 0.0001s and LP=25%

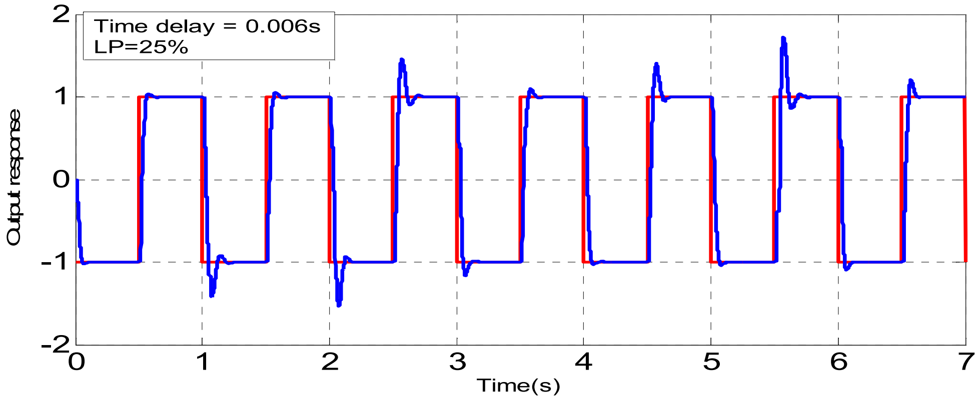


Figure 21.The system response for PID with time delay= 0.006s and LP=25%

Parameters of PID controller after refinement as shown in equation (11)

$$K= 2.2704e-3 \qquad (11)$$
$$T_i =1.935e-4$$
$$T_d =4.85e-5$$

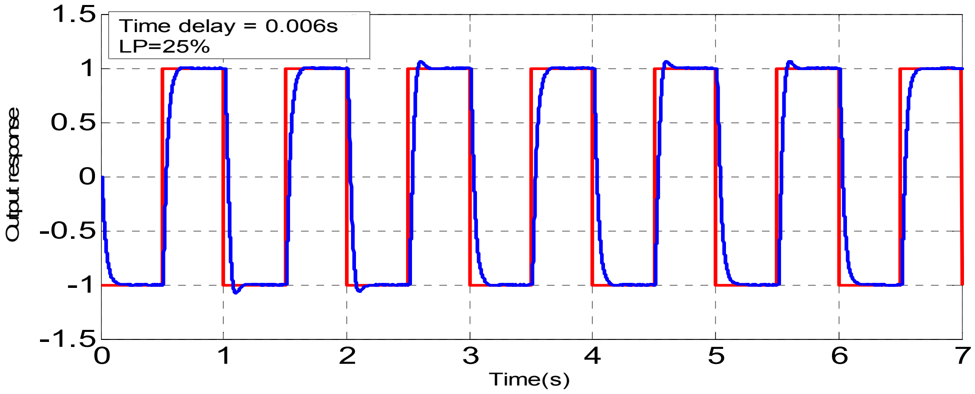


Figure 22: The system response for PID with time delay= 0.006s and LP=25% after refinement

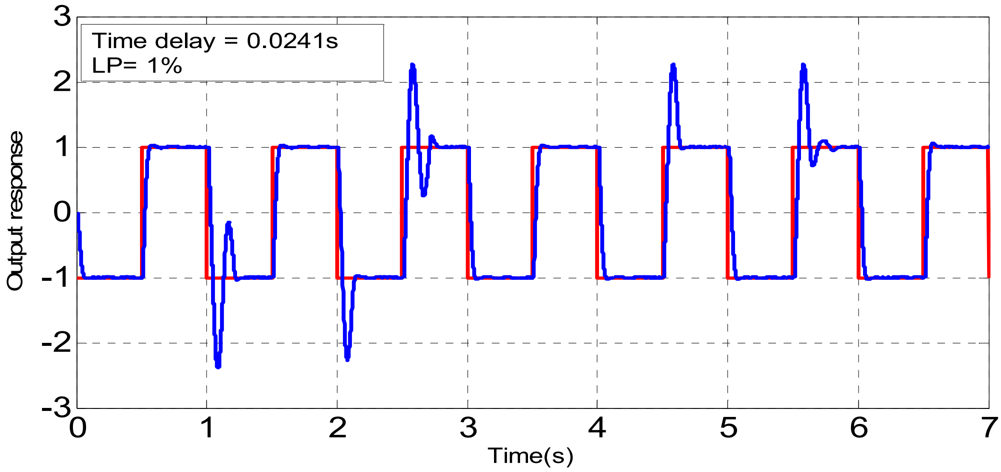


Figure 23.The system response for PID with time delay= 0.0241s and LP=1%

Refinement of PID controller parameters is made for the above case as shown in equation (12)

$$K= 1.2704e-3 \quad (12)$$
$$T_i =1.935e-4$$
$$T_d =4.85e-5$$

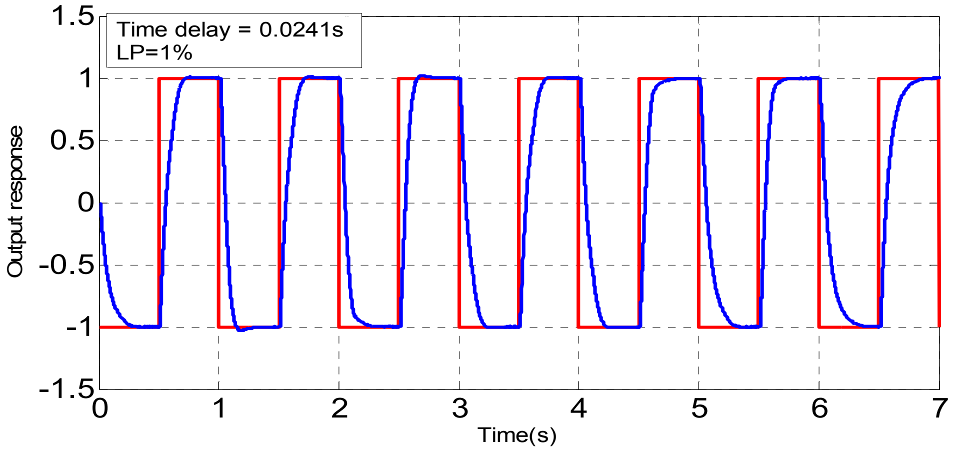


Figure 24.The system response for PID with time delay= 0.0241s and LP=1% after refinement

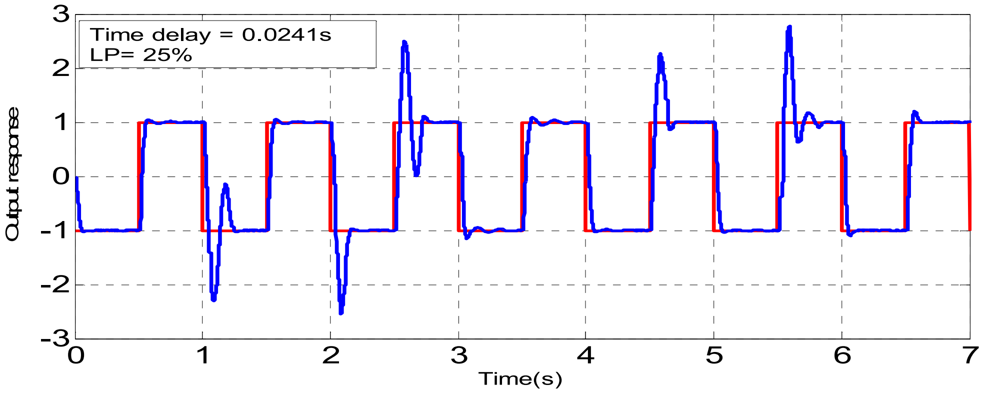


Figure 25.The system response for PID with time delay= 0.0241s and LP=25%

Refinement of PID controller parameters is made for the above case as shown in equation (13)

$$\begin{gathered} K= 1.2704e\text{-}3 \\ T_i =1.935e\text{-}4 \\ T_d =4.85e\text{-}5 \end{gathered} \tag{13}$$

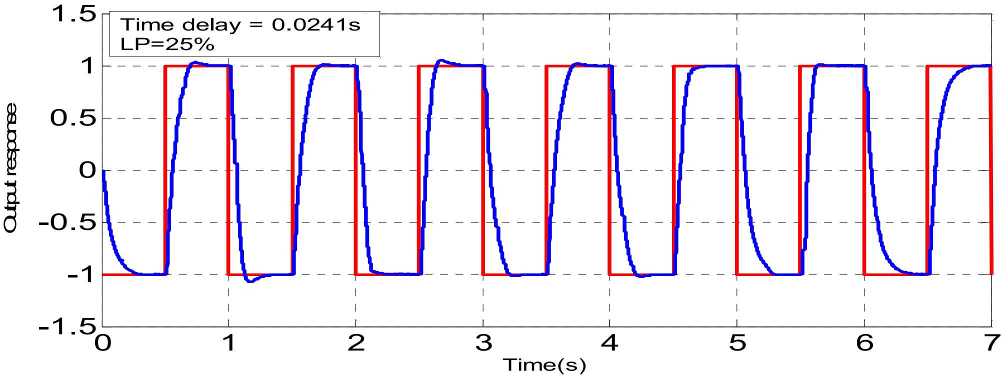


Figure 26. The system response for PID with time delay= 0.0241s and LP=25% after refinement

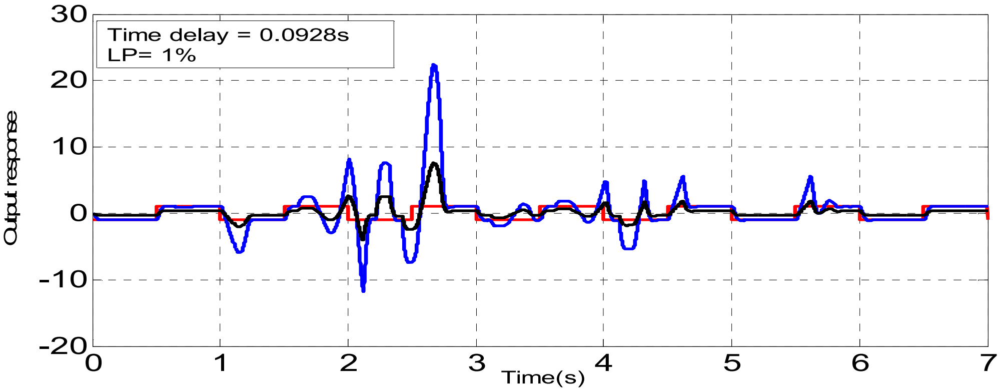


Figure 27.The system response for PID with time delay= 0.0928s and LP=1%

12.2 Variable load for SMC

Testing the system with the SMC for the same random variable time delays and packet loss probability that applied in PID controller and check the results as shown in figures 28-34. Tests are conducted on the cases of random delays of 0.0001s, 0.006s, 0.0241 and 0.0928s between actuator and plant with packet loss 1% and 25%. The results are good for all cases in opposite of PID controller that shows high overshoot and lead to instability.

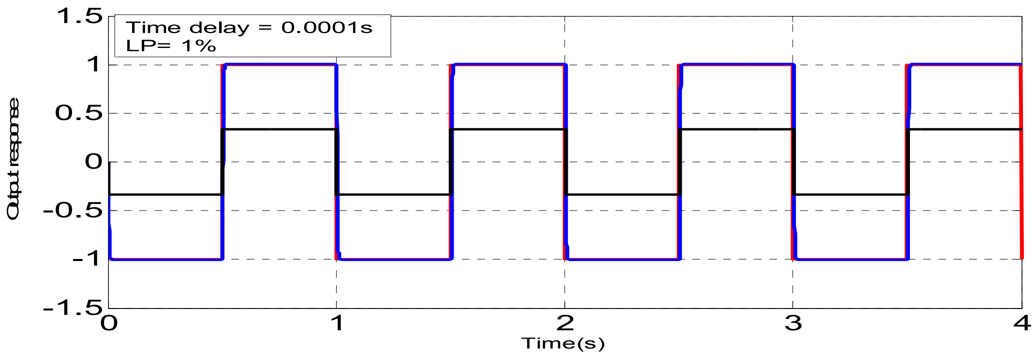


Figure 28.The system response and control action for SMC with time delay= 0.0001s, LP=1%

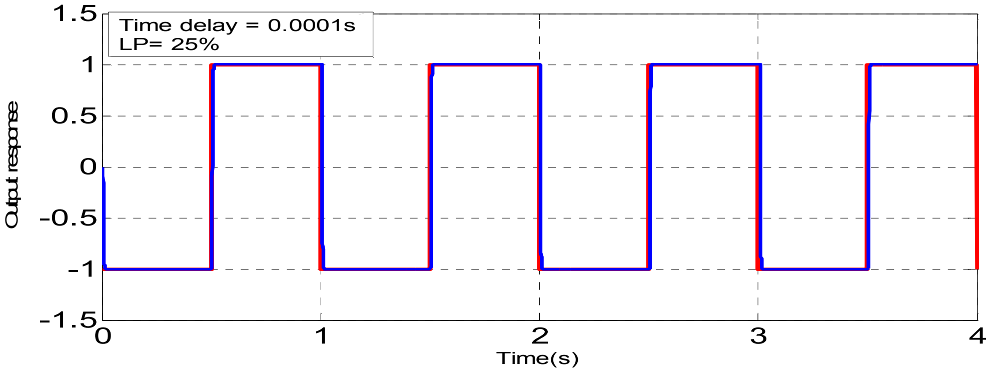


Figure 29.The system response for SMC with time delay= 0.0001s and LP=25%

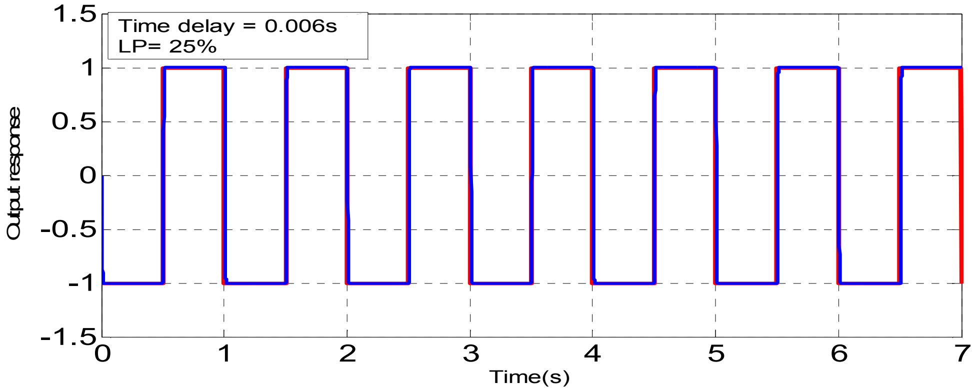


Figure 30.The system response for SMC with time delay= 0.006s and LP=25%

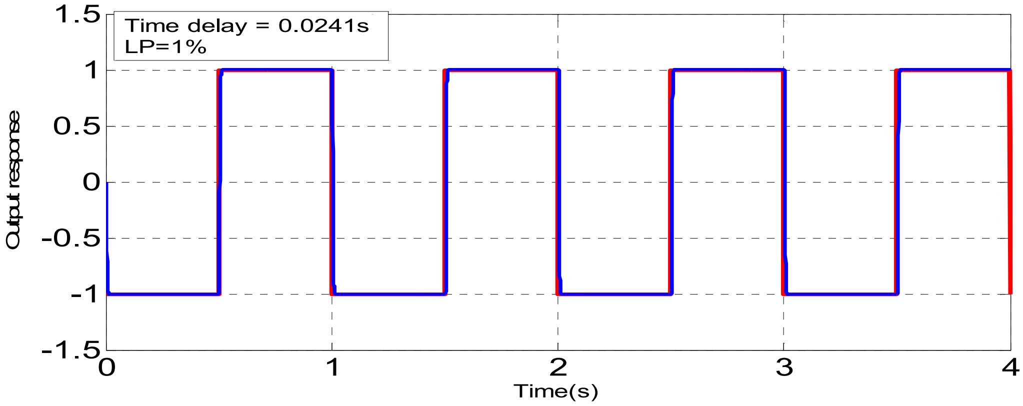


Figure 31.The system response for SMC with time delay= 0.0241s, LP=1%

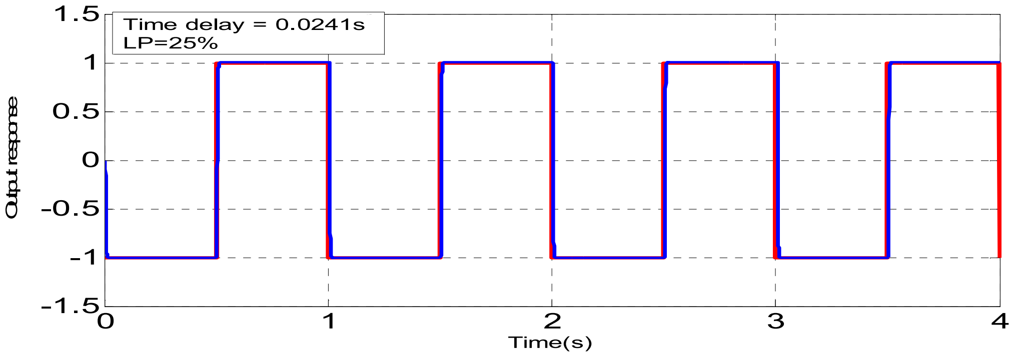


Figure 32.The system response for SMC with time delay= 0.0241s and LP=25%

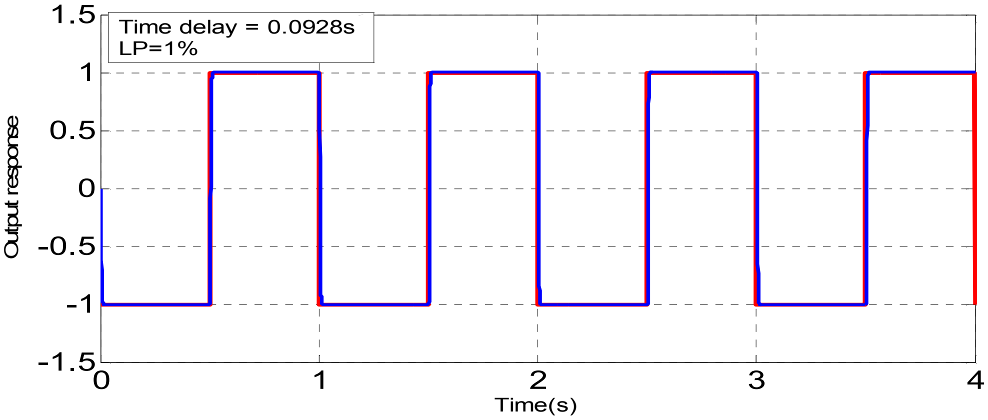


Figure 33.The system response for SMC with time delay= 0.0928s, LP=1%

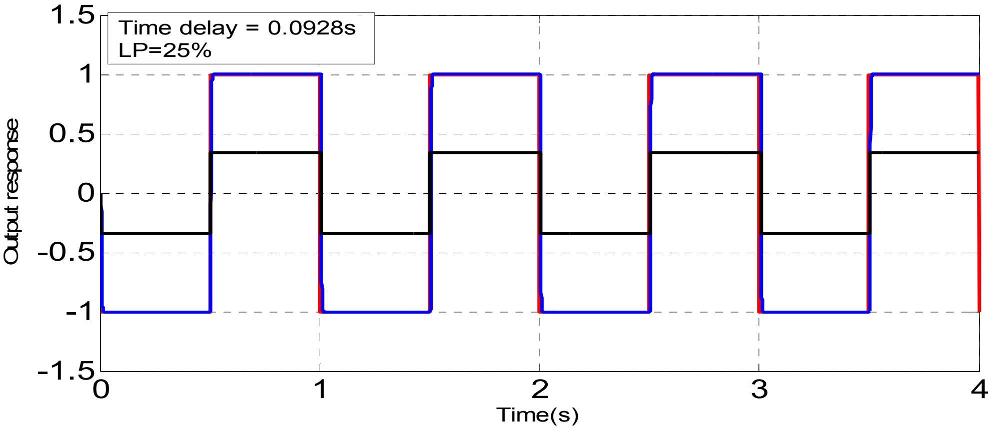


Figure 34.The system response for SMC with time delay= 0.0928s and LP=25%

A special hard test for a case of concurrent network parameter variations is considered. The ZigBee Parameters are as shown in Table3. The robustness of the SMC is guaranteed for maintaining the performance of the DC motor speed at an acceptable level.

Table 3. The special hard case of ZigBee parameters

Parameter	Magnitude
Data rate	40kbps
Sampling period	0.02s
Packet dropout	30%
Variable time delay	0.05s
Ack. timeout	0.00004s
Retry limit	1

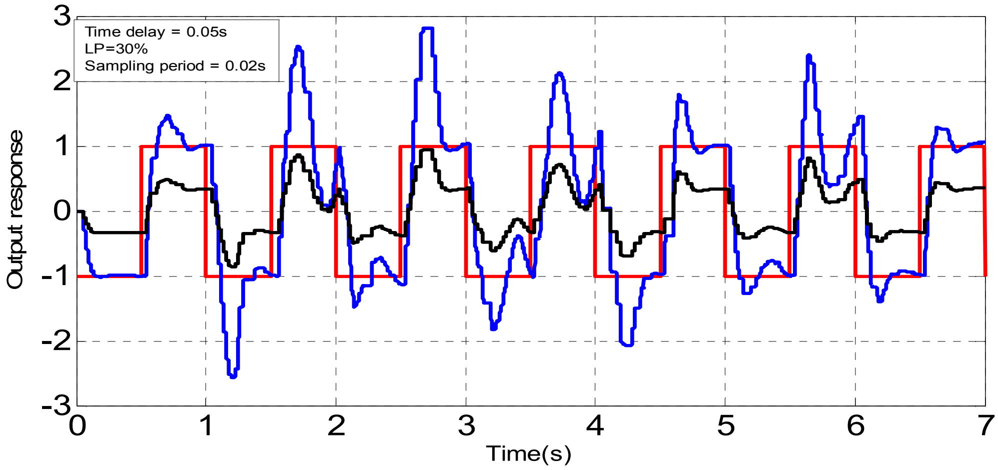


Figure 35.The DC motor speed response with PID for the hard test case.

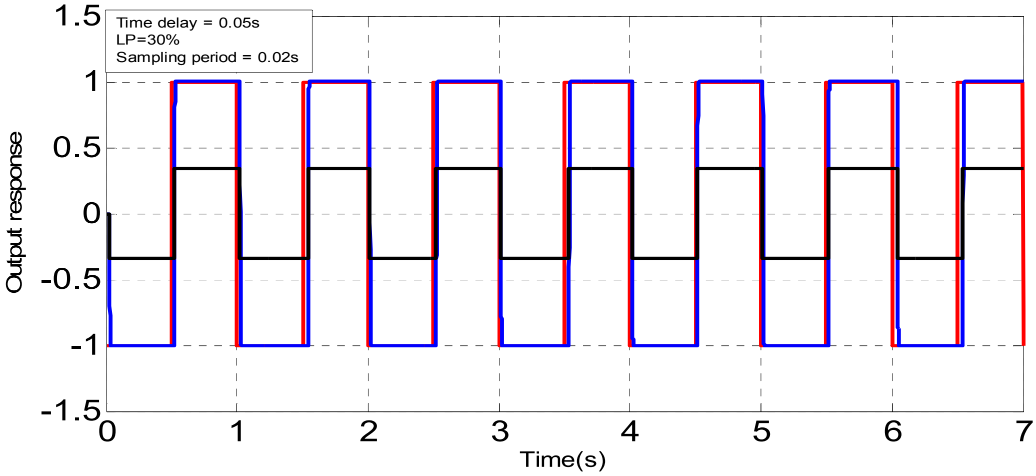


Figure 36.The DC motor speed response with SMC for the hard test case.

10. Conclusion

In order to design WNCS, time delay should be taken into consideration. The assumption of considering the time delay is proportional to the traffic load or (interference nodes) is justified. Variable time delay is an important issue that may lead the system to be unstable. It is taken into account in the proposed designed model. Performance of the system with the PID controller is highly degraded when a time delay of more than 0.006s is inserted. The SMC can react in a more powerful manner to a limit of 0.0928s time delay without affecting the system stability. The SMC is successfully designed and its robustness is proved for the ZigBee network under hard and concurrent parameter variations.

References

M. Zhao, H. Liu, Z. Li & D. Sun. (2011) “Fault tolerant control for networked control systems with packet loss and time delay”, *International Journal of Automation and Computing*, 8(2), 244 -253.

X. Tang and B. Ding, (2012), “ Design of Networked Control Systems with Bounded Arbitrary Time Delays”, *International Journal of Automation and Computing*, 9(2), 182-190.

I. Gochev, G. Nadzinski & M. Stankovski (2016), “Effects of Time Delay and Loss Probability on Performance”, *XIII International SAUM Conference on systems, Automatic Control and Measurement.*

R. K. Munje, M. R. Roda & B. E. Kushare (2010),” Speed Control of DC Motor Using PI and SMC”, *Conference Proceedings,* 945- 950.

O. Ali, M. Monqith (2017), “Evaluation of a PID Wireless Zigbee Networked Control System Using Truetime Toobox”, *International Conference on Communication, Management and Information Technology (ICCMIT17)* held in Warsaw April 3-5,2017 (Accepted) and to be published in conference proceeding. http://iccmit.net/ICCMIT17PAbstract.pdf .

I. Laith and O. Ali (2015), "Gain Scheduling PID Controller for Networked Control System with Random

Delay", International Journal of Enhanced Research in Science Technology & Engineering, 4(2), 184-193.

N. Phyo Aung, Z. Min Naing, M. Mo Myint Wai and H. Myo Tun (2016), "Simulation Of Wireless Networked Control System Using TrueTime and MATLAB", *International Journal of Scientific & Technology Research*, 5(6), 31-3.

ZigBee Home Pag:. http://www.zigbee.org/

S. Hwang & D. Yu (2012), "Remote Monitoring and Controlling System Based on ZigBee Networks", *International Journal of Software Engineering and Its Applications*, 6(3), 35-42.

A. Chopade & Prof. N. Raut (2014), "Implementation of ZIGBEE Protocol for Patient's Health Monitoring- A Review," *International Journal of Engineering Research & Technology (IJERT)*, 3(2), 716-718.

A. R. Raut & L. G. Malik (2011), "ZigBee in Building Industrial Control and Automation" *International Journal of Wireless Communications and Networking*, 3 (2), 149-154.

R. Ashok Gupta & M. Chow (2011), "Networked Control System: Overview and Research TrendsS, 57(10), 150-180.

Htoo Aung Maw, H. Xiao, B. Christianson & J. A. Malcolm (2014), "A Survey of Access Control Models in Wireless Sensor Networks", *Journal of Sensor and Actuator Networks*, 150-180.

P. Cepeda, P. Ponce & A. Molina (2012), "A Novel Speed Control for DC Motors: Sliding Mode Control, Fuzzy Inference System, Neural Networks and Genetic Algorithms", *2012 11th Mexican International Conference on Artificial Intelligence,* 116-121.

A. Prasad K.M, B. M. Krishna & U. Nair (2013), "Modified Chattering Free Sliding Mode Control of DC Motor", 3(3), pp-1419-1423.

Yang Zhao (2013), "Application of Sliding Mode Controller and Linear Active Disturbance Rejection Controller to a PMSM Speed System," in Master of Science in Electrical Engineering, Cleveland State University, 2013.

P. Suryawanshi, P. Shendge & S. Phadke (2016), "A boundary layer sliding mode control design for chatter reduction using uncertainty and disturbance estimator", *International Journal of Dynamics and Control*, 4(4), 456-465 .

O. Ozen, E. Sariyildiz, H. Yu, K. Ogawa, K. Ohnishi & A. Sabanovic (2015), "Practical PID Controller Tuning for Motion Control" *in IEEE International Conference on Mechatronics (ICM)*, 240-245.

Ch. Dey & R. K. Mudi (2006), "A PID controller with dynamic set-point weighting", *Industrial Technology, 2006. ICIT 2006. IEEE International Conference on. IEEE, Mumbai,* 1071-1076.

R. Jacob & S. Murugan (2016), "Implementation of Neural Network Based PID Controller*", International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT),* 2769-2771.

N. Afrasiabi & M. Hairi Yazdi (2013), "Sliding Mode Controller for Dc Motor Speed Control," *Global Journal of Science, Engineering and Technology*, no. 11, 45-50.

Cervin, A., Henriksson, D., & Ohlin, M. (2010), [Online] Available http://www.control.lth.se/truetime (June 2010).

M. Andersson and D. Henriksson (2005), "Simulation of Wireless Networked Control Systems", Proceedings of the 44th IEEE Conference on Decision and Control, and the European Control Conference 2005, Seville, Spain.

C. Snickars (2008), "Design of WirelessHART simulator for studying delay compensation in networked control systems", Master's Degree Project, KTH Electrical Engineering, Stockholm, Sweden.