International Journal of Control, Energy and Electrical Engineering (CEEE)
Copyright – IPCO-2014
Vol.1, pp. 1-9

# New Internal Multi-Model Controller for a linear process with a variable time delay

TOUZRI Mustapha[#1], NACEUR Mongi[#2], SOUDANI Dhaou[#3]

[#] *Laboratory of Research on Automatic (LARA) National Engineers School of Tunis, University of Tunis el Manar BP 37, LE BELVEDERE 1002 TUNIS*

[1]touzri.mustapha@gmail.com

[2]m.naceur@ttnet.tn

[3]dhaou.soudani@enit.rnu.tn

***Abstract*— This document introduces a new Internal Multi-Model controller design method for a linear system with a limited variable time delay. This design method is based on the use of a models collection to approximate the system functioning using Padé approximations; these models are inversed and multiplied by low pass filters in order to obtain a set of controllers that calculate the command value through a fusion procedure. These controllers are obtained by the multiplication of a low pass filters and models inverses, in order to impose poles and zeros for the considered system and to control the command robustness through the filters parameters, which shall confirm a compromise between stability and rapidity. In this paper the Multi-Model Command controller design method will be described through six sections; first section introduces the realized research on this paper, the second section describes Internal Model Control concepts, third section describes effects of presence of a time delay on systems dynamics, the fourth section shows briefly Multi-Model concepts, the fifth section presents the new Internal Multi-Model controller design Method and finally section six deals with the obtained results of the new controller design method application for a system with a limited variable time delay and the filters parameters variations effects.**

***Keywords*— Internal Model Control, Multi-Model approach, Internal Mutli-Model Control, System with a limited variable time delay, Padé approximation.**

## I. Introduction

Systems that contain delays are widely present in industry and in other fields such as biology or economy; that's why this class of systems has become one of the most attractive research domains. [10]

Time delay can be caused by some of these phenomena: transport of mass, energy or information; the required processing time for sensors, such as analysers; controllers that need some time to implement a complicated control algorithm or the accumulation of a great number of low order system connected in series ...[5]

The presence of a time delay in the process can cause a lot of control constraints such as; disturbances effect is felt after the time delay, error correction is based on the previous error value and additional phase lag that may cause instability when using classic feedback control and for high frequency.

Then the control of a system with a time delay is generally difficult; due to the constraints imposed by the time delay. These constraints can cause performance deterioration that leads the process to instability especially when operating in closed loop. [5]

For this purpose we use robust command structure, to surpass the constraints related to the time delay presence, such as Internal Model Control and Muti-Model Control to obtain robust performances.

These commands structures, are known by their robustness and can ensure a perfect set-point tracking; when achieving a controller that fits theses command structures (Internal Model Control and Muti-Model Control) requirements; such as realizing a controller based on Internal Model Control that requires inversion of the process model; which is the main constraint related to Internal Model Control due to models expression, that could include delays and/or instable zeors ect… [9] and to implement an efficient command algorithm for a Multi-Model Controller.

This paper deals with the control of linear process with a variable time delay using Internal model Control and Multi-Model Control in order to surpass constraints due to the non linear variation of the time delay.

The non linear variations of the time delay; gives alternatives for instability due to non accuracy of time delay modelisation that's why we use a Multi-Model Control, known by its robustness, approach to obtain an accurate representation for the time delay.

These Models will be a set rational fraction; obtained after the application of a first, second and a third order Padé approximation. Then for each model a controller will be calculated using a low pass filter to eliminate instable zeros and to make the Internal Model Controller fit for inversion procedure.

This research object; is to introduce a new controller design method based on Internal Model Control adopted with Multi-Model Control concepts, in order to surpass constraints related to a model inverse realization and the presence of a

International Journal of Control, Energy and Electrical Engineering (CEEE)
Copyright – IPCO-2014
Vol.1, pp. 1-9

variable time delay, in order to obtain a robust process behavior.

## II. Internal Control description

Many command structures were developed using the feedback concept; which is based on mathematical approaches to solve problems related to processes command, these approaches were implemented by the apparition of the first calculator.[4] Internal Model Control, noted as IMC, uses feedback concept and uses the robust command characteristics, to ensure an acceptable degree of performance even in the presence of parameters uncertainties and/or modelisations errors [1]. The basic structure of an IMC command is composed by the process compared to its model, and a controller as it shown on figure 1.[7]

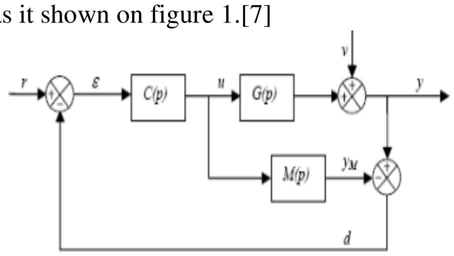



Fig. 1 Basic IMC structure

Where *C(p)* is the IMC controller, *G(p)* the process and *M(p)* the process model which is an approximation of the plant G(p). This command structure applies the command signal *u* for both of the process *G(p)* and its model *M(p),* d is a disturbance signal which attacks the output directly and r is the reference signal; the output signal of the plant is compared to the set point signal in order to minimize the error between the reference and the output.

Internal model Control is one of the most popular command structure used for its simplicity and its robustness; this command structure can give a perfect reference tracking in the case of the use of a controller similar to the model inverse. [7]

Achieving the inverse of the model is the main problem associated with this command structure, because of the denominator order generally greater than the numerator on the model expression or the presence of time delay or/and instable zeros. [2]

## III. Constraints imposed by time delay

Systems with delays are found in many industrial processes and time delay presence is due to many factors such as transfer of information, energy or chemical reactions. [5,10] Then delays presence make systems analysis and controller design more complex, [10] due to the time delay effects on the systems behaviors that imposes many constraints on systems command. Delays constraints may cause instability and deterioration on the system performances especially on a closed loop.

The time delay may cause a lag on the system phase especially for its high values [5] and for high frequency, which can be the reason of deterioration or instability on the closed loop. Time delay presence makes also the effect of the disturbances not felt until a considerable time has elapsed, the effects of the control action take some time to be felt in the controlled variable and the control action that is applied based on the actual error tries to correct a situation that originated some time before.[5]

Using the IMC structure, the associated controller can be used as the inverse of the process model; however in the case of the presence of a time delay it gives a predictive system, when the inverse is calculated, making the realization of this type of systems difficult. For this purpose a Padé approximation is used to surpass these constraints, of inversion and realization, and giving a rational representation of the process makes the inversion of the process model possible.

But this approximation gives an alternative to modelisations errors which can deteriorate system performances and drive its behavior to the instability, to face these constraints we use on our command structure three Padé order approximation; a first order, a second order and a third order approximation to decrease the effects of modelisations errors by elevating the approximation order to have models that can behave as the original process for high frequency. The obtained models using Padé approximation will be used to calculate the Internal Multi-Model Command controller, and section V objective is to give a command approach that can solve the realization problem of the IMC controller.

## IV. Multi-Model Command concepts

This section describes briefly the concepts of a Multi-Model controller. Multi-Model concepts are used on modelisation for the nonlinear systems and the uncertain systems; the main purpose of using Multi-Model approach is to obtain the best representation for systems dynamics by calculating validity coefficients and then realizing commutation or fusion between these models.

These concepts were generalized for the design of a controller that uses different commands at the same time and selects the best one for the process using many parameters and/or algorithms in order to obtain an optimal behavior for the considered process. [3]

Multi-Model approach is based on a collection of models that represents system dynamics on several operating points for nonlinear system, then calculates models validities and realizes the fusion of these collected data using specified methods. [3]

Then a Multi-Model controller uses these concepts in order to obtain a robust command that ensures optimal performances for the considered process.

In fact Multi-Model controller uses a collection of models and their validities to calculate the best command for the process by using an algorithm for the fusion between these data.

For this purpose many fusion methods were developed to satisfy the Multi-Model controller requirements [3] where the designer uses different algorithms to obtain the best command that allows a robust behavior for the process.

In this document we will use a Multi-Model controller combined with Internal Model Control concepts which will be generalized as Internal Multi-Model Controller that uses commutation between controllers as a fusion method for the command of a linear system with a variable limited time delay which will be described on the next section.

## V. Internal Multi-Model Controller design procedure

This section describes the design method of the new Internal Multi-Model Controller based on the use of different low pass filters associated with each model of the considered process.

In fact the new Internal Multi-Model controller design method is a combination between the Internal Model Controller design method described on [8,9] and Multi-Model approach; this new command structure can be described by this figure:

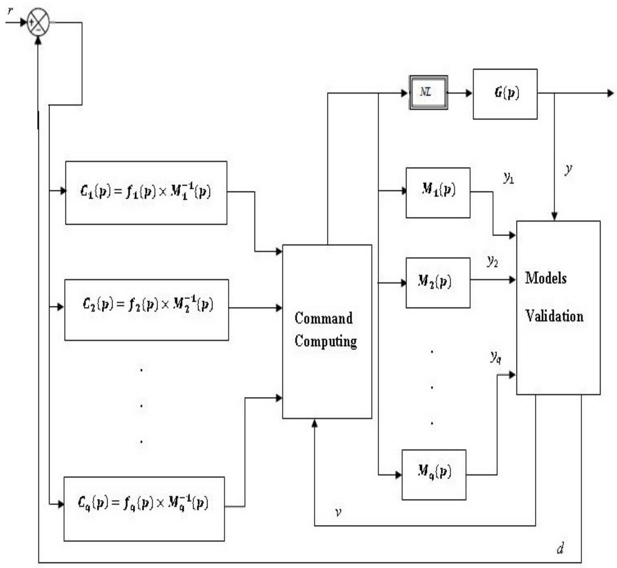



Fig. 2 Internal Multi-Model Control structure

This command structure applies the same command for the process (a linear process with a variable time delay considered as non linearity) and its models $M_1(p)...M_q(p)$, then calculates validity coefficient v which will be used to compute the command value; that will be selected from one of the associated controllers $C_1(p)...C_q(p)$ that receives the difference between the reference and the outputs of the used models in order to minimize the errors. In fact the used command is based on the commutation between models using a validity coefficient which leads to the controller to use; this validity coefficient is calculated by realizing the differences between the process output *y* and its models output $y_1...y_q$ then the model which has the minimum difference, will be used for the command by using its index as a validity coefficient, then this validity coefficient will be used to select the appropriate controller.

Each one of these controllers $C_i(p)$ is achieved by multiplication of a low pass filter $f_i(p)$ and the inverse of the model $M_i(p)$ and can be written as:

$$C_i(p)=f_i(p)\times M_i^{-1}(p) \quad (1)$$

(i=1…q), where $f_i(p)$ is associated to the model inverse $M_i(p)$ and each filter $f_i(p)$ contains instable zeros that can appear on the process model expression $M_i(p)$.

Then for each Controller $C_i(p)$ the used filter $f_i(p)$ can be written in this form [6]:

$$f_i(p)=\frac{\sum_{j=0}^{m}\beta_j p^j}{(1+\alpha p)^n} \quad (2)$$

Where:

$\sum_{j=0}^{m}\beta_j p^j$ represents the instable zeros that can appear on the process model $M_i(p)$.

n: is a natural integer chosen to make the controller $C_i(p)$ proper.

α :is a float used to adjust the performance of the controlled process.

And each controller $C_i(p)$ can be computed using this method:

$$M_i(p)=\frac{N_{ZS}(p)\times N_{ZI}(p)}{D(p)} \quad (3)$$

$$M_i^{-1}(p)=\frac{D(p)}{N_{ZS}(p)\times N_{ZI}(p)} \quad (4)$$

$$f_i(p)=\frac{N_{ZI}(p)}{(1+\alpha p)^n} \quad (5)$$

$$C_i(p)=f_i(p)\times M_i^{-1}(p)=\frac{D(p)}{N_{ZS}(p)\times(1+\alpha p)^n} \quad (6)$$

Where:

$N_{ZS}(p)$ : is the stable zeros on the numerator of the process model $M_i(p)$.

$N_{ZI}(p)$ : is the instable zeros that can be present on the process model $M_i(p)$.

$D(p)$ : represent the denominator of the process model $M_i(p)$.

International Journal of Control, Energy and Electrical Engineering (CEEE)
Copyright – IPCO-2014
Vol.1, pp. 1-9

n: is a natural integer chosen to make the controller proper $C_i(p)$.

α: is a float used to adjust the system performances.

In this command structure, the aim of using a Multi-Model approach is to surpass constraints due to the variation of the time delay, besides the combination between Multi-Model concepts and Internal Model Control is to ensure the robustness of the command in spite of disturbance presence and modelisation errors. In fact this command structure allows us to impose the poles and zeros of the process through the filters parameters, such as the filters orders, the filters poles or the filters zeros, these characteristics allow the designer to control the robustness level of the command by choosing the parameters that ensures the best compromise between robustness and rapidity.

Then for each filter the choice of its pole must confirm an acceptable compromise between stability and rapidity, the filter pole can be chosen using these recommendations:

if α=0 the system response will be $H_2$– optimal [6]

if α is chosen greater than the poles of the controlled system the filter dynamics will dominate the closed loop response of the system [6]

and if α is chosen inferior to the poles of the system the filter effect will not dominate the closed loop response of the system.[6]

Then the filter parameter α allows us to control the speed of the closed loop response then the adjusting of α is the same as adjusting the speed of the closed loop response. [6]

## VI. Obtained results for a variable time delay first order system using different Padé approximation

This section shows the obtained results of the simulations of a linear process with a nonlinear variation time delay functioning; using the new command structure, the considered process is characterized by this expression: $G(p)=\frac{e^{-\tau(t)p}}{1+5p}$ where $\tau(t)$ is a limited variable time delay $(\tau(t)\le 4,2)$ its variation is described by figure 3.

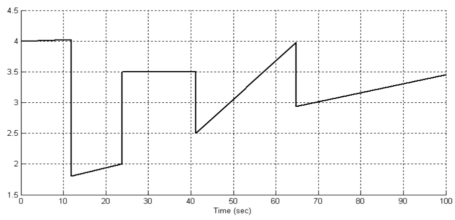


Fig. 3 Time delay variation

This time delay will be estimated using four models each one of them will be calculated for $\tau_1=1s$, $\tau_2=2s$, $\tau_3=3s$ and $\tau_4=4s$, then the considered process will be estimated to four systems with a fixed time delay expressed by: $G_1(p)=\frac{e^{-p}}{1+5p}$, $G_2(p)=\frac{e^{-2p}}{1+5p}$, $G_3(p)=\frac{e^{-3p}}{1+5p}$, and $G_4(p)=\frac{e^{-4p}}{1+5p}$.

Then for each one of these transfer functions a first order, a second order and a third order Padé approximations will be used to obtain model's expression. This section contains three subsections, the first one shows the obtained results of using a first order Padé approximation to calculate system models, the second one shows the obtained results of using a second order Padé approximation and the third one shows the obtained results using a third order Padé approximation to calculate system models.

### A. *Obtained results using a first order Padé approximation*

The considered process is estimated to four systems with a fixed time delay, then a first order Padé approximation will be used to calculate system models described by:

$$M_1(p)=\frac{1-\frac{p}{2}}{1+5.5p+2.5p^2} \text{ for } \tau=1s,$$

$$M_2(p)=\frac{1-p}{1+6p+5p^2} \text{ for } \tau=2s,$$

$$M_3(p)=\frac{1-\frac{3}{2}p}{1+6.5p+7.5p^2} \text{ for } \tau=3s,$$

$$\text{and } M_4(p)=\frac{1-2p}{1+7p+10p^2} \text{ for } \tau=4s.$$

Then a filter $f_i(p)$ will be associated with each model $M_i(p)$; which contains instable zeros of these models that will be eliminated from the controller $C_i(p)$ expression which will be calculated as it was described on the previous section by multiplying the models inverse and low pass filters.

Then the used filters and the calculated controllers are expressed on the table below:

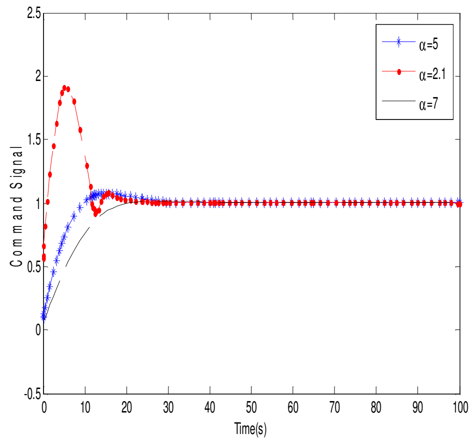
TABLE I. List of filters and controllers for each process model

| $M_i(p)$ | $f_i(p)$ | $C_i(p)=f_i(p)\times M_i^{-1}(p)$ |
|---|---|---|
| $M_1(p)$ | $f_1(p)=\frac{1-\frac{p}{2}}{(1+\alpha p)^2}$ | $C_1(p)=\frac{1+5.5p+2.5p^2}{(1+\alpha p)^2}$ |
| $M_2(p)$ | $f_2(p)=\frac{1-p}{(1+\alpha p)^2}$ | $C_2(p)=\frac{1+6p+5p^2}{(1+\alpha p)^2}$ |

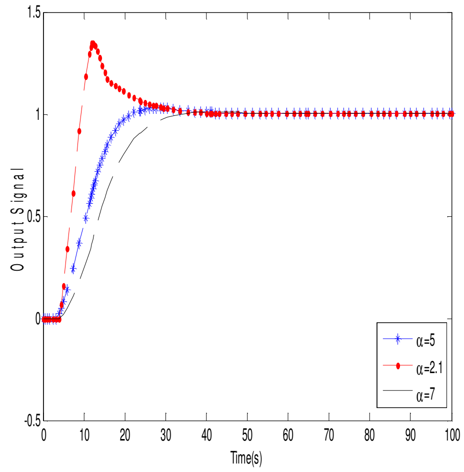
| | | |
|---|---|---|
| $M_3(p)$ | $f_3(p)=\dfrac{1-\frac{3}{2}p}{(1+\alpha p)^2}$ | $C_3(p)=\dfrac{1+6.5p+7.5p^2}{(1+\alpha p)^2}$ |
| $M_4(p)$ | $f_4(p)=\dfrac{1-2p}{(1+\alpha p)^2}$ | $C_4(p)=\dfrac{1+7p+10p^2}{(1+\alpha p)^2}$ |

The simulation's results will be shown on figure 4 and figure 5 where the controllers are used for different values of the filters parameter α to show its variation's effects on the process behavior in the cases of absence and presence of disturbance at t=40s.

Case of disturbance absence




Command signal



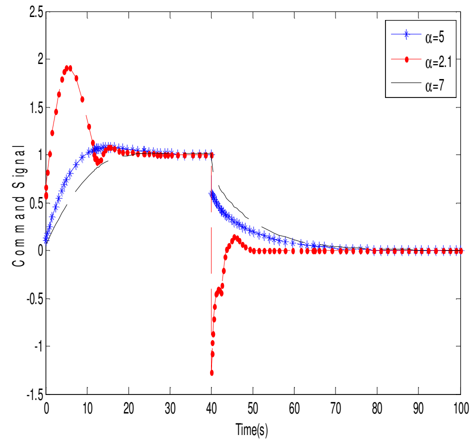

Output signal

Fig. 4 System evolution for different values of α

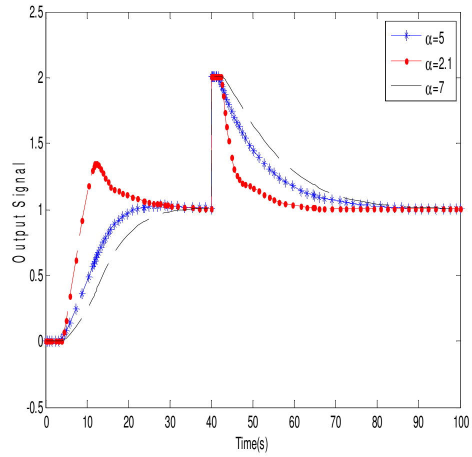
It can be seen that the new Internal Multi-Model Control structure shows a robust behavior characterized by a fast set-point tracking even in the presence of the variable time delay, which can be seen on the system step response and the command signal for α=5; where the filter effects dominate the system behavior and modelisations errors effects did not dominate the process behavior realizing a good compromise between robustness and rapidity.

However using small values of α could make the effects of modelisations errors dominates the system behavior; which is remarkable on the system response for α=2,1 where the process shows a peak and dumped oscillation on the transient before pursuing the reference. In addition to that, using high values of α could make the system response slow and not robust such is the case of α=7 where the process response pursues the reference after 40 second which is not acceptable.

Case of disturbance presence




Command signal




Output signal

Fig. 5 System response for different values of α in case of disturbance presence

These simulations show that the new command structure gives a robust behavior even in the presence of a disturbance which attacks the process output directly. This can be seen on the process step response for α=5 (filter's pole greater than the

International Journal of Control, Energy and Electrical Engineering (CEEE)
Copyright – IPCO-2014
Vol.1, pp. 1-9

model's poles) ; where the process reaches the steady state and rejects the disturbance smoothly due to the filter's effects that dominate the process behavior and impose zeros and poles of the new controller that gives such robust performances. But, when using values closer to the system poles, the filter dynamics could not dominate the process behavior and can give an opportunity to an oscillatory and instable behavior such is the case when using α=2.1where a peak appears on the process output and some dumped oscillations appears also on the command signal, this can be due to the effects of the system's poles that dominate the filter effect then using smaller values for α (the filter pole) could make the process behavior instable and not robust.

Moreover using values for the filter pole much greater than the models poles gives a slow and a no robust behavior such is the case for α=7 where it can be noted a slow behavior when reaching the steady state and when rejecting the disturbance.

*B. Obtained results using a second order Padé approximation*

As it was done in the previous section .The process is estimated to four systems with a fixed time delay then a second order Padé approximation will be used to compute system models $M_i(p)$ ; described by:

$$M_1(p)=\frac{1-\frac{p}{2}+\frac{p^2}{12}}{1+5.5p+\frac{31}{12}p^2+\frac{5}{12}p^3} \text{ for } \tau=1s,$$

$$M_2(p)=\frac{1-p+\frac{p^2}{3}}{1+6p+5.33p^2+\frac{5}{3}p^3} \text{ for } \tau=2s,$$

$$M_3(p)=\frac{1-\frac{3}{2}p+\frac{3}{4}p^2}{1+6.5p+8.25p^2+\frac{15}{4}p^3} \text{ for } \tau=3s,$$

$$\text{and } M_4(p)=\frac{1-2p+\frac{4}{3}p^2}{1+7p+\frac{44}{3}p^2+\frac{20}{3}p^3} \text{ for } \tau=4s$$

After this, a filter $f_i(p)$ will be associated with each model $M_i(p)$; that contains instable zeros of these models, which will be removed from the controller $C_i(p)$ expression, the used filters are described by:

$$f_1(p)=\frac{1-\frac{p}{2}+\frac{p^2}{12}}{(1+\alpha p)^3} \text{ for } M_1(p),$$

$$f_2(p)=\frac{1-p+\frac{p^2}{3}}{(1+\alpha p)^3} \text{ for } M_2(p),$$

$$f_3(p)=\frac{1-\frac{3}{2}p+\frac{3}{4}p^2}{(1+\alpha p)^3} \text{ for } M_3(p),$$

$$\text{and } f_4(p)=\frac{1-2p+\frac{4}{3}p^2}{(1+\alpha p)^3} \text{ for } M_4(p).$$

Then the controllers can be computed as it is described in section IV, and are described by:

$$C_i(p)=f_i(p)\times M_i^{-1}(p) \text{ for } i=1, 2, 3 \text{ and } 4;$$

where

$$C_1(p)=\frac{1+5.5p+\frac{31}{12}p^2+\frac{5}{12}p^3}{(1+\alpha p)^3},$$

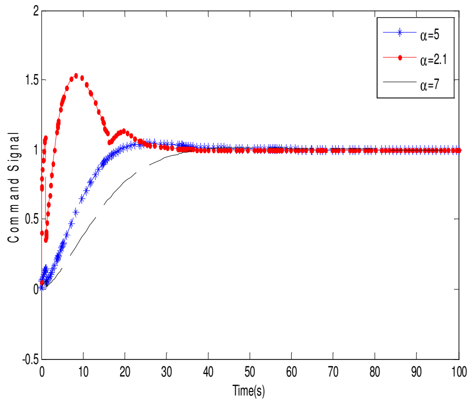
$$C_2(p)=\frac{1+6p+5.33p^2+\frac{5}{3}p^3}{(1+\alpha p)^3},$$

$$C_3(p)=\frac{1+6.5p+8.25p^2+\frac{15}{4}p^3}{(1+\alpha p)^3},$$

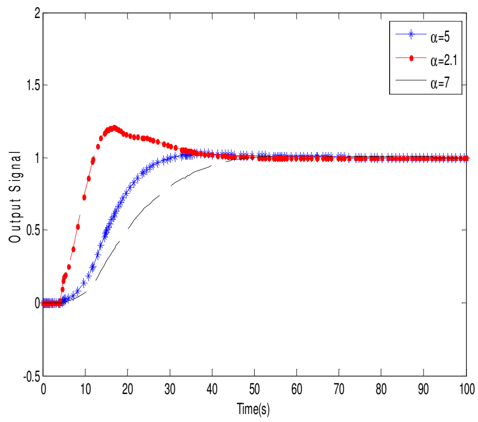
$$\text{and } C_4(p)=\frac{1+7p+\frac{44}{3}p^2+\frac{20}{3}p^3}{(1+\alpha p)^3}.$$

The simulation's results will be shown in figures 6 and 7 where the controllers are used for different values of the filter's parameter α to show the effects of its variation on the process behavior.

Case of disturbance absence



Command signal

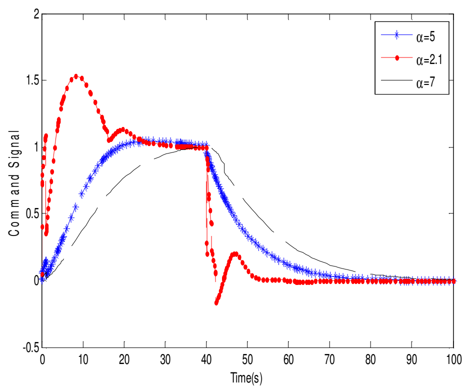



Output signal

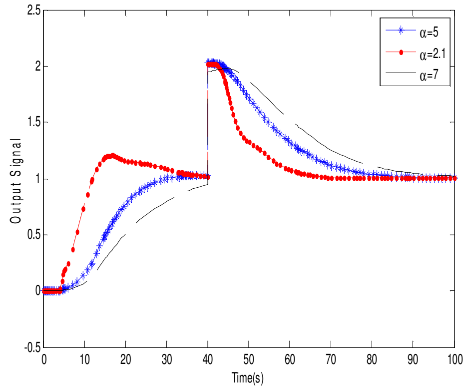
Fig. 6 System evolution for different values of α

It can be noted that by the use a second order Padé approximation, modelisations error's effects decrease, which can be seen on the command signal and the output signal for α=2,1 where the peak value decreases and the process gives a smoother behavior than the obtained behavior using a first order Padé approximation with the same filter pole. Then using a higher value of α could give an acceptable process behavior such is the case of using α=5 where the filter dynamics dominates the system behavior and the process shows a robust behavior even on the variation of the time delay; characterized by a fast set-point tracking which can be seen on the output signal and the command signal. However, the use of much higher value of α could make the system's response slow and not robust, this can be seen in the case of α=7 where the system's response became slow and not robust.

Case of disturbance presence




Command signal




Output signal

Fig. 7 System response for different values of α in case of disturbance presence

It can be seen that the new command structure gives a robust behaviour even on the presence of a disturbance ,that attacks the output directly on t=40s, and the variable time delay; this is remarkable when using α=5 where the process reaches the steady state and rejects the disturbance smoothly; this is due to the decrease of modelisation error's effects by using a second order approximation that gives opportunity for the filter poles to dominate the process behavior ; also the use of α=2,1 gives an acceptable behavior that can be seen on the reference tracking and the disturbance rejection; this behavior is more robust than the one obtained using a first order Padé approximation. However using greater values for α gives a slow and a not robust behavior such is the case for α=7 where we can see a slow step response when reaching slowly the steady state and when rejecting the disturbance which is not the objective of developing our new command structure.

*C. Obtained results using a third order Padé approximation*

As it was done when using a first and a second order Padé approximation. The process is estimated to four systems with a fixed time delay then a second order Padé approximation will be used to compute system models $M_i(p)$ ; described by:

$$M_1(p)=\frac{1-\frac{p}{2}+\frac{p^2}{10}-\frac{1}{120}p^3}{1+5.5p+2{,}6p^2+\frac{61}{120}p^3+\frac{5}{120}p^4}\quad \text{for } \tau=1s\ ,$$

$$M_2(p)=\frac{1-p+\frac{2}{5}p^2-\frac{1}{15}p^3}{1+6p+\frac{27}{5}p^2+\frac{31}{15}p^3+\frac{1}{3}p^4}\quad \text{for } \tau=2s\ ,$$

$$M_3(p)=\frac{1-\frac{3}{2}p+\frac{9}{10}p^2-\frac{9}{40}p^3}{1+6.5p+8.4p^2+4.72p^3+\frac{9}{8}p^4}\quad \text{for } \tau=3s\ ,$$

$$\text{and } M_4(p) = \frac{1 - 2p + \frac{16}{10}p^2 - \frac{2}{15}p^3}{1 + 7p + \frac{58}{5}p^2 + \frac{122}{15}p^3 + \frac{2}{3}p^4} \text{ for } \tau = 4s$$

After this, a filter $f_i(p)$ will be associated with each model $M_i(p)$ which contains instable zeros of these models that will be removed from the controller $C_i(p)$ expression, the used filters are described by:

$$f_1(p) = \frac{1 - \frac{p}{2} + \frac{p^2}{10} - \frac{1}{120}p^3}{(1+\alpha p)^4} \text{ for } M_1(p),$$

$$f_2(p) = \frac{1 - p + \frac{2}{5}p^2 - \frac{1}{15}p^3}{(1+\alpha p)^4} \text{ for } M_2(p),$$

$$f_3(p) = \frac{1 - \frac{3}{2}p + \frac{9}{10}p^2 - \frac{9}{40}p^3}{(1+\alpha p)^4} \text{ for } M_3(p),$$

and

$$f_4(p) = \frac{1 - 2p + \frac{16}{10}p^2 - \frac{2}{15}p^3}{(1+\alpha p)^4} \text{ for } M_4(p).$$

Then the controllers can be computed as it is described on section IV, and are described by:

$$C_i(p) = f_i(p) \times M_i^{-1}(p) \text{ for } i=1, 2, 3 \text{ and } 4;$$

where

$$C_1(p) = \frac{1 + 5.5p + 2,6p^2 + \frac{61}{120}p^3 + \frac{5}{120}p^4}{(1+\alpha p)^4},$$

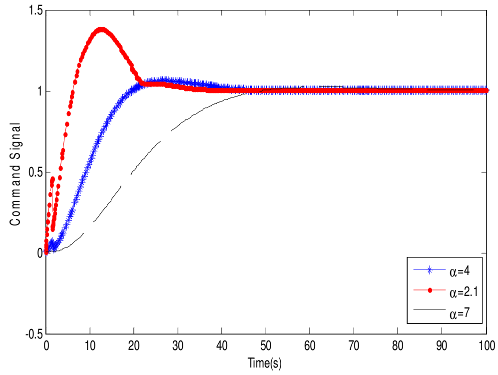
$$C_2(p) = \frac{1 + 6p + \frac{27}{5}p^2 + \frac{31}{15}p^3 + \frac{1}{3}p^4}{(1+\alpha p)^4},$$

$$C_3(p) = \frac{1 + 6.5p + 8.4p^2 + 4.72p^3 + \frac{9}{8}p^4}{(1+\alpha p)^4},$$

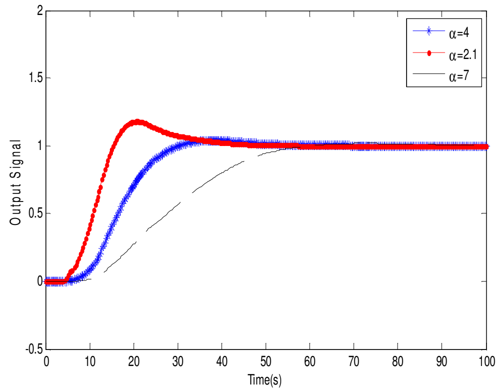
$$\text{and } C_4(p) = \frac{1 + 7p + \frac{58}{5}p^2 + \frac{122}{15}p^3 + \frac{2}{3}p^4}{(1+\alpha p)^4}.$$

The simulation's results will be shown on figures 8 and 9 where the controllers are used for different values of the filter's parameter α to show the effects of its variation on the process behavior.

Case of disturbance absence




Command signal

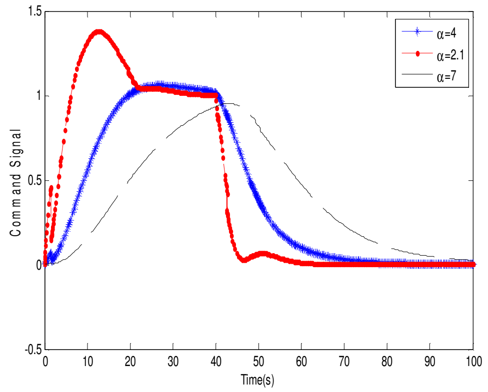



Output signal

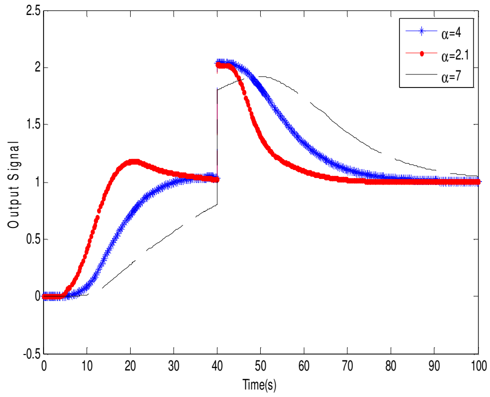
Fig. 8 System evolution for different values of α

It is remarkable that the new command structure gives robust behavior characterized by the fast reference tracking even in the presence of the variable time delay. The robustness of the command is due to the domination of the filter's poles on the process behavior this can be seen when using α=5 (the filter pole) where the process reaches smoothly the steady state. But using a filter pole closer to the model's poles could give some oscillations and the more the filter pole is closer to system poles the more the behavior is not robust this can be seen when using α=2,1 where the process reaches the steady state, after a peak its value decreases by using a third order Padé approximation. Moreover using greater values for the filter pole could lead the process to a slow and a not robust behavior such is the case when using α=7 where the process reaches the steady state slowly after 80 second which is not the goal of our command.

Case of disturbance presence




Command signal




Output signal

Fig. 9 System response for different values of α in case of disturbance presence

It can be noted that the new command structure shows a robust behavior; this can be seen in the fast reference tracking even on the presence of a disturbance that affects the process output directly and the variable time delay. The robust behavior is due to the use of a controller that imposes poles and zeros for the process; which are included on the filter dynamics that dominates the process behavior by choosing filter's poles greater than model's poles in order to ensure an acceptable compromise between robustness and rapidity; this can be seen when using α=5 where the process reaches the steady state and rejects the disturbance smoothly and shows the speed and the robustness of the new Internal Multi-Model Controller. However, by using values closer to the system's pole, we obtain faster step response and some instability criteria such as peak and oscillations this can be seen when using α=2,1 where a peak and some dumped oscillations are present on the command signal. But when using values higher than the model's poles, for the filter's pole, we obtain a slow and a not robust step response; this can be seen on the process command and output signal when α=7, where the process reaches the steady state and rejects the disturbance slowly; and shows a not robust behavior which is not the aim of the new controller that shall give a fast and a robust command that gives the required process performances.

## VII. Conclusion

In this work a new command structure was developed for the control of a linear system with a limited variable time delay. This command structure is based on the combination of Multi-Model concepts and Internal Model Control in order to obtain a robust system behavior. Unfortunately a collection of models, calculated using Padé approximations, are used to approximate the process expression and their inverses will be associated with a collection of low pass filters; in order to obtain a set of controllers, composed by the multiplication of low pass filters and models inverses.

This new Internal Multi-Model Command design method gives interesting results for a linear process with a limited variable time delay, shows a robust behavior; and allows the designer to control the robustness level of the command through the variation of the filter's parameters in order to obtain an acceptable compromise between stability and rapidity; which is the main advantage of this command structure.

## References

[1] ACKERMANN J., "Robust control: Systems with uncertain physical parameters", Springer-Verlag, New York, 1993.

[2] BROWN M.D., LIGHTBODY G., and IRWIN G.W., "Nonlinear internal model control using local networks", IEE Proceedings-Control Theory and Applications, Vol. 144, pp. 505-514, 1997.

[3] DELMOTE F., " Analyse multimodèle", Thèse de Doctorat, USTL, Lille, 1997.

[4] GARCIA C.E. et MORARI M.," Internal Model Control 1- A unifying review and some results", Ind. Eng. Chem. Process Des. Dev., Vol. 21, pp. 403-411, 1982.

[5] J.E.NORMEY-RICO et E.F CAMACHO, "Control of Dead-time Processes", Springer–Verlag London,2007.

[6] MORARI M. et ZAFIROU E., "Robust process control ", Prentice Hall, USA, 1989.

[7] NACEUR M. , " Sur la commande par modèle interne des systèmes dynamiques continus et échantillonnés " , Thèse de Doctorat, ENIT, Tunis, 2008.

[8] TOUZRI M. , NACEUR M. , SOUDANI D. , "A New IMC Controller Design Method Using a Low Pass Filter and Variation Effects of Its order", 2nd International Conference on System and Control, ICSC'2012, Marrakech MAROCCO

[9] TOUZRI M. , NACEUR M. , SOUDANI D. , "A new design method of an imc controller for a second order system with time delay and an instable zero", Twelfth International conference on Science and Techniques of Automatic Control & computer engineering, STA'2011, Sousse TUNISIA, 2011, pp 123-133.

[10] ZHONG Qing-Chang, "Robust control of time-delay systems", Springer-Verlag London 2006.