ROBUSTNESS OF FUZZY OPTIMAL CONTROL FOR VARIABLE COMMUNICATION DELAYS IN NETWORKED CONTROL SYSTEMS

Adrian-Bogdan HANCHEVICI[1], Ioan DUMITRACHE[2]

In this article we propose one networked control strategy for linear SISO systems affected by variant communication delays. This control strategy is adjusting optimal controller's control by using two Fuzzy Logic Controllers (FLCs). The FLCs are used to compensate the bad influences over the closed loop system performances of the communication delays between the controller node and the actuation node and those between the sensor node and the controller node. Simulation and implementation results are presented. The results show performance improvement when is used our control strategy.

Keywords: networked control systems, fuzzy logic, optimal control, Ethernet TCP/IP

1. Introduction

Networked Control Systems (NCS) are feedback control systems, where the information from the sensors about the controlled parameters and the controls for the actuators are exchanged through a communication network. Fig.1 presents the general architecture of this type of systems, where S1 to Sn are used to describe the sensor nodes, A1 to An the actuator nodes, and finally C1 to Cn the controller nodes [1].

The main problems of these networked control systems are the variant communication delays and packet losses.

[1] Teaching Assistant, Ph.D. Student, Faculty of Automatic Control and Computers, University POLITEHNICA of Bucharest, Romania, e-mail: adrian.hanchevici@upb.ro
[2] Prof., Faculty of Automatic Control and Computers, University POLITEHNICA of Bucharest, Romania, e-mail: idumitrache@ics.pub.ro

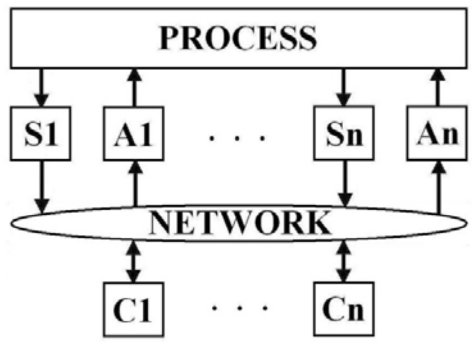

Fig. 1. The architecture of a Networked Control System [1]

The challenges and opportunities in Wireless Sensor/Actuator Networks (WSANs) are presented in [1] and [2]. A Wireless Sensor/Actuator Network is a highly used type of Networked Control System.

In [3] and [4] are presented methods to reduce the traffic through the network in order to reduce the possibility of high communication delays. It is used the event-based control, which means that the control signals are constant as long as the output signals have an accepted variation.

In [5] and [6] are presented two intelligent control strategies which make use of genetic algorithms. These control strategies are applied for linear SISO systems affected by variant communication delays. In both cases is performed the estimation of the communication delay and, by using genetic algorithms, are found the proper parameters for the PID controller. The communication delays estimation and the PID controller parameters tuning are performed in the same sampling time.

Fuzzy logic is an intelligent control technique used for control of all type of systems (linear, non-linear, SISO, MIMO) [7], [8], [9]. This type of controller has the advantage of being able to handle the issues provided by the nonlinearities which are present in a system. In [10] is propose a networked control strategy for linear SISO systems affected by variant communication delays, where the control provided by a PID controller is adjusted, considering the communication delay, using a Fuzzy Logic Controller.

The paper is organized as follows. Section II contains the presentation of the proposed control strategy. In Section III is described the case study, starting with the presentation of the process, and continue with the simulation and experimental results. Section IV contains the conclusions and the future research directions.

2. Proposed control strategy

In NCSs main problems that appear and must be considered are the uncertainties of variable delays and sometimes the losses of information. To design the control strategy in these conditions imposes some considerations on the robustness of control systems. The control strategy presented in this paper is proposed for linear SISO systems which have variant communication delays due to the communication network. Fig. 2 presents the control strategy structure.

There are used two fuzzy logic controllers in order to adjust the control provided by the optimal controller [11]. The first FLC (CA-FUZZY CONTROLLER) is used to adjust the control according to $\hat{\tau}_{CA}$ which is the estimated communication delay between the control node and actuation node, and $\dot{\hat{\tau}}_{CA}$ which is the estimated communication change in delay. The second FLC (SC-FUZZY CONTROLLER) is used to adjust the control according to $\hat{\tau}_{SC}$ which is the estimated communication delay between the sensor node and control node, and $\dot{\hat{\tau}}_{SC}$ which is the estimated communication change in delay.

The DELAYS ESTIMATOR module performs the estimation of the delays and changes in delays. The adjustment of the control computed by the optimal controller (u^0_k) is performed according to the fuzzy logic (Δu_k).

Also, in Fig. 2, y_k is the controlled variable, r_k represents the setpoint, u_k is the control signal, F is the control matrix and x represents the state of the process.

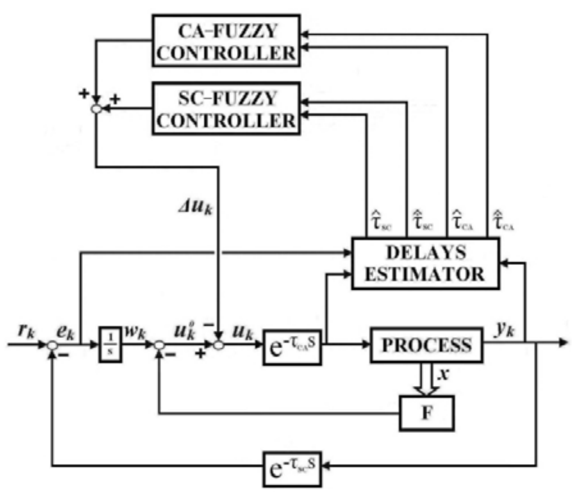

Fig. 2 - The proposed control strategy

In order to perform the estimation, the DELAYS ESTIMATION module uses ping requests. The ping request is a powerfull tool used by computer network administrator to collect data about the state of the computer network in order to ensure that the network works fine, or to find the connexion problems between computers.

In our case, the control node sends, in every sampling time, a ping request to the sensor node and another ping request to the actuation node. The answers to these requests will contain, among other information, the communication delays between these nodes. Also, we have analyzed the delay introduced by control computation and after comparing it with the communication delays we have decided that it can be neglected.

3. Case study

3.1. Experimental Setup and Crane Model

The non-linear SISO system taken into study in this paper is the *Oy* axis of a 3-dimensional (3D) Crane. The 3D Crane setup consists of a payload (lifted and lowered in the *Oz* direction by a motor mounted on a cart) hanging on a pendulum-like lift-line. The cart is mounted on a rail, giving the system capability of horizontal motion in the *Ox* and *Oy* directions [12].

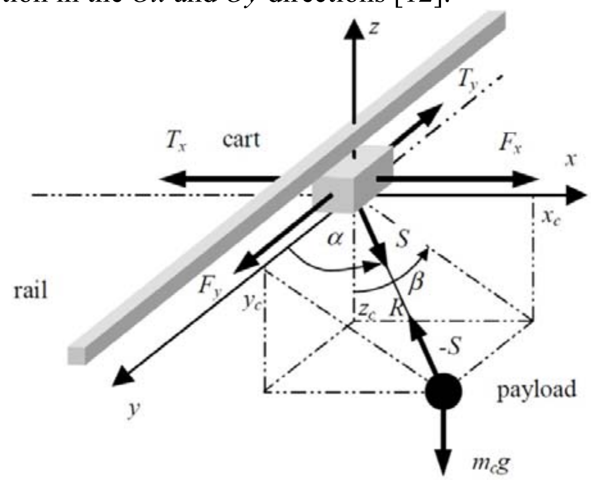

Fig. 3. The crane system [12]

The 3D Crane is a MIMO system, having three input variables (control signals for the three DC motors) and five output variables (encoder signals). The non-linear characteristic is given by the pendulum-like motion of the payload in space, with a variable line length. Figure 3 presents the crane system, where: x_w (not represented) is the distance of the rail with the cart from the center of the construction frame; y_w (not represented) is the distance of the cart from the center of the rail; R is the length of the lift-line; α represents the angle between the *Oy* axis and the lift-line; β represents the angle between the negative direction on the

Oz axis and the projection of the lift-line onto the *Oxz* plane; m_c is the mass of the payload; m_w is the mass of the cart; m_s is the mass of the moving rail; x_c, y_c, z_c are the coordinates of the payload; $S = F_R - T_R$ represents the reaction force in the lift-line acting on the cart; F_x is the force driving the rail with cart; F_y is the force driving the cart along the rail; F_R is the force controlling the length of the lift-line; T_x, T_y, T_R are friction forces.

If we define the state variables and the relations of them we get a mathematical model as:

$$\begin{cases}\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\\ \dot{x}_5\\ \dot{x}_6\end{bmatrix}=\begin{bmatrix}0 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & s_5^2\dot{\beta}^2+\dot{\alpha}^2+Z & 0\end{bmatrix}\cdot\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\\ x_5\\ x_6\end{bmatrix}+\\ +\begin{bmatrix}0 & 0 & 0\\ 0 & 1 & \mu_1 s_5 s_7\\ 0 & 0 & 0\\ 1 & 0 & \mu_1 c_5\\ 0 & 0 & 0\\ -c_5 & -s_5 c_7 & -(1+\mu_1 c_5^2+\mu_1 s_5^2 s_7^2)\end{bmatrix}\cdot\begin{bmatrix}N_1\\ N_2\\ N_3\end{bmatrix}\\ \begin{bmatrix}x_c\\ y_c\\ z_c\end{bmatrix}=\begin{bmatrix}1 & 0 & 0 & 0 & s_5 s_7 & 0\\ 0 & 0 & 1 & 0 & c_5 & 0\\ 0 & 0 & 0 & 0 & 0 & -s_5 c_7\end{bmatrix}\cdot\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\\ x_5\\ x_6\end{bmatrix}\end{cases}$$

where the following notations have been used: $x_1 = x_w$; $x_2 = \dot{x}_1$; $x_3 = y_w$; $x_4 = \dot{x}_3$; $x_5 = R$; $x_6 = \dot{x}_5$; $\mu_1 = m_c / m_w$; $\mu_2 = m_c /(m_w + m_s)$; $N_1 = (F_y - T_y)/ m_w$; $N_2 = (F_x - T_x)/(m_w + m_c)$; $N_3 = (F_R - T_R)/ m_c$; $s_5 = \sin\alpha$; $c_5 = \cos\alpha$; $s_7 = \sin\beta$; $c_7 = \cos\beta$; g is the gravitational acceleration; $Z = (g s_5 c_7)/ R$ is a nonlinear function.

More details of this model can be found in [12].

3.2. Simulation and Experimental Study

The nonlinear SISO system studied in this paper is an axis from a 3-dimensional (3D) crane (laboratory system). We have considered the linear approximation of the process and we obtained the linear state representation (the variant communication delays τ_{SC} and τ_{CA} are included in the process model):

$$\begin{cases} \dot{x}(t) = A \cdot x(t) + B \cdot u(t - \tau_{CA}) \\ y(t - \tau_{SC}) = C \cdot x(t). \end{cases} \quad (1)$$

We have designed the optimal controller (the control matrix F) for the case when there are no communication delays. The next step was to consider different values for the communication delays. In Fig. 4 is presented the simulation analysis considering the same optimal controller and different values for the communication delays. The control (left) is getting higher values as the delays are higher and the closed loop system becomes unstable (right).

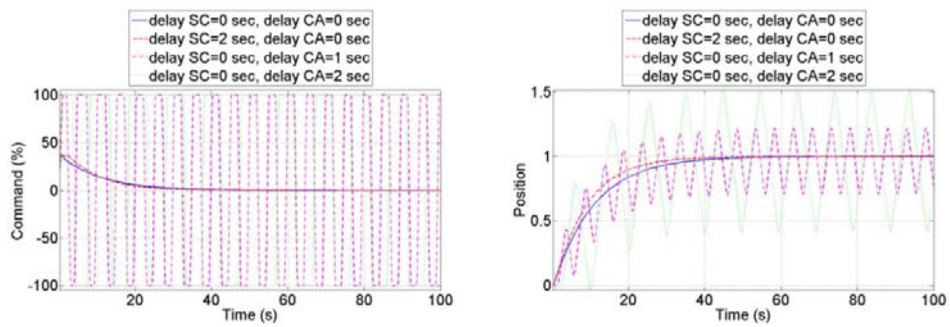

Fig. 4 – The simulation analysis of the control (left) and the output (right) of the system using the same optimal controller and different communication delays

We have used our proposed control strategy to keep the stability and the performances of the closed loop system. The rule bases of the fuzzy logic controllers used in simulation are presented in Fig. 5 and Fig. 6.

Command		Delay								
	u	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8
Change in delay	POZ4	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ3	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8
	POZ2	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8
	POZ1	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8
	ZERO	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8
	NEG1	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7
	NEG2	POZ0	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6
	NEG3	POZ0	POZ0	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5
	NEG4	POZ0	POZ0	POZ0	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4

Fig. 5 - The rule base of the SC-FUZZY CONTROLLER used in simulation study

Command u		Delay								
		POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8
Change in delay	POZ4	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ3	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ2	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ1	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8
	ZERO	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8
	NEG1	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8
	NEG2	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8
	NEG3	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7
	NEG4	POZ0	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6

Fig. 6 - The rule base of the CA-FUZZY CONTROLLER used in simulation study

For all fuzzy logic controllers used in simulation and experimental study the membership functions are *POZ0-POZ8* (positive), *NEG4, NEG3, NEG2, NEG1* (negative) and *ZERO* (zero) membership functions.

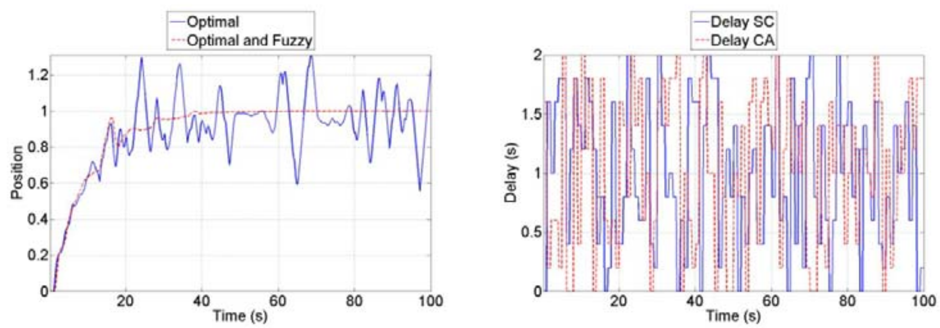

Fig. 7 - Simulated responses for both situations with variant delays (left) and the distributions of the delays (right - case S1)

In Fig. 7 are presented the simulated responses of the closed loop system when is used and not used the fuzzy logic adjustment. The responses from Fig. 7 (left) were obtained for variant delays (S1). The distributions of the variant delays are presented in Fig. 7 (right).

The process computer used for experimental study has the following hardware configuration: Intel(R) Core(TM)2 Duo CPU E7200 @ 2.53GHz 2.53GHz, 2.00 GB of RAM. As operating system, it was used Microsoft Windows XP Professional Version 2002 Service Pack 3. For our study we have also used the Matlab developing platform. We have considered a sampling time of 0.2 seconds and the highest bound for the delays is 2 seconds.

In TABLE I and TABLE II are presented the following cases:

- Optimal (fixed delay) represents the cases when were considered fixed communication delays.

- Optimal (variant delay) represents the cases when the communication delays have variations between 0 and 2 seconds.
- Optimal-Fuzzy (variant delay) represents the cases when is used the proposed control strategy and the communication delays have variations between 0 and 2 seconds.

Table 1

Simulation study analysis

		Settling Time (s)	**Overshoot (%)**
		Oy	*Oy*
Optima (fixed delays)	S1 (τ_{SC}=0.0 s, τ_{CA}=0.0 s)	32.6	0.0
	S2 (τ_{SC}=0.0 s, τ_{CA}=1.0 s)	Unstable	
	S3 (τ_{SC}=0.0 s, τ_{CA}=2.0 s)	Unstable	
	S4 (τ_{SC}=2.0 s, τ_{CA}=0.0 s)	26.2	0.0
	S5 (τ_{SC}=1.0 s, τ_{CA}=1.0 s)	Unstable	
	S6 (τ_{SC}=1.0 s, τ_{CA}=2.0 s)	Unstable	
Optimal (variant delays)	S1 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	S2 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	S3 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	S4 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	S5 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	S6 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
Optimal-Fuzzy (variant delays)	S1 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	28.0	0.0
	S2 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	28.8	0.0
	S3 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	26.8	0.3
	S4 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	30.2	0.0
	S5 (τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	25.6	1.8
	S6 (τ_{SCmax}=2.0 s, τ_{CAdmax}=2.0 s)	29.6	1.9

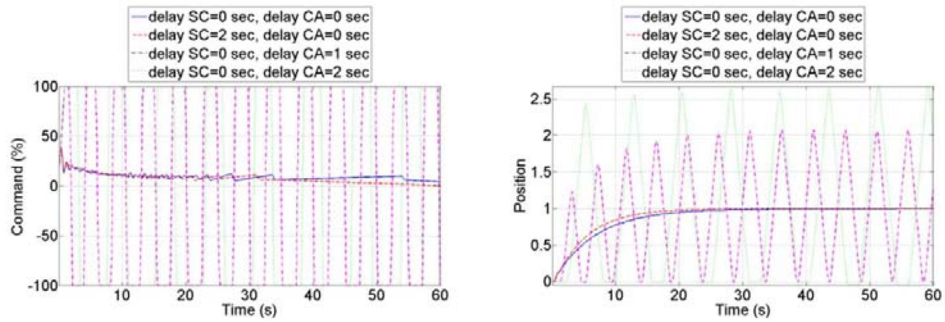

Fig. 8 - System's control (left) and output (right) experimental analysis using the same optimal controller and different communication delays

Command		Delay								
u		POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8
Change in delay	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8
	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8
	ZERO	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8
	NEG1	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8
	NEG2	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7
	NEG3	POZ0	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6
	NEG4	POZ0	POZ0	POZ0	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5

Fig. 9 - The rule base of the SC-FUZZY CONTROLLER used in experimental study

Command		Delay								
u		POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8
Change in delay	POZ4	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ3	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ2	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8
	POZ1	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8	POZ8
	ZERO	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8	POZ8
	NEG1	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8	POZ8
	NEG2	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8	POZ8
	NEG3	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8	POZ8
	NEG4	POZ0	POZ1	POZ2	POZ3	POZ4	POZ5	POZ6	POZ7	POZ8

Fig. 10 - The rule base of the CA-FUZZY CONTROLLER used in experimental study

Table 2

Experimantal study analysis

		Settling Time (s)	**Overshoot (%)**
		Oy	*Oy*
Optimal (fixed delays)	E1 (τ_{SC}=0.0 s, τ_{CA}=0.0 s)	20.4	0.0
	E2 (τ_{SC}=0.0 s, τ_{CA}=1.0 s)	Unstable	
	E3 (τ_{SC}=0.0 s, τ_{CA}=2.0 s)	Unstable	
	E4 (τ_{SC}=2.0 s, τ_{CA}=0.0 s)	15.8	0.0
	E5 (τ_{SC}=1.0 s, τ_{CA}=1.0 s)	Unstable	
	E6 (τ_{SC}=1.0 s, τ_{CA}=2.0 s)	Unstable	
Optimal (variant delays)	E1(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	E2(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	E3(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	E4(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	E5(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
	E6(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	Unstable	
Optimal-Fuzzy (variant delays)	E1(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	14.6	0.0
	E2(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	11.8	1.4
	E3(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	16.8	0.0
	E4(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	18.0	0.0
	E5(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	17.4	0.0
	E6(τ_{SCmax}=2.0 s, τ_{CAmax}=2.0 s)	18.6	0.0

The communication protocol used during the experimental study was the Ethernet/IP (TCP/IP).

Also in experimental environment the stability and the performances of the closed loop system are getting worse as the communication delays are getting higher values. These can be observed by analyzing Fig. 8 and Table 2.

The fuzzy logic controllers rule bases used in experimental study are presented in Fig. 9 and Fig. 10.

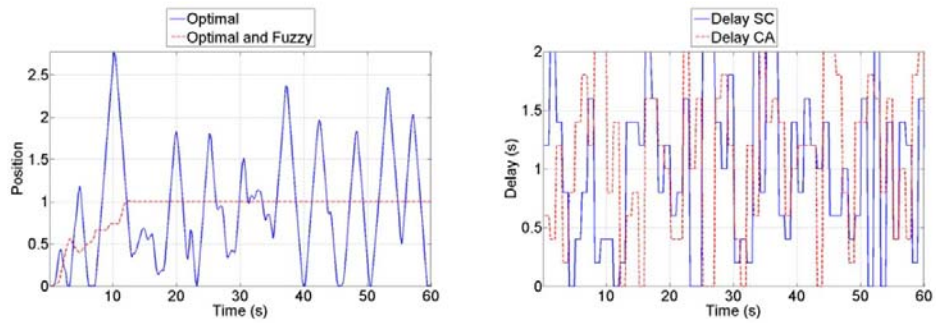

Fig. 11 - Experimental responses for both situations with variant delays (left) and the distributions of the delays (right - case E2)

In Fig. 11 are described the experimental responses of the closed loop system when is used and not used the fuzzy logic adjustment. The responses from the left side were obtained for variant delays (E2). The distributions of the variant delays are presented in the right side of the figure.

After analyzing the simulation and experimental results presented in Fig. 4, Fig. 7, also in Fig. 8, Fig. 11 we can conclude that the performances of the closed loop system are improved by using our proposed control strategy.

4. Conclusions

In this article we proposed a networked control strategy for linear SISO systems affected by variant communication delays. We used the linear state representation for the process and the optimal controller. The control of the optimal controller was adjusted by using two Fuzzy Logic Controllers (FLCs). The FLCs were used to increase the robustness of the closed loop system and thus to minimize the bad influence of the communication delays between the controller-actuation nodes and those between the sensor-control node over the stability and performances of the closed loop system. The simulation and implementation results proved that the performances of the closed loop system were improved when was used our control strategy. For experimental analysis was used an axis from a 3D crane (laboratory system) and the Ethernet/IP (TCP/IP) communication protocol.

In the future work we will analyze the influence of the FLCs rules bases complexity over the robustness of our control strategy. Also, we will apply our proposed control strategy on a nonlinear process.

Acknowledgements

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/88/1.5/S/61178.

Fig. 3 and the non-linear crane model are presented with the courtesy of INTECO.

R E F E R E N C E S

[1] *C. Aubrun, D. Simon, Y. Song*, Co-design Approaches for Dependable Networked Control Systems, John Wiley&Sons Inc, USA, 2010.
[2] *F. Xia,* "QoS Challenges and Opportunities in Wireless Sensor/Actuator Networks", Sensors, 8, 1099-1110, 2008.
[3] *D. Lehmann, J. Lunze*, "Event-based control with communication delays", Proceedings of 18th IFAC World Congress, Milano, Italy, 3262-3267, 2011.
[4] *M. Mazo, P. Tabuada*, "Decentralized Event-triggered Control Over Wireless Sensor/Actuator Networks", IEEE Transactions on Automatic Control, 2456-2461, 2011.
[5] *A. B. Hanchevici, I. Dumitrache*, "Online Tuning of PID Controller for Linear SISO System with Random Communication Delay by Using Genetic Algorithms", Proceedings of IFAC Conference on Advances in PID Control, Brescia, Italy, 2012.
[6] *A. B. Hanchevici, I. Dumitrache*, "Intelligent PID Control for Linear SISO System with Random Communication Delay by Using Online Genetic Algorithms", Proceedings of 11th IFAC/IEEE International Conference on Programmable Devices and Embedded Systems, Brno, Czech Republic, 2012.
[7] *I. Dumitrache*, Ingineria Reglării Automate. Volumul 2. Editura Politehnica Press, Bucuresti, Romania, 2010.
[8] *M. Patrascu, A.B. Hanchevici*, Sisteme Avansate de Conducere. Indrumar de laborator, Editura Politehnica Press, Bucuresti, Romania, 2011.
[9] *K. Passino, S. Yurkovich*, Fuzzy Control. Addison Wesley Longman, Inc., 1998.
[10] *A. B. Hanchevici, M. Patrascu, I. Dumitrache*, "A Hybrid PID-Fuzzy Control for Linear SISO Systems with Variant Communication Delays", Advances in Fuzzy Systems, vol. 2012, doi:10.1155/2012/217068, 2012.
[11] *H. Kwakernaak, R. Sivan*, Linear Optimal Control Systems. First Edition, Wiley-Interscience, 1972.
[12] InTeCo. 3D Crane. InTeCo Ltd., Krakow, Poland, 2000.