ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

New Method for the Control of Complexes Systems with Unknown and Bounded Delay

Nawel Mensia, Moufida ksouri
Unit of research: Analysis and Control of Systems, National Engineering School of Tunisia

Abstract*—in this paper, we have proposed an original method for the calculation of closed-loop control allowing guaranteeing a specific dynamic for a large class of complex systems with unknown and bounded delay. The method is based on one hand on the presentation of the complex process by basis of generic models whose parameters are calculated based on the extreme and average values of delay. On the other hand it uses Padé's approximation to take account of the delay during the construction of the models. The established control can be perceived as a fusion of the parameters of partial correctors, or a fusion of orders computed from each model. The development stages of this control method are explained in this paper, and its validity and robustness are tested and proven against some benchmark.

***Index Terms*—Approximation of Padé, basis of generic models, control of systems with delay, multimodal approach.**

I. INTRODUCTION

Large numbers of control techniques have been developed for general time delay systems [1], [2], [3]. Of course, when the delay is introduced in the control loop, the achievable performances (speed, robustness, precision…) depend to a great extent on the delay value. In the case of an uncertain delay, the usual techniques for time delay systems cannot give satisfactory performances and one has to apply more sophisticated control. In the present paper, we propose a new method of control of complex systems with uncertain and bounded delay. This method uses the multimodal approach to present the system by a basis of five linear generic models whose parameters are calculated according to the delay extreme and means values. Each model of the base allows the generation of a partial controller which is used to derive the global control to be applied to the system. The simplicity of the five models involves a powerful and easy control law which can be implemented in real time.

II. DETERMINATION PRINCIPLE OF MODEL BASE OF SYSTEMS WITH UNCERTAIN AND LIMITED DELAY

In this work, we will consider the processes with uncertain parameters and delay which are described by the following equation:

$$a_0(.)\,y + a_1(.)\,y^{(1)} + \ldots + a_n(.)\,y^{(n)} = b_0(.)\,u(t-\tau) \qquad (1)$$

where:

- $\tau_{\min} < \tau < \tau_{\max}$
- $a_i \in \left[\underline{a_i}, \overline{a_i}\right],\; b_0 \in \left[\underline{b_0}, \overline{b_0}\right] \;\forall i = 0,1,\ldots,n-1$
- (.) includes all parametric nonlinearities associated with the process.

The determination principle of model base is based on the following steps:

Step1: development of models base of the deprived delay system, by using the systematic determination method suggested in [4] which rests on kharitonov work [5]. These models are called extreme models and given by the following transfer functions:

$$F_1(s) = \frac{\underline{b_0}}{\underline{a_0} + \overline{a_1}s + \overline{a_2}s^2 + \ldots s^n} \qquad (2)$$

$$F_2(s) = \frac{\underline{b_0}}{\underline{a_0} + \underline{a_1}s + \overline{a_2}s^2 + \ldots s^n} \qquad (3)$$

$$F_3(s) = \frac{\overline{b_0}}{\overline{a_0} + \overline{a_1}s + \underline{a_2}s^2 + \ldots s^n} \qquad (4)$$

$$F_4(s) = \frac{\overline{b_0}}{\overline{a_0} + \underline{a_1}s + \underline{a_2}s^2 + \ldots s^n} \qquad (5)$$

Step2: replace the delay operator $e^{-\tau s}$ by the Padé's approximation given by the following equation:

$$e^{-\tau s} = \frac{\sum_{k=0}^{r} \frac{(2r-k)!(-\tau s)^k}{k!(r-k)!}}{\sum_{k=0}^{r} \frac{(2r-k)!(\tau s)^k}{k!(r-k)!}} \qquad (6)$$

where *r* is the order of Padé's approximation.

Step3: Establishment of four linear models M_i $(i = 1,2,3,4)$ corresponding to the system with delay, by assembling in cascade an extreme model with the Padé's approximation as explained in the following scheme:

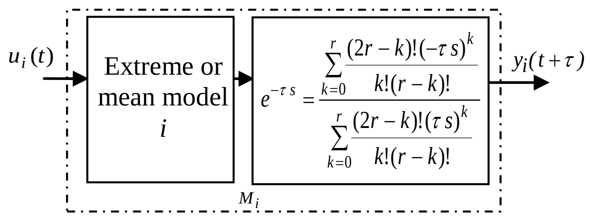

Fig. 1. Structure of model M_i

The Padé's approximation can be written as:

$$e^{-\tau s} = \frac{\sum_{k=0}^{r} h_k(-\tau s)^k}{\sum_{k=0}^{r} h_k(\tau s)^k} \quad \text{with} \quad h_k = \frac{(2r-k)!}{k!(r-k)!}$$

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

If one writes the transfer functions $F_i\ (i=1,2,3,4)$ in the following general form:

$$F_i(s)=\frac{\tilde{b}_{i0}}{\tilde{a}_{i0}+\tilde{a}_{i1}s+\tilde{a}_{i2}s^2+\ldots+\tilde{a}_{in}s^n} \qquad (7)$$

where the parameters $\tilde{b}_{i0}$ (respectively $\tilde{a}_{ij}$ $j=1,\ldots,n$) indicate the minimal or maximum values of b_0 (respectively of a_j), then the model M_i described in figure 1, is expressed by the following transfer function:

$$M_i:\quad F_{Di}(s)=\frac{\tilde{b}_{i0}\sum_{k=0}^{r}h_k(-\tau s)^k}{(\sum_{j=0}^{n}\tilde{a}_{ij}s^j).(\sum_{k=0}^{r}h_k(\tau s)^k)} \qquad (8)$$

Step 4: Determination of Padé's approximation order by assigning the delay $\tau_{\max}$ to the model F_1 then by comparing the response y_1 of $F_1 e^{-\tau_{\max}}$ to that of M_1 $(\tilde{y}_1)$ where r = 1. Then r is increased until obtaining two close responses, while respecting the tradeoff between the approximation order minimization and the following performances:

time of response: t_r

settling time: t_s

quadratic error: $S=\frac{1}{N}\sum_{j=1}^{N}\|y_1(j)-\tilde{y}_1(j)\|$

The approximation of the order of M_2, M_3 and M_4 is determined in the same way as M_1.

Step 5: Since M_i is regarded as extreme model of system with delay, then its coefficients can be calculated according to the minimal and maximum values of a_i, b_0 and τ. So the transfer functions of $M_i\ (i=1,2,3,4)$ are expressed as:

M_1 :

$$F_{D1}(s)=\frac{\underline{b}_0h_0-\underline{b}_0h_1\tau_{\max}s+\underline{b}_0h_2\tau_{\max}^2s^2+\ldots}{\beta_{10}+\beta_{11}s+\beta_{12}s^2+\ldots\beta_{1(n+r)}s^{n+r}} \qquad (9)$$

with :

$\beta_{10}=\underline{a}_0h_0$; $\beta_{11}=\underline{a}_0h_1\tau_{\max}+\overline{a_1}h_0$;

$\beta_{12}=\overline{a_2}h_0+\overline{a_1}h_1\tau_{\max}+\underline{a}_0h_2\tau_{\max}^2$;

$\beta_{13}=\underline{a}_3h_0+\overline{a_2}h_1\tau_{\min}+\underline{a}_0h_3\tau_{\min}^3+\overline{a_1}h_2\tau_{\min}^2$;

⋮

M_2 :

$$F_{D2}(s)=\frac{\underline{b}_0h_0-\underline{b}_0h_1\tau_{\min}s+\underline{b}_0h_2\tau_{\max}^2s^2+\ldots}{\beta_{20}+\beta_{21}s+\beta_{22}s^2+\ldots\beta_{2(n+r)}s^{n+r}} \qquad (10)$$

with :

$\beta_{20}=\underline{a}_0h_0$; $\beta_{21}=\underline{a}_0h_1\tau_{\min}+\underline{a}_1h_0$;

$\beta_{22}=\overline{a_2}h_0+\underline{a}_1h_1\tau_{\max}+\underline{a}_0h_2\tau_{\max}^2$;

$\beta_{23}=\overline{a_3}h_0+\overline{a_2}h_1\tau_{\max}+\underline{a}_1h_2\tau_{\max}^2+\underline{a}_0h_3\tau_{\max}^3$;

⋮

M_3 :

$$F_{D3}(s)=\frac{\overline{b_0}h_0-\overline{b_0}h_1\tau_{\max}s+\overline{b_0}h_2\tau_{\min}^2s^2+\ldots}{\beta_{30}+\beta_{31}s+\beta_{32}s^2+\ldots\beta_{3(n+r)}s^{n+r}} \qquad (11)$$

$\beta_{30}=\overline{a_0}h_0$; $\beta_{31}=\overline{a_1}h_0+\overline{a_0}h_1\tau_{\max}$;

$\beta_{32}=\underline{a}_2h_0+\overline{a_1}h_1\tau_{\min}+\overline{a_0}h_2\tau_{\min}^2$;

$\beta_{33}=\underline{a}_3h_0+\underline{a}_2h_1\tau_{\min}+\overline{a_1}h_2\tau_{\min}^2+\overline{a_0}h_3\tau_{\min}^3$;

⋮

M_4 :

$$F_{D4}(s)=\frac{\overline{b_0}h_0-\overline{b_0}h_1\tau_{\min}s+\overline{b_0}h_2\tau_{\min}^2s^2+\ldots}{\beta_{40}+\beta_{41}s+\beta_{42}s^2+\ldots\beta_{4(n+r)}s^{n+r}} \qquad (12)$$

with :

$\beta_{40}=\overline{a_0}h_0$; $\beta_{41}=\underline{a}_1h_0+\overline{a_0}h_1\tau_{\min}$;

$\beta_{42}=\underline{a}_2h_0+\underline{a}_1h_1\tau_{\min}+h_2\tau_{\min}^2$;

$\beta_{43}=\overline{a_3}h_0+\underline{a}_2h_1\tau_{\max}+\underline{a}_1h_2\tau_{\max}^2+\overline{a_0}h_3\tau_{\max}^3$;

⋮

Besides, we propose to include an average model in the model basis, which is expressed as an average of the four extreme models. We have then the transfer function:

$$F_{DM}(s)=\frac{b_{M0}h_0-b_{M0}h_1\tau_Ms+b_{M0}h_2\tau_M^2s^2+\ldots}{\beta_{M0}+\beta_{M1}s+\beta_{M2}s^2+\ldots s^{n+r}} \qquad (13)$$

with :

$\beta_{M0}=a_{M0}h_0$; $\beta_{M1}=a_{M1}h_0+a_{M0}h_1\tau_M$

$\beta_{M2}=a_{M2}h_0+a_{M1}h_1\tau_M+h_2\tau_M^2$

$\beta_{M3}=a_{M3}h_0+a_{M2}h_1\tau_M+a_{M1}h_2\tau_M^2+a_{M0}h_3\tau_M^3$; wh

⋮

ere

$$\tau_M=\frac{\tau_{\min}+\tau_{\max}}{2};\quad a_{Mi}=\frac{\overline{a_i}+\underline{a}_i}{2};\quad b_{Mi}=\frac{\overline{b_0}+\underline{b}_0}{2}$$

III. CONTROL LAW ESTABLISHEMENT

The simplicity of the models $M_i\ (i=1,2,3,4,M)$ involves an easy partial controller that derives by fusion the global control to be applied to the complex process with delay. This fusion is piloted by the validity v_i associated with the partial models M_i .

The determination of validity index, in this work is based on the geometrical approach [6], [7] which is based on the estimation of residues. The latter can be assimilated to the

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

distances d_i between the output of the model and the process output.

$$d_i = \|y - y_i\|;\ i = 1,2,3,4,M \quad (14)$$

A normalized distance d_{iN} can be defined by:

$$d_{iN} = \frac{\|y - y_i\|}{\sum_j \|y - y_j\|};\ j = 1,2,3,4,M \quad (15)$$

and the validity can then be expressed by:

$$v_i = 1 - d_{iN} \quad (16)$$

In practice, it is important to proceed to an overweighing of the validity indexes in order to get rid of perturbation induced by “inconvenient” models over the satisfactory ones. The new validity can be stated as follows:

$$v_i^{renf} = v_i \prod_{j \neq i} (1 - v_i);\ j = \{1,2,3,4,M\} \quad (17)$$

Once the validity indexes determined, the global control law u to be applied to the complex system can be processed either by fusion of the partial control laws u_i derived from the models M_i expressed by:

$$u = \sum_{i=1}^{M} v_i^{renf} u_i \quad (18)$$

or by fusion of coefficients of partial regulators corresponding to the models M_i in the basis.

IV. SIMULATION EXAMPLES

A. *Example 1*

In order to illustrate this approach, let us consider a strongly non-linear non stationary process with delay represented by the following model under the general form:

$$\dot{x}(t) = A(x,t)\,x(t) + B\,u(t-\tau)$$
$$y(t) = C\,x(t) \quad (19)$$

where the state matrices are expressed by:

$$A(x,t) = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -a_0 & -a_1 & -a_2 \end{bmatrix};\ B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix};\ C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}$$

The different parameters of the model are supposed to be ill-defined and can be expressed by the following relations:

$$a_0 = 21 + \frac{\cos(y)}{1 + \sin^2(y)} \quad (20)$$

$$a_1 = 25 + \cos(2t) \quad (21)$$

$$a_2 = 3 + 0.2\sin(y) \quad (22)$$

The coefficients a_0, a_1, a_2 and τ are supposed to be bounded by:

$$20 \le a_0 \le 22;\ 24 \le a_1 \le 26;\ 2.8 \le a_2 \le 3.2;\ 2 \le \tau \le 8$$

The transfer function of the deprived delay system can be obtained by:

$$F(s) = C(sI - A)^{-1} B \quad (23)$$

then the four extreme models and the average model constituting the model base of the system without delay, are given by the following functions:

First model: $$F_1(s) = \frac{1}{\underline{a_0} + \overline{a_1}s + \overline{a_2}s^2} \quad (24)$$

Second model:

$$F_2(s) = \frac{1}{\underline{a_0} + \underline{a_1}s + \overline{a_2}s^2} \quad (25)$$

Third model:

$$F_3(s) = \frac{1}{\overline{a_0} + \overline{a_1}s + \underline{a_2}s^2} \quad (26)$$

Forth model: $$F_4(s) = \frac{1}{\overline{a_0} + \underline{a_1}s + \underline{a_2}s^2} \quad (27)$$

Average model: $$F_M(s) = \frac{1}{\hat{a}_0 + \hat{a}_1 s + \hat{a}_2 s^2} \quad (28)$$

where the upper and lower arrow notation design respectively the maximum (max) and minimum (min) values of the ill-defined parameters, and $\hat{a}_j = \frac{\overline{a}_j + \underline{a}_j}{2};\ j = 1,2,3$

Padé’s order determination

To derive the Padé’s approximation order (r) to be assigned to the base models of the system with delay, we use the method presented in step four. The following table show the performances obtained for each model where r increases from 1 up to 3. We appoint by P_1, P_2 and P_3 respectively the Padé’s approximation with order 1, 2 and 3.

Table. 1. Performances obtained for M_1, M_2, M_3, M_4 and M_M.

where r increase from 1 up to 3

Model		t_r	t_s	S
First model	$F_1 e^{-\tau_{max} s}$	9.48	11.83	0
	$F_1.P_1$	8.22	16.2	0.12
	$F_1.P_2$	9.48	13	0.06
	$F_1.P_3$	9.48	12.59	0.044
Second model	$F_2 e^{-\tau_{max} s}$	9.3	11.5	0
	$F_2.P_1$	8.22	16.2	0.11
	$F_2.P_2$	9.12	13	0.061
	$F_2.P_3$	9.87	12.67	0.045
Third model	$F_3 e^{-\tau_{max} s}$	9.26	11.65	0
	$F_3.P_1$	8.16	16.47	0.11
	$F_3.P_2$	9.27	13.07	0.062
	$F_3.P_3$	9.47	12.7	0.045
Fourth model	$F_4 e^{-\tau_{max} s}$	9.09	11.27	0
	$F_4.P_1$	8.16	16.02	0.12
	$F_4.P_2$	9.09	12.63	0.065
	$F_4.P_3$	9.27	12.5	0.047
Average	$F_M e^{-\tau_{max} s}$	9.27	11.27	0
	$F_M.P_1$	8.17	16.92	0.11

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

model	$F_M.P_2$	9.27	13.01	0.062
	$F_M.P3$	9.48	12.54	0.044

Based on the results given in the table above, we notice that for each model, the performances obtained using the third order Padé's approximation are closest to the real model performances. Also we note that the difference between the performances of F_iP_2 $(i=1,2,3,4,M)$ and those of F_iP_3 is weak. So we retain the second order approximation to respect the tradeoff between performances and order.

Model basis determination

The extreme models M_i $(i=1,2,3,4)$ and the average model M_M of the system with delay are linear models of the fifth order, given respectively by the following transfer functions:

$$F_{d1}=\frac{12-48s+64s^2}{240+1272s+2566.4s^2+142.4s^3+88s^4} \quad (29)$$

$$F_{d2}=\frac{12-12s+64s^2}{240+528s+2470.4s^2+1574.4s^3+204.8s^4} \quad (30)$$

$$F_{d3}=\frac{12-48s+4s^2}{254+1368s+433.6s^2+392s^3+179.2s^4} \quad (31)$$

$$F_{d4}=\frac{12-12s+4s^2}{264+552s+325.6s^2+9350.4s^3+179.2s^4} \quad (32)$$

$$F_{dM}=\frac{12-30s+25s^2}{252+930s+811s^2+715s^3+75s^4} \quad (33)$$

Control law development

The idea we propose to develop is a generalization of the linear quadratic method [8] to systems with uncertain parameters and delay. In this control law, the classical gains l and K are derived from the gains l_i and K_i of the four extreme models, plus the average model weighted by the validity indexes v_i^{renf}.

$$l=\sum_i v_i^{renf} l_i; \quad (i=1,2,3,4,\ M) \quad (34)$$

$$K=\sum_i v_i^{renf} K_i; \quad (35)$$

The determination of the state feedback vectors K_i is based on ksouri approach [9] which repose on benrjeb and born theorems [10], [11] and gives a sufficient condition for stability of systems controlled by state feedback vectors fusion. This condition is necessary for the stability of the system with delay. And the gains l_i are determined so as to cancel the static error in position for the model M_i and then are defined by:

$$l_i=-\left[C_i\left(A_i-B_iK_i\right)^{-1}B_i\right]^{-1} \quad (36)$$

The expression of the process order is given by the following equation:

$$u=ly_c-Kx_p \quad (37)$$

where:

y_c: setpoint

x_p: state vector of the process with delay approximated by the second order Padé's approximation.

Result of simulation

As the real process can have several values of delay included between 2 and 8 second, we have considered in the simulation three different values of delay (3s, 5s and 7s). The obtained results are given in the following figure which illustrates the evolution of the system's response for each delay.

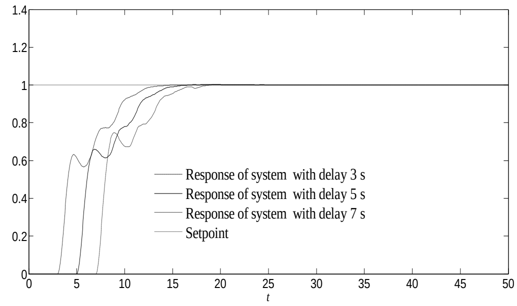

Fig. 2. The Unit Step Responses of Process with Delays (3s, 5s and 7s).

We notice that the curves are quite similar. This proves the command ability to ensure good performances (stability, precision) for all values of delay between τ_{min} and τ_{max}. In order to test the robustness of this approach, we considered three other values of delay which are superior to τ_{max}. The figure 3 shows the answers obtained for the delays 9s, 10s and 11s.

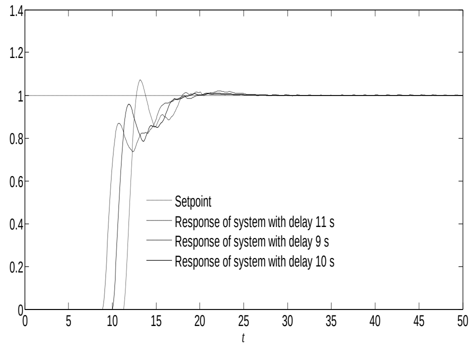

Fig. 3. The Unit Step Responses of Process with Delays (9s, 10s And 11s).

We observe that the command always manages to stabilize the process by providing good performances, which proves the robustness of the control.

B. *Example 2*

In this example, we consider a complex system with uncertain and variable parameters in time given by equation (38). The unknown delay of this system is reduced by $\tau_{min}=3s$ and increased by $\tau_{max}=10\ s$.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

$$x+\alpha\,\dot{x}=k\,u\,(t-\tau)$$
$$k=36\,x\,(x-1)+10 \tag{38}$$
$$\alpha=15-10x$$

where $5<\alpha<15$ and $1<k<10$

The models basis of the system without delay comprise the following extreme models M_1, M_2, M_3, M_4 and average model M_M.

$$M_1:\ \frac{1}{1+5s};\quad M_2:\ \frac{1}{1+15s};\quad M_3:\ \frac{10}{1+5s};$$
$$M_4:\ \frac{10}{1+15s};\quad M_M:\ \frac{5}{1+10s}$$

To fix the order of the Padé's approximation which has to be used, we proceeded in the same way as the example 1, and we have chosen the second order approximant. The basis of the system with limited and unknown delay (38) comprises the following models:

$$\tilde{M}_1:\ \frac{12-9s+64s^2}{12+84s+184s^2+45s^3} \tag{39}$$
$$\tilde{M}_2:\ \frac{12-24s+64s^2}{12+189s+199s^2+960s^3} \tag{40}$$
$$\tilde{M}_3:\ \frac{120-90s+90s^2}{12+84s+54s^2+45s^3} \tag{41}$$
$$\tilde{M}_4:\ \frac{120-240s+90s^2}{12+189s+144s^2+960s^3} \tag{42}$$
$$\tilde{M}_M:\ \frac{60-82.5s+151.25s^2}{12+136.5s+195.25s^2+302.5s^3} \tag{43}$$

Control law establishment

Each model $\tilde{M}_i$ is controlled according to the output feedback mode illustrated in figure 4.

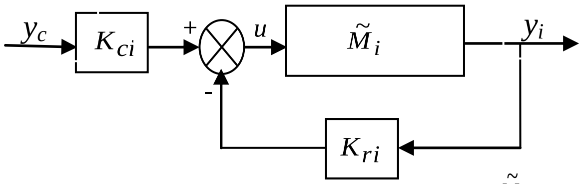

Fig. 4. Output feedback control of model $\tilde{M}_i$ with approximate delay

The gains K_{ci} and K_{ri} are calculated to guarantee closed-loop stability and cancel the static error for the model $\tilde{M}_i$. The K_{ri} values that guarantee the stability can be found through the application of Routh criterion and the gains K_{ci} must check the following relation:

$$K_{ci}=\frac{\beta_{i0}}{\alpha_{i0}}+K_{ri} \tag{44}$$

to ensure a zero static error.

The process and the $\tilde{M}_i$ outputs are used to calculate the residues according to formula (14), and the validity is calculated by the formulas (15) and (16), then reinforced according the formula (17). The global order is established from the fusion of partial orders of extreme models with approximated delay.

$$u=\sum_i v_i^{renfN} K_{ci} y_c-\sum_i v_i^{renfN} K_{ri}\,y \tag{45}$$
$$i=\{1,\ 2,\ 3,\ 4,\ M\}$$

Implementation

Having arbitrarily chosen three different values of delay $\tau_1=5s,\ \tau_2=7s, \tau_3=10\,s$ in the interval [3 10], and calculated the parameters K_{ri} and K_{ci}, we implemented the proposed control strategy. The responses of the system with delays $\tau_1,\ \tau_2$ and τ_3 are given in Figure 5.

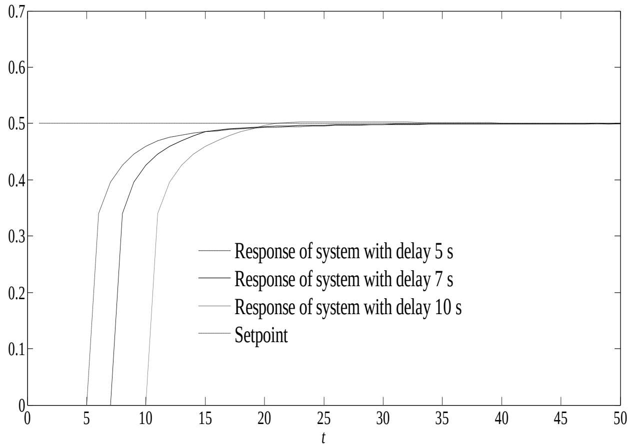

Fig. 5. Outputs of the system with delays 5s, 7s and 10s.

We notice the good performances obtained.

Let us now test the robustness of the proposed method with regard to the increase of the delay by considering values of delay which exceed $\tau_{\max}$. The outputs of the system with delays $\tau_1=11s,\ \tau_2=12s, \tau_3=13\,s$ are given in the following figure:

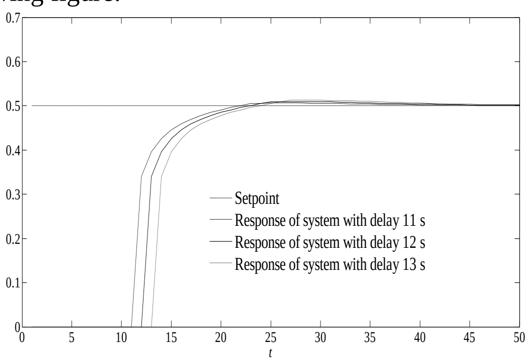

Fig. 6. Outputs of the system with delays 11s, 12s and 13s.

We notice that the response overshoot increases with the delay, but it remains less than 5%, which proves the robustness of the proposed method.

V. CONCLUSION

The method consists in defining a complex system with delay presentation by means of simple linear models which allows the generation of a partial controller that derives by

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

fusion an efficient and robust control law which can be implemented in real time. Each basis model is composed by a generic model of the deprived delay system assembled in cascade with the Padé's approximation of order *r* which replace the delay operator. This order r is fixed so as to respect the compromise between the desired performances and the minimization of the approximation order. The constructed models are regarded as extreme and average models of the complex system with delay, since its coefficients are calculated according to the minimal, maximum and mean values of the system's parameters and delay. To show the performances provided by this method, we considered two simulation examples. The Control developed for the first example is a generalization of the linear quadratic method to systems with uncertain parameters and delay, and the second example control is established from the fusion of partial orders of basis models. The results obtained after simulations have shown good closed loop performances. A robustness test, carried out taking into account delays superior to τ_{max}, has demonstrated the control ability to maintain stability with ensuring desired performances.

REFERENCES

[1] J. Chiasson and J...J. Loiseau, "Applications of time delay systems", Springer, 2007.

[2] S.I. Niculescu, "Delay effects on stability: a robust control approach", Springer, 2001.

[3] J. P. Richard, "Time delay systems: an overview of some recent advances and open problems," Automatic, vol. 39, pp. 1667–1694, 2003.

[4] A. Elkamel, M.L. Ksouri, P. Borne and M. Benrjeb, "Contribution to multimodel analysis and control," In. J. of studies in informatics and control, vol. 9, n° 1, pp. 29-38, 2000.

[5] V. L. Kharitonov, "Asymptotique stability of an equilibrium position of a family of systems of linear differential equations". Differential. Uravnen, vol 14, pp. 2086-2088, 1978.

[6] R. Isermann., "Process fault detection based on modeling and estimation methods - a survey," Automatic, vol. 20, n° 4, , pp. 387-404, 1984

[7] M. Staroswiecki, V. Cocquempot, and J.P Cassar, "Comparison of observer based and parity approaches for failure detection and identification," symposium IMACS/IFAC, Lille, 1991.

[8] P. Borne, G.T. Dauphin, J.P. Richard, and F. Rotella, and I. Zambettakis, Analyse et régulation des processus industriels, Tome I, Technip, France 1993.

[9] M. L. .Ksouri, "Contribution à la commande multi-modèle des processus complexes," Thesis, UST Lille, 1999.

[10] M., Benrjeb, "Sur l'analyse et la synthèse de processus complexes hiérarchisés, " Thesis of state in physical science, UST Lille, 1980.

[11] P. Borne, G.T. Dauphin, J.P. Richard, F. Rotella, and I. Zambettakis, Modélisation et identification des processus Tome I, Technip, France 1992.

AUTHOR'S PROFILE

Nawel Mensia is a professor in Higher Institute of Science and Technology of sousse (Tunisia). She received her Ph.D. degree in Electrical Engineering from the Elmanar Tunis University in 2011. Her research interests include control of systems with delay, multimodel control and the computational intelligence techniques

Moufida Ksouri is a professor at the National School of Engineering of Tunis. She received her Ph.D. degree in Electrical Engineering from the University of Science and Technology of Lille in 1998.. Her research interests include Identification and control of non linear systems and industrial applications of advanced control. . She is the author or co-author of more than 30 papers in international conferences and journals. She has also published a book entitled "Commande numérique des processus".