7th International Conference on Recent Trends in Engineering, Science & Management
Genba Sopanrao Moze College of Engineering, Balewadi-Baner, Pune (ICRTESM-17)
01st-2nd April 2017, www.conferenceworld.in ISBN: 978-93-86171-12-2

VARIOUS CONTROL TECHNIQUES FOR NETWORKED CONTROL SYSTEM FOR DIFFERENT PROCESSES

[1]Prof Priyanka Jain(MCA), [2]Prof Prashant Salve(MCA, NET)

[1,2]Computer Department, MES Garware College Of Commerce,Pune, (India)

ABSTRACT

This paper proposes several controllers for Networked control system to provide robustness against the challenges of NCS, namely varying time-delays. To avoid the system instability due to delays in the NCS, intelligent control techniques such as fuzzy logic control, artificial neural network based control are used except conventional controllers for second and third order process models. A comprehensive comparative study is carried out for the performance of all conventional, intelligent fuzzy and neural network controllers on the basis of certain performance indices.

I. INTRODUCTION

A major trend in modern industrial commercial systems is to integrate computing, communication, and control into different levels [1]. In every practical control loop there is a time-delay generated from sampling, computations of the control signal and the less speed of the measurement sensors. In most cases such a delay is time-varying and stochastic in nature. Moreover the time delays in control applications can degrade the system's performance and even cause system instability. So first and foremost priority is to design the controller for time delay to make the system stable. Intelligent schemes are needed to address such problems. Two such approaches are to utilize fuzzy logic and neural networks.

In this paper the problem of varying time delay and system instability in the networked control system is solved by implementing fuzzy and neural network controllers which are the class of intelligent controllers. The comprehensive comparative study of performance of intelligent controllers has also been done with the conventional controllers on the basis of rise time, peak over shoot, settling time, and steady state error.

II. NETWORKED CONTROL SYSTEM

The feedback control systems [1], where the process sensors, actuators, and controllers are interconnected by a communication networks are called Networked Control Systems (NCSs). It is a type of distributed control systems. There are the advantages of using the network in terms of reliability, reduced wiring, reconfigurability and ease of system diagnosis as all the information is available everywhere in the system. However implementing the communication network induces the stochastic and time varying delay which can degrade the performance of the system and even could make the system unstable. Because of the variability of network-induced time delays, the NCSs may be time-varying systems which make analysis and design more difficult.

Every control loop definitely has a time-delay. Often it is quite small resulting from sampling, computations of the control signal and the limited speed of the industrial sensors. Other delays can be caused by the process itself. These are usually longer. Such delays come from dead times These delays can be constant, but in some cases they are time- or state-dependent or random in nature. This complicates the situation from the control design point of view. A time-delay is also introduced into a control loop when the loop is over a network, because of the transmission delay. The network can be anything from an industrial control network to even Internet. The nature of the delay depends on the network type. The general sketch of such time delay system is showed in Fig. 1.

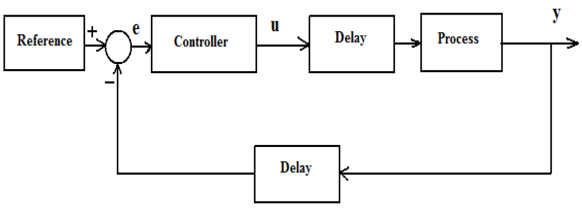

Fig. 1 Example of time delay system

Conventional control engineering approaches are based on mathematical models, typically using differential and difference equations. However, these methods can only be applied to a relatively narrow class of models, including linear models and some specific types of nonlinear models [2]. Application of classical control design falls short in the situation when no mathematical model of the process to be controlled is available, or when it is nonlinear to such a degree that the available techniques cannot be applied. This led to the introduction of the introduction of "intelligent" control.

Intelligent techniques like fuzzy and neural networks employ biologically motivated procedures to develop models of reality and to design controllers for dynamic systems. Fuzzy control is an example of a rule-based representation of human knowledge and deductive processes. Artificial neural networks, on the other hand, realize learning and adaptation capabilities by imitating the functioning of biological neural systems.

III. TIME DELAY COMPOSITION

Since an NCS operates over a network, data transfers between the controller and the other system components will induce network delays in addition to the controller processing delay. Network delays in an NCS can be categorized from the direction of data transfers as the sensor-to-controller delay and the controller-to-actuator delay . The delays are computed as:

$$\tau^{sc} = t^{cs} - t^{se}$$

$$\tau^{ca} = t^{rs} - t^{ce}$$

where t^{se} is the time instant that the remote system encapsulates the measurement to a frame or a packet to be sent, t^{cs} is the time instant that the controller starts processing the measurement in the delivered frame or packet, t^{ce} is the time instant that the main controller encapsulates the control signal to a packet to be sent, and t^{rs} is the time instant that the remote system starts processing the control signal. Moreover, both network delays can be longer or shorter than the sampling time T: The controller processing delay τ_c and both network delays can be lumped together as the control delay τ for ease of analysis. Although the controller processing delay τ_c

always exists, this delay is usually small compared to the network delays, and could be neglected. The delays τ^{sc} and τ^{ca} are composed of at least the following parts [19].

- ***Waiting time delay.*** The waiting time delay is the delay, of which a source (the main controller or sensors) has to wait for queuing and network availability before actually sending a packet out.
- ***Frame time delay.*** The frame time delay is the delay during the moment that the source is placing a frame or a packet on the network.
- ***Propagation delay.*** The propagation delay is the delay for a frame or a packet traveling through a physical media. The propagation delay depends on the speed of signal transmission and the distance between the source and destination.

These three delay parts are fundamental delays that occur on a local area network. When the control or sensory data travel across networks, there can be additional delay such as the queuing delay at a switch. The delays τ^{sc} and τ^{ca} also depend on other factors such as maximal bandwidth and frame or packet sizes. In the analysis we made the following assumption for ease of calculation:

- The delays τ^{sc} and τ^{ca} are equal
- The sensor node, controller node and actuator node are time synchronous
- No data packet dropout occurs

IV. CONSEQUENCES OF DELAY IN THE LOOP

A. Performance degradation

Delays in a control loop are widely known to degrade system performances of a control system, so are the network delays in an NCS. The goal of NCS design is to guarantee the performance and stability of applied control systems, i.e. meet the control system specifications. These specifications include overshoot, settling time, rise time and steady state error. The limited network bandwidth introduces unavoidable time delays in a control system. These time delays could potentially degrade a system's performance and possibly cause system instability. The closed-loop proportional- integral (PI) controller is implemented in NCS for varying time-delays. The results will be discussed in later section which shows that as the delays increases, the degradation in performance specification increases.

B. Destabilization

Delays in-the-loop including network delays and data packet dropout in an NCS can destabilize the system by reducing the system stability margin. Networks can be viewed as unreliable data transmission paths, where packet collision and network node failure occasionally occur. Thus it is valuable to analyze the rate at which the data should be transmitted to achieve the desired performance (stability). There have been various techniques for analyzing the stability of NCS. For example, an NCS on a periodic delay network [20] is stable if all eigen values of a specific formulation are contained in a unit circle. Another formulation (Hong, 1995) uses a general frequency domain analysis for checking stability, but the stability criterion is limited to a single-dimensional system. Stability analysis for an NCS with random network delays is more challenging, since more advanced algorithms are usually required. For example [6], stabilities of NCS were analyzed based on stochastic stability analysis, but with different formulations. The underlying protocol of the MAC sub layer in the network is the key to controlling the length of packets to be transmitted. For example, in Ethernet, the data field of the protocol is 1500 bytes i.e. the maximum data length transmitted in one packet which can avoid the unwanted packet dropout.

V. IMPLEMENTATION OF FUZZY PID & FAMILY

The mathematical modeling of fuzzy concepts was first presented by Professor Lotfi Zadeh in 1965 to describe, mathematically, classes of objects that do not have precisely defined criteria of membership.

VI. RESULTS AND DISCUSSION

The results of the tuning and simulation of the conventional P, PI, and PID controllers and intelligent controllers including fuzzy PI, PD, and PI+PD controllers and Neural network controllers are analyzed and compared for second and third order process of networked control system. The second order transfer function of process [21] is

$$G(s) = \frac{1770}{s^2 + 60s}$$

The third order transfer function of process is:

$$G(s) = \frac{1}{s^3 + 3s^2 + 3s}$$

A. Response of uncontrolled second order process

The Fig. 2 shows the response of the networked control system without any controller. The amplitude of response explains that how the network delays can degrade the system's performance and cause the instability.

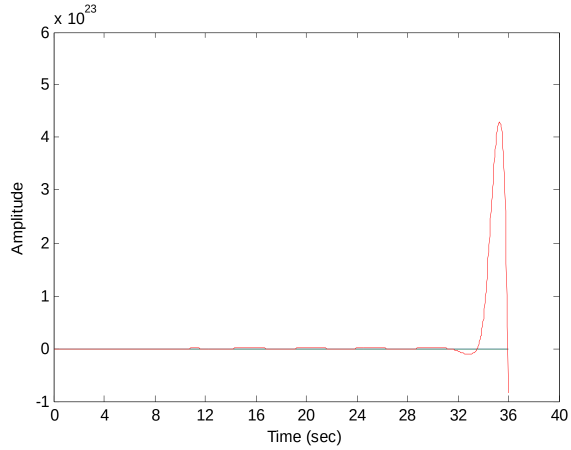

Fig 2: Step response of uncontrolled process

B. Response of conventional controllers for second order process

The step response of P, PI, and PID controllers is shown in Fig. 3.

It can be seen that performance of PI controller is better than any other controller. It has smallest overshoot and smallest settling time among all controllers. P and PID controllers have lesser rise time but large overshoot and large settling time.

Table 1: Performance Indices of Conventional Controllers

Conv. Controller	Performance Index			
	Rise Time Tr (Sec.)	Max. Overshoot Mp (%)	Settling Time Ts (Sec.) (2% Band)	Steady State Error (after 400 sec)
P	4.5	15.3	13.6	≈ 0
PI	5.1	10.75	11.2	0.3%
PID	3.7	28.3	18.5	0.2%

Also the closed loop response without any delay is shown which is far better than delayed response of any conventional controller. The comparison between controllers has been shown in Table 1.

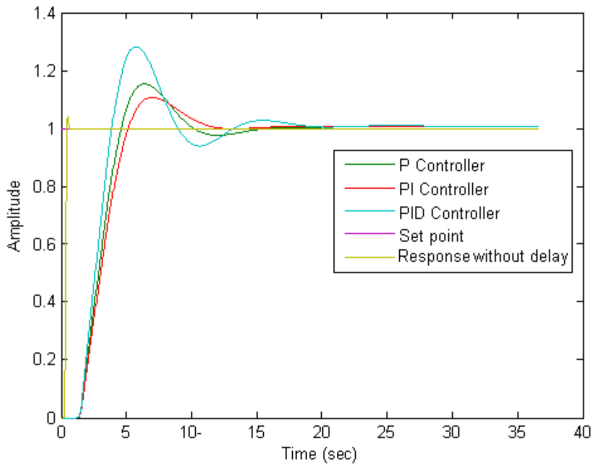

Fig. 3: Step response of conventional controllers

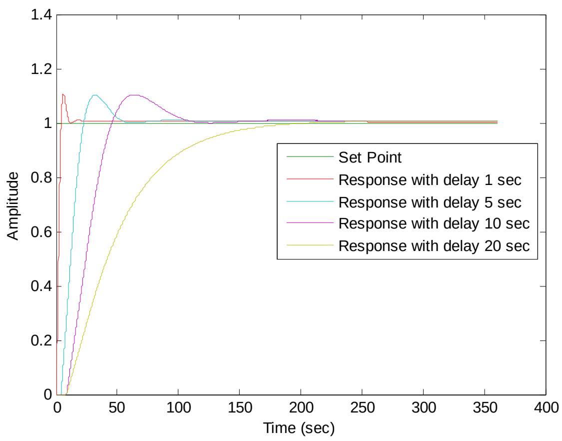

Fig. 4: Step response of PI controller with various delays

Response of PI controller for varying-time delays 1sec, 5sec, 10sec, and 20sec using the lookup table is shown below in Fig. 4. It shows that as the time delay increases, system performance gets worse.

C. Response of Intelligent Fuzzy controllers for second order process

Fig. 5 shows the response of fuzzy PI controller which has increasing oscillations and highly unstable response. From Fig. 6 it can be concluded that fuzzy PD and fuzzy PI+PD controllers are stable and fuzzy PD has slightly better response than other. Response shows that the peak overshoot in fuzzy controllers has been drastically reduced than conventional controllers.

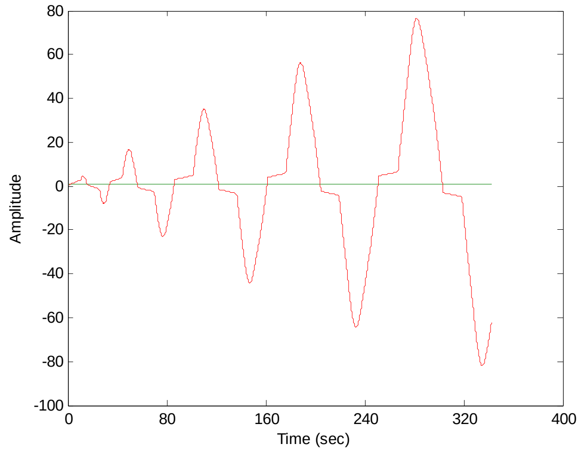

Fig. 5: Step response of Fuzzy PI controller

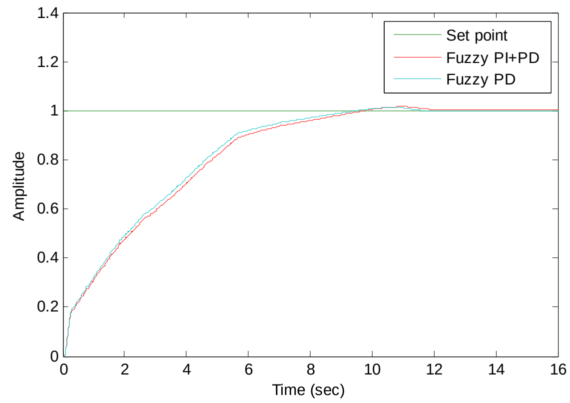

Fig. 6: Step response of Fuzzy PD and PI+PD controller

The comparison of performance of various fuzzy controllers is given in the Table 2. It shows that the fuzzy PI controller has increasing oscillations and is unstable. Fuzzy PD and PI+PD controllers have almost same performance, but fuzzy PD controller is slightly better in terms of settling time and peak overshoot.

Table 2: Performance Indices of Fuzzy Controllers

Fuzzy Controller	Performance Index			
	Rise Time Tr (Sec.)	Max. Overshoot Mp (%)	Settling Time Ts (Sec.)(2% Band)	Steady State Error (after 400 sec)
FPI	Unstable			
FPD	7.3	1.3	9.1	≈ 0
FPI+FPD	7.5	1.7	9.4	≈ 0

D. Response of Intelligent Neural Network Controllers (NNC) for second order process

Fig. 7 shows the step performance of intelligent neural network controller. The response shows smaller settling time than fuzzy PD controller and less than 2% of overshoot.

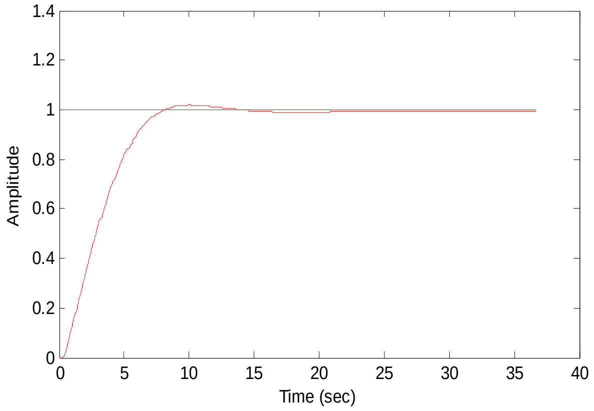

Fig. 7: Response of neural network controller

Fig. 8 shows training of neural controller. Performance goal of minimizing the error up to 0.00001 has been achieved in 2130 epochs.

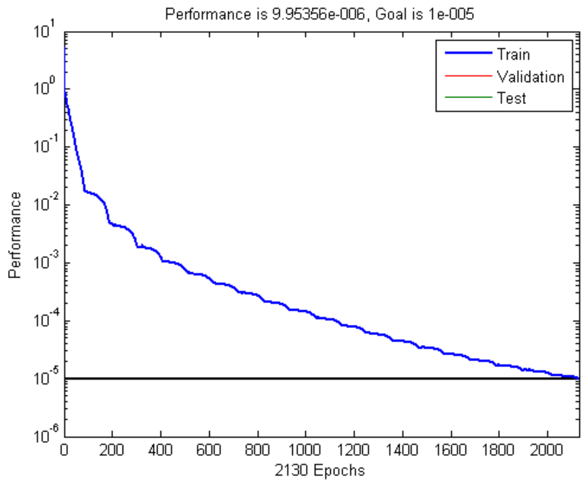

Fig. 8: Training Process in Neural Network Controller

The correlation coefficient (R-value) between the network output and the target is found to be 0.99997 whereas R=1 for perfect correlation.

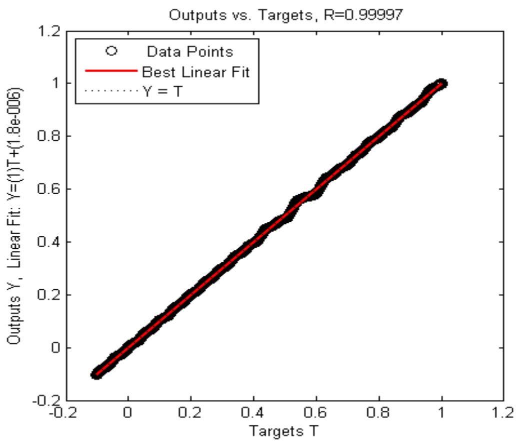

Fig. 9: Linear regression graph between network output and targets

Fig. 9 shows correlation coefficient R in linear regression graph i.e. the correlation between output and target is almost perfect. Fig. 10 shows assessment of network output and desired (target) output.

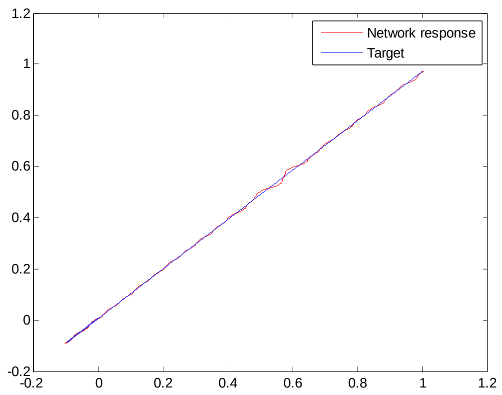

Fig. 10: Assessment of network output and targets for NNC

E. Comparison of Various Controllers for second order process

In the Fig. 11 performance of the best controllers in their respective categories has been compared. The performance of various controllers has been compared in the Table 3. It can be seen that both intelligent controllers, fuzzy and neural network (NNC) have performed better than conventional controllers for networked control systems.

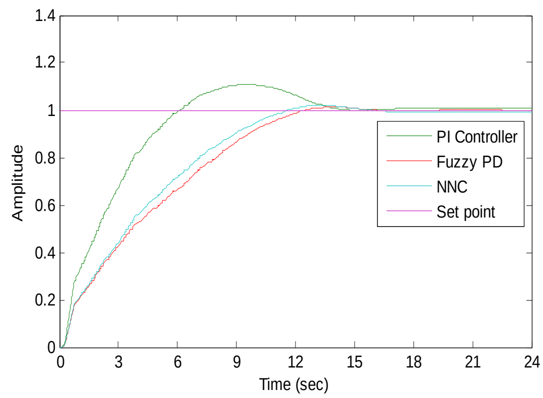

Fig. 11: Comparison of different controllers

However, the NNC has slightly better performance than Fuzzy PD controller in terms of rise time and settling time. PI controller has large overshoot of 10.75% while Fuzzy PD and NNC have less than 2% overshoot. Also settling time for fuzzy and neural controllers is 2-3 sec less than the conventional PI controller.

Table 3: Performance Indices of Various Controllers

Controller Type	Performance Index			
	Rise Time Tr (Sec.)	Max. Overshoot Mp (%)	Settling Time Ts (Sec.)(2% Band)	Steady State Error (after 400 sec)
Conv. PI	5.1	10.75	11.2	0.3
FPD	7.3	1.3	9.1	≈ 0
NNC	6.8	1.95	8.28	≈ 0

F. Padé Approximation of the time delay process for second order process

The Figs 12 and 13 show that how accurately the padé first and second order approximate the actual output and eliminate the time delay.

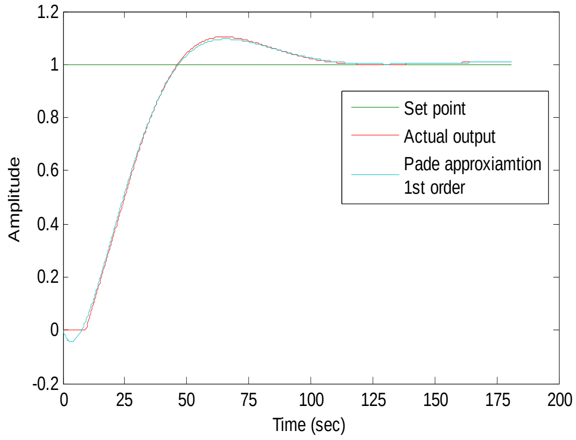

Fig. 12: Padé first order approximation

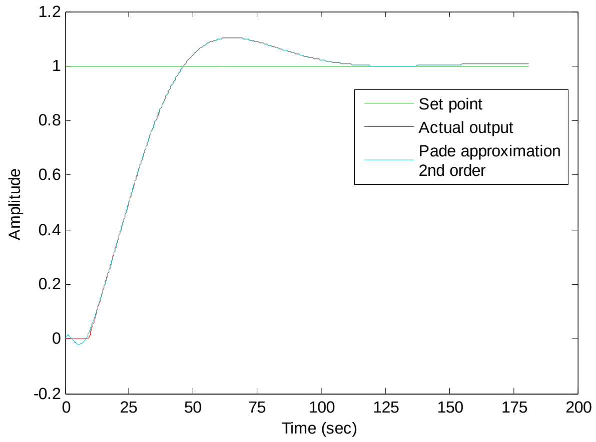

Fig. 13: Padé second order approximation

G. Response of the Conventional Controllers for third order process

Fig. 14 and Table 4 show comparison of conventional controllers with 10sec delay.

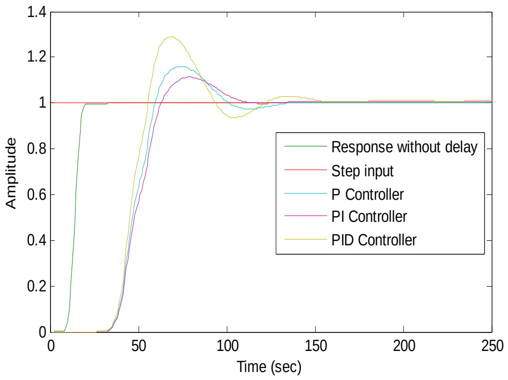

Fig. 14: Step response of conventional controllers

Table 4: Performance Indices of Conventional Controllers

Conv. Controller	Performance Index			
	Rise Time Tr (Sec.)	Max. Overshoot Mp (%)	Settling Time Ts (Sec.)(2% Band)	Steady State Error (after 400 sec)
P	46.6	16.1	144	≈ 0
PI	52.6	11.35	116.1	1%
PID	38.6	29	192.7	1%

As the tuning of third order process is done for 10 sec delay. It can be seen that performance of PI controller is better than any other controller. It has smallest overshoot of 11.35% and smallest settling time among all controllers. P and PID controllers have lesser rise time but large overshoot and large settling time. Also the closed loop response without any delay is shown which is far better than delayed response of any conventional controller. The comparison between controllers has been shown in table 4.

H. Response of the Fuzzy Controllers for third order process

Fig. 15 and 16 show the fuzzy controllers' response with 10 sec delay.

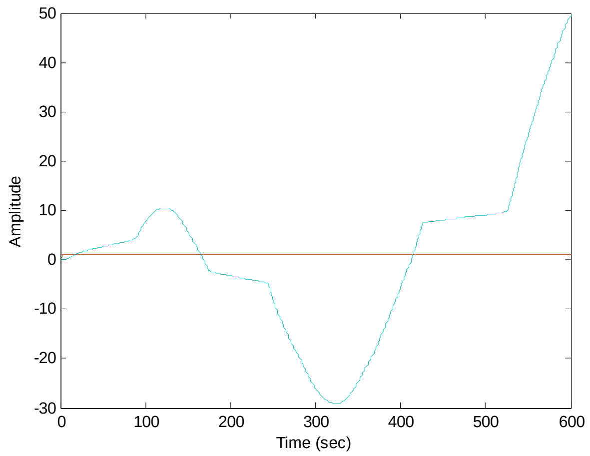

Fig. 15: Unstable response of fuzzy PI controller

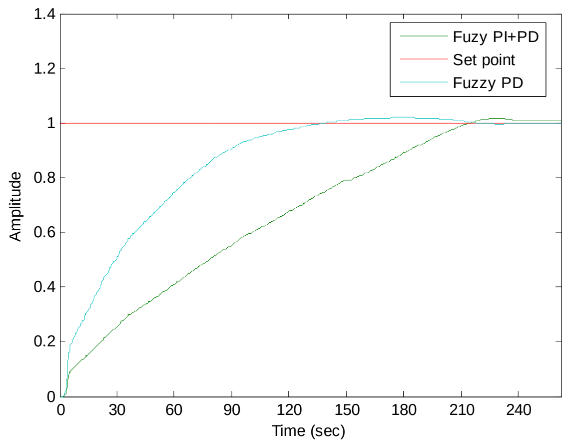

Fig. 16: Comparison the response of fuzzy PD and PI+PD controllers

Table 5: Performance Indices of Fuzzy Controllers

Fuzzy Controller	Performance Index			
	Rise Time Tr (Sec.)	Max. Overshoot Mp (%)	Settling Time Ts (Sec.)(2% Band)	Steady State Error (after 400 sec)
FPI	Unstable			
FPD	73.6	1.96	89.6	≈ 0
FPI+FPD	120.7	1.82	140.6	1%

Response of fuzzy PI controller is unstable as in second order process. Fuzzy PD controller has best performance among them. Table 5 shows the comparison among the fuzzy controllers. Fuzzy PI controller has increasing oscillations and is unstable. As in the second order process fuzzy PD and PI+PD controllers had almost same performance, but for third order process fuzzy PD controller is far better than fuzzy PI+PD controller. Table shows that there is 50 sec difference in the rise time and settling times. For higher order processes and higher delays the gap in the performance of conventional and intelligent controllers is increased.

I. Response of the Neural Controllers for third order process

Fig. 17 shows the response of NNC for third order process.

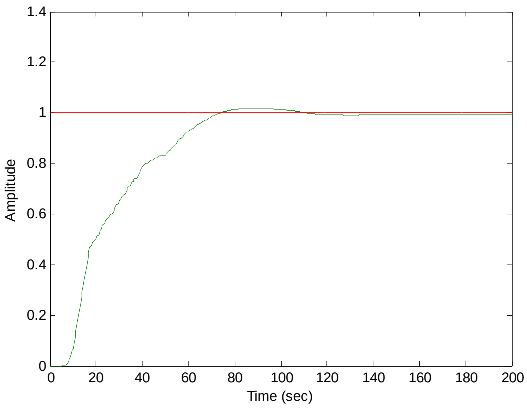

Fig. 17: Response of neural network controllers

The correlation coefficient between network output and target has been found R=0.99997. Performance goal of minimizing the error has been achieved in 18061 epochs.

J. Comparison of Various Controllers for third order process

The performance of various controllers for third order process and 10sec delay has been compared in the Table 6 and Fig. 18

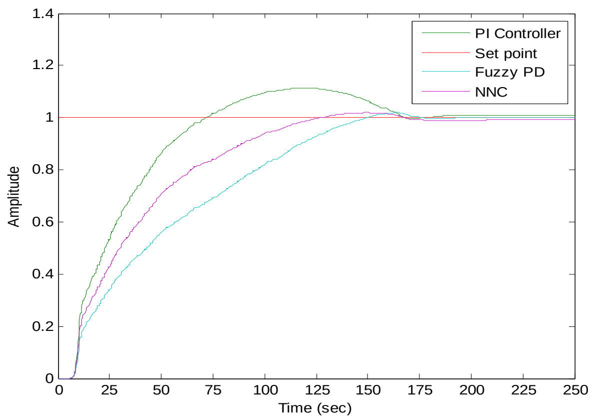

Fig. 18: Comparison of various controllers

It can be seen that both intelligent controllers, fuzzy and neural network have performed better than conventional controllers for networked control systems with varying time delays. However, the NNC has slightly better performance than Fuzzy PD controller in terms of rise time and settling time.

Table 6: Performance Indices of Various Controllers

Controller Type	Performance Index			
	Rise Time Tr (Sec.)	Max. Overshoot Mp (%)	Settling Time Ts (Sec.)(2% Band)	Steady State Error (after 400 sec)
Conv. PI	52.6	11.35	116.1	1%
FPD	73.6	1.96	89.6	≈ 0
NNC	60	1.88	73	1%

VI. CONCLUSIONS

Finally it can be concluded that intelligent control techniques are well suited to time delayed NCS. They can deliver the better performance for higher order systems and high delays where the conventional techniques have their limitations and cannot give better results.

VII. ACKNOWLEDGEMENTS

This work has been done in Industrial Electronics lab, Netaji Subhas Institute of Technology, N. Delhi for the fulfilment of M.Tech. Degree.

REFERENCES

[1] T.C. Yang, “Networked control system: a brief survey”, IEE Proc.-Control Theory Appl., Vol. 153, no. 4, July 2006, pp. 403-412.

[2] Robert Babuska, “Fuzzy and Neural Control”, Delft University of Technology Delft, Netherlands, October 2001.

[3] T. Katayama, T. McKelvey, A. Sano, C. Cassandras, M. Camp, “Trends in Systems and Signals”, In proc. 16th IFAC World Congress, Prague, Czech Republic, 2005, pp 5-17.

[4] M. Malek-Zavarei and M. Zamshidi, "Time-Delay Systems: Analysis, Optimization and Applications", North-Holland, vol-9, 1987, pp. 500.

[5] H. Gorecki, S. Fuksa, P. Grabowski, and A. korytowski, "Analysis and Synthesis of time delay systems", John wiley & Sons, 1989.

[6] J. Nilsson, "Real-Time Control Systems with Delays", Ph.D. thesis, Lund Institute of Technology, Department of Automatic Control, February 1998.

[7] W. Zhang, M. S. Branicky, S. M. Phillips, "Stability of Networked Control Systems", IEEE Control Systems Magazine, Vol. 21, Issue 1, pp. 84-99, February 2001.

[8] B. Lincoln, "Dynamic programming and Time-Varying Delay Systems", Ph.D. thesis, Department of Automatic Control. Lund institute of Tecnology, Sweden, 2003.

[9] K. J. Åström, and T. Hägglund, "PID Controllers: Theory, Design, and Tuning", 2nd edition, Instrument Society of America, 1995.

[10] S. Chai, "Design and Implementation of Networked Predictive Control Systems", In proc. 16th IFAC World Congress, Prague, Czech Republic, 2005, pp. 336-341.

[11] M. Sugeno, (Ed.), "Industrial Applications of Fuzzy Control", Elsevier Science Publishers B.V., North-Holland, Amsterdam, pp. 231–239, 1985.

[12] J. Yen, R. Langari, and L. A. Zadeh, (Eds), "Industrial Applications of Fuzzy Logic and Intelligent Systems", IEEE Press, Washington, 1995.

[13] L. A. Zadeh, "Fuzzy sets, Information and Control", proc. IEE, vol. 8, pp. 338-353, 1965.

[14] E. H. Mamdani, "Applications of fuzzy algorithms for control of simple dynamic plant", Proceedings IEE, 121, pp. 1585–1588, 1974.

[15] W. McCulloch and W. Pitts, "A logical calculus of the ideas immanent in nervous activity", Bulletin of Mathematical Biophysics, Vol. 5, pp. 115-133, 1943.

[16] F. Rosenblatt, "The perceptron: A probabilistic model for information storage and organization in the brain", Psychological review, Vol. 65, pp. 386-408, 1958.

[17] K. J. Astrom and T. H. Hagglund, "New tuning methods for PID controllers", Proceedings of the 3rd European Control Conference, 1995.

[18] J. C. Bolot, "Characterizing End-to-End Packet Delay and Loss in the Internet", Journal of High-Speed Networks. Sigcomm. pp. 289–298, 1993.

[19] F. L. Lian, J. R. Moyne and D. M. Tilbury, "Performance evaluation of control networks: Ethernet, Control-Net, and Device-Net", IEEE Control Systems Magazine, 21(1), pp. 66–83, 2001.

[20] Y. Halevi and A. Ray, "Integrated communication and control systems: Part I—analysis", Journal of Dynamic Systems, Measurement and Control, 110, pp. 367–373, 1988.

[21] F. Du and Q. Q. Qian, "Fuzzy Immune Self-Regulating PID Control Based on Modified Smith Predictor for Networked Control Systems", proceedings of IEEE conference on networking, sensing and control, pp. 424-428, ICNSC 2008, Hainan, China, 6-8 april, 2008

[22] G. Stephanopoulos, "Chemical Process control an introduction to theory and practice," Pearson Education, Inc 1984.

[23] K. J. Astrom and T. Hagglund, "Automatic Tuning of PID Controllers", Instrument Society of America, Research Triangle Park, NC, 1988.

[24] G. S. Patel, "Study of Self Organizing Fuzzy Controller for different Process models", M.Tech. thesis, NSIT, Delhi, October, 2008.

[25] J. Wilkie, M. Johnson, and R. Katebi, "Control engineering an introductory course", Palgrave publication, 2002.