MULTI-CONTROLLERS APPROACH APPLIED TO A WRIST OF A ROBOT .

Youcef Zennir[(1)], **Pascal Mouille**[(2)]

[(1)]*Laboratoire d'automatique de Skikda, 26 route El-hadaeik,21000 Skikda, Algérie.*
[(2)]*Polytech Annecy-Chambéry, BP 80439, 74944 Annecy-le-Vieux, France.*

[(1)]youcefzennir@yahoo.com [(2)]Pascal.Mouille@univ-savoie.fr

ABSTRACT
The work presented in this paper focuses on the multi-controller approach of control. In the first time we modeled the process (wrist of a Staubli robot RX 90) and we identified local parametric models around operating points. The originality of our approach lies in the use of an integrator in the process to avoid the use of the operating points in an explicit way in the control law, and the fact that several controllers scanned linear type RST with the delta operator (δ), one hand a working (free switching) to develop the control signal sent to the process. We present the results obtained in the different simulations before opening perspectives for future work.

Keywords: Modelling, Identification, Local Control, Multi-controller control, free commutation, adaptive control

1. INTRODUCTION

Invariant linear model for a physical process can only be an approximation. Indeed, a physical process generally has non-linearities (Slotine 1991) that are not taken into account in the modeling process. For some operating points of the physical process can be determined a local model linear. These linear models can be derived from a priori knowledge of the process or be derived from an identification step. We may then seek to enslave the whole process in operational space using the local information. The objectives of this work are to introduce an integrator in the process and develop a command structure in which control laws together several local synthesized from local models of the process. The purpose of the multi-controller command (Balakrishnan 1997) is to control the output of any process in space operation using controls developed by different local controller use the multi-controller command is to specify:

- The structures of the controllers used.
- The type of switching (Pagès 2000; Duchamp 1998).
- The method of working of the control law.

Different solutions are proposed for the control law such as:

- Use controllers of RST type.
- Use of adaptive controllers.
- Use free or fuzzy commutation (Pagès 2000; Foulloy 1998).
- Use direct or indirect approach to collaboration control law.

In our work we have chosen the solution is to use an indirect approach based on local controllers and switching straightforward.

2. PROCESS MODELING

The process can be represented by the following figure:

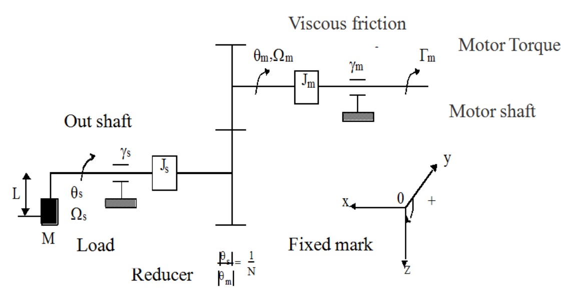

Figure 1: Process model.

It corresponds to a robot wrist (one axis). It is composed of a drive shaft and an output shaft connected by a reducing agent. The output shaft drives a mechanical load. By applying the fundamental law of mechanics (rotation) to the motor shaft and the output shaft we obtain the following equation:

$$\Gamma_m + \frac{M \cdot g \cdot L}{N} \cdot \sin(\theta_s) = J_t \cdot \ddot{\theta}_m + \gamma_t \cdot \dot{\theta}_m \qquad (1)$$

With:

$$J_t = J_m + \frac{J_s'}{N^2} \qquad (2)$$

J_t: Moment of inertia reduced to the motor shaft. J_s: total moment of inertia of the output shaft (output shaft over the mechanical load).

$$\gamma_t = \gamma_m + \frac{\gamma_s}{N^2} \qquad (3)$$

γ_t: total Viscous friction reduced to the motor shaft. The motor torque is given by:

$$\Gamma_m = K_e \cdot u \qquad (4)$$

With : K_e: torque constant, u: control voltage.
The nonlinear model is:

$$X_1 = \theta_m(t);\ X_2 = \dot{\theta}_m(t)\ ;\quad X = \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} \qquad (5)$$

$$\dot{X} = \begin{bmatrix} 0 & 1 \\ \frac{M \cdot g \cdot L}{N \cdot J_t} & -\frac{\gamma_t}{J_t} \end{bmatrix} \cdot \begin{bmatrix} \sin\left(\frac{X_1}{N}\right) \\ X_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K_e}{J_t} \end{bmatrix} \cdot u \qquad (6)$$

$$Y = \begin{bmatrix} -\frac{1}{N} & 0 \end{bmatrix} \cdot X \qquad (7)$$

This is a model of a nonlinear system affine. To find the structure of local parametric models, we used the tangent linearization and the linear model is as follows:

$$\delta\dot{X} = \begin{bmatrix} 0 & 1 \\ -\frac{M \cdot g \cdot L}{N^2 \cdot J_t} \cdot \cos\left(\frac{X_{10}}{N}\right) & -\frac{\gamma_t}{J_t} \end{bmatrix} \cdot \delta X + \begin{bmatrix} 0 \\ \frac{K_e}{J_t} \end{bmatrix} \cdot \delta u \qquad (8)$$

$$\delta Y = \begin{bmatrix} -\frac{1}{N} & 0 \end{bmatrix} \cdot \delta X \qquad (9)$$

The transfer function G (p) of the process corresponds the linear model is given by the following formula:

$$G(p) = \frac{-K_p}{p^2 + a_{p1} \cdot p + a_{p2}} \qquad (10)$$

$$\text{With: } K_p = \frac{K_e}{N \cdot J_t};\ a_{p1} = \frac{\gamma_t}{J_t};\ a_{p2} = \frac{M \cdot g \cdot L}{N^2 \cdot J_t} \cdot \mathrm{COS}\left(\frac{X_{10}}{N}\right) \qquad (11)$$

For identify around each operating point considered a linear model of order two, we place the process around the operating point (u_0=0, X_{10}=0) and we excite the process with the following signal:

$$u(t) = 0.2 \cdot [\sin(2\pi t) + \sin(4\pi t) + \sin(8\pi t)] \qquad (12)$$

This command is blocked sampled at the frequency of 1 KHz before being sent to the process. After the identification we obtained the following discrete model:

$$G(z) = \frac{-0.0001109 \cdot z}{z^2 - 1.989 \cdot z + 0.9888} \qquad (13)$$

This model corresponds to discrete continuous model as follows:

$$G(p) = \frac{-0.05566 \cdot p - 111.5}{p^2 + 11.25 \cdot p + 79.14} \qquad (14)$$

We see that the coefficient (-0.05566) is small, more the process model (10) contains no zeros. So we remove this factor and are taken as the continuous model:

$$G(p) = \frac{-111.5}{p^2 + 11.25 \cdot p + 79.14} \qquad (15)$$

We deduce:

$$\begin{cases} K_p = 111.5;\ a_{p1} = 11.25; \\ a_{p2} = C_1 \cdot \mathrm{COS}\left(\frac{X_{10}}{N}\right);\ C_1 = 79.14 \end{cases} \qquad (16)$$

So, we can deduce the two local models corresponding to the operating point's $\theta_{s0}=\pi/3$ and $\theta_{s0}=2\pi/3$ respectively:

$$G(p) = \frac{-111.5}{p^2 + 11.25 \cdot p + 39.57};\quad G(p) = \frac{-111.5}{p^2 + 11.25 \cdot p - 39.57} \qquad (17)$$

3. INTRODUCTION OF AN INTEGRATOR

Interest of the integrator does no longer have to introduce the operating points (u0, y0) in an explicit way to compute the control laws. Indeed, it is he who will give the nominal control and guarantee the performance static. The integrator is arranged as follows:

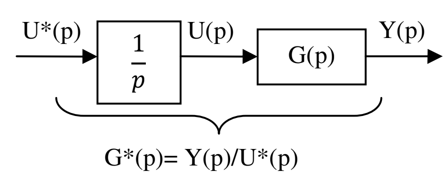

Figure 2: Process with Integrator

From this diagram, it is assumed that the integrator is in the process. So we consider we have a new transfer function G * (p):

$$G^*(p) = \frac{-K_p}{p \cdot (p^2 + a_{p1} \cdot p + a_{p2})} \qquad (19)$$

4. LOCAL CONTROLLERS STRUCTURE

The structure of the local controllers is of type (RST). The command is a command used by the reference model and output feedback (Chebassier 1999; Balakrishnan 1994).We choose the parameters of the reference model for the latter as follows:

$$Y_m(p) = \frac{\gamma^3}{(p+\gamma)^3} \cdot R(p) = G_m(p) \cdot R(p) \qquad (20)$$

With: R (p) is the set of the loop closes. In this case, we can represent the local controller by the following block diagram:

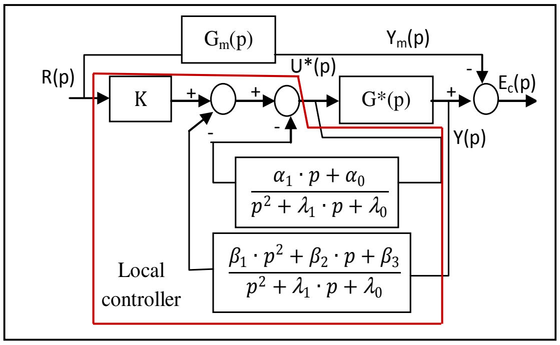

Figure 3: Structure of local Controller

G * (p): transfer function of the local method with the integrator.

5. THE FIRST SIMULATION

The synthesis of the controllers is continuous. The simulation is done in discrete time operating points are used θ_{s0}=0rad, $\theta_{s0}=\pi/3$rad and $\theta_{s0}=2\pi/3$rad. The parameter values of the reference model λ_0 and λ_1 are:

$$\gamma = 10{:}\ \lambda_0 = 900;\ \lambda_1 = 60 \qquad (21)$$

The values λ_0 and λ_1 are chosen so that controllers are stable. The parameters of the controllers around the operating points chosen are:

parameters	K	$\alpha_0(e^{+003})$	α_1
Controller (θ_s=0)	-8.96	1.13	18.75
Controller ($\theta_s=\pi/3$)	-8.96	1.17	18.75
Controller ($\theta_s=2\pi/3$)	-8.96	1.25	18.75
	$B_1(e^{+003})$	B_2	$B_3(e^{+003})$
Controller (θ_s=0)	-8.07	-151.34	-1.51
Controller ($\theta_s=\pi/3$)	-8.07	-157.29	-2.22
Controller ($\theta_s=2\pi/3$)	-8.07	-223.20	-3.72

Table 1: Parameters of the local Controller

Two simulations have been performed for each operating point in order to verify the role of the integrator, the stability of the closed loop and the proper functioning of the controllers around the operating points.

For the validation of the use of the integrator the controller around the operating point θ_{s0}=0rad, the reference signal r (t) is a step of amplitude 0.1rad happens at t=1s. the figure 4.a corresponds to error control and the figure.4.b corresponds to the process and the outputs of reference model.

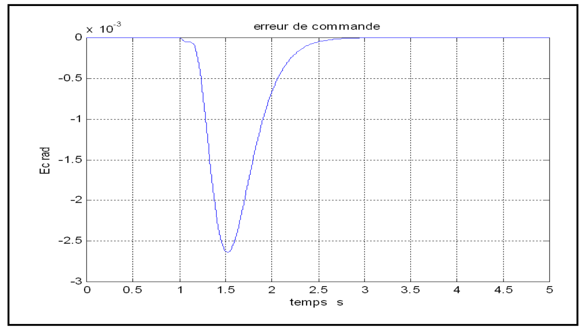

Figure 4.a: Control error e_c (t).

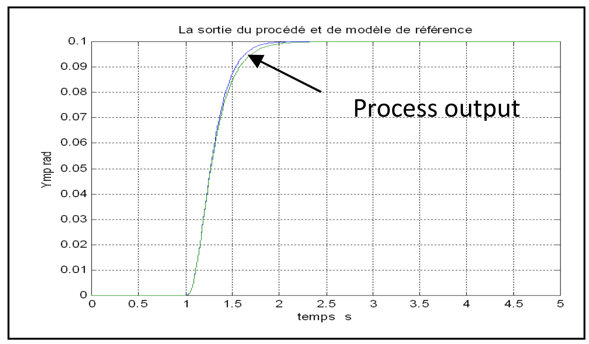

Figure 4.b: outputs of the process and the reference model.

From Figure 4.a, we see that after a transient, the command error tends to zero. From Figure 4.b, we see that the static gain is equal to 1. Thus, we conclude that the integrator guarantees static performance. It was also a good trajectory tracking. We can conclude that the integrator introduced just upstream of the process, plays its role.

For the Operation of the controllers around the operating points the controller around the operating point θ_{s0}=0 rad, the reference signal is equal to:

$$\mathrm{r(t)} = 0.1 \cdot \sin(20 \cdot \mathrm{t}) \qquad (22)$$

The figure 5.a corresponds to error control and figure 5.b corresponds to the process and the outputs of the reference model.

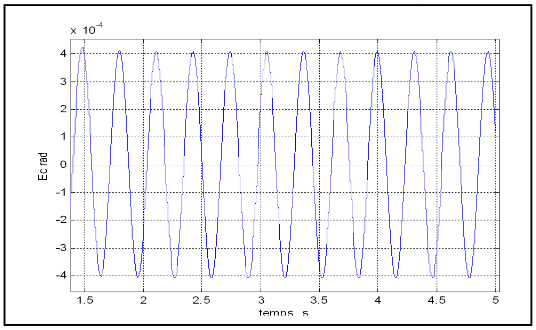

Figure 5.a: control error e_c (t) (rad).

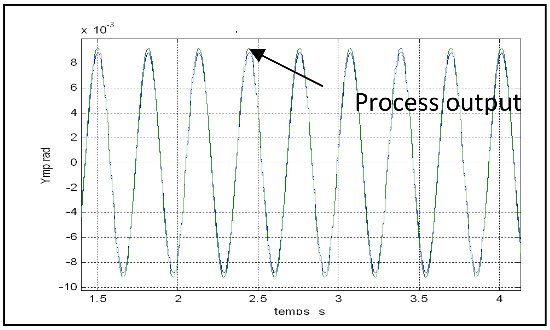

Figure 5.b: outputs of the process and the reference model (rad).

On figure.5.a we see that the control error is very low. We note from the figure.5.b we have a good trajectory tracking of the output of the process compared to the output of the reference model. We can conclude that the local controllers give good performances locally.

6. MULTI-CONTROLLERS STRUCTURE OF CONTROL

The first object of the multi-controllers structure of the control is to control the output of the process in a whole space of variation of parameters under consideration using commands developed by the various local controllers. The diagram is as follows:

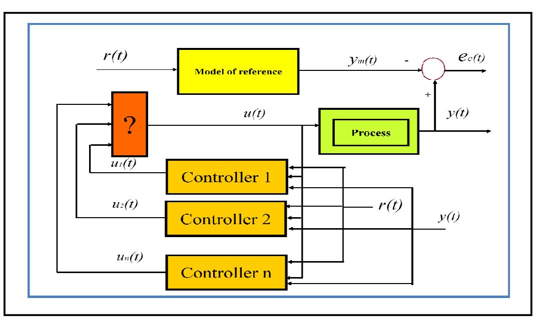

Figure 6: Multi-controller structure of control.

Different solutions are possible to calculate the control to be applied to the process (table 2) and we focus in this study on the use of free switching controllers. That is to say, at each instant a single controller will generate the command to be applied to the process (u (t) = u (t), i = 1 ... n).

Switching or mixing of different orders is overseen by local information about the "distance" between the current state of the process and the different operating points. This information can be measurement (output of the method, for example) or rebuilt (using predictors).

	Frank commutation	**Fuzzy commutation**
Indirect approach based on reconstructed information	**category 1** N linear predictors associated with N linear controllers RST	**category 3** N linear predictors associated with N linear controllers RST
Direct approach commutation based on measured information	**category 2** N linear controllers R.S.T	**category 4** N linear controllers R.S.T

Table 2: Category of multi-controller control.

The work presented in this article relates to first category.

7. INDIRECT APPROACH WITH FRANK COMMUTATION

Control u (t) applied to the process is equal, at every moment, one of the outputs of local controllers. Switching is based on information reconstructed by predictors. These are calculated from the local controllers. The reconstructed information is estimated from the output of the process figure 7. This approach was developed by KS Narendra and J. (Balakrishnan 1997; Toscano 1998; Pagès 2000). Calculating for each predictor an indicator (quadratic criterion) performance defined by the following formula:

$$j_j(t) = \alpha \cdot e_j^2(t) + \beta \cdot \int_0^t e^{(-\lambda \cdot (t-\tau))} \cdot e_j^2(\tau) \cdot d\tau \qquad (23)$$

with : $\alpha \geq 0;\ \beta > 0;\ \lambda > 0$

ej (t) associated with the identification error predictor of index j.
$J_j(t)$: quadratic criterion indicator associated with the performance predictor of index j.

Free switching is based on the following criteria quadratic each time the command is applied to the process equal to the output of the controller associated with the predictor that gives small quadratic criterion. Each local controller is associated with a predictor.

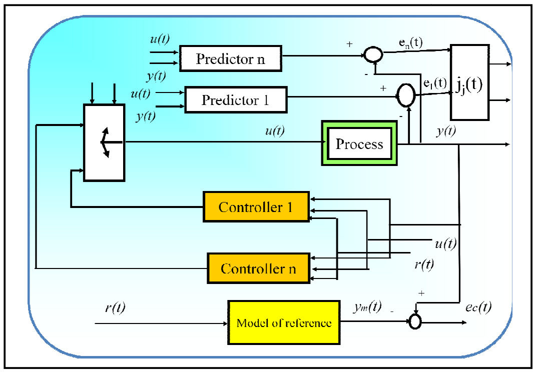

Figure 8: Indirect approach with frank commutation.

We used the predictor proposed by Narendra and Balakrishnan [1] [7], modeled by the following equation:

$$Y(p) = Y_m(p) = G_m(p) \cdot R(p) = G_m(p) \cdot \left[\frac{\varphi(p)}{\lambda(p)} \cdot U^*(p) + \frac{\beta(p)}{\lambda(p)} \cdot Y(p)\right] \quad (24)$$

Note that the polynomials $\beta(p)$, $\varphi(p)$, $\lambda(p)$ will directly result of the controller.

8. THE SECOND SIMULATION

The synthesis of the predictors is continuous. The simulation is done in discrete time. The operating points are used θ_{s0}=0 rad, θ_{s0}=3/π rad and θ_{s0}=2π /3 rad. For predictor around the operating point θ_{s0}=0 rad, the reference signal is equal to:

$$r(t) = 0.1 \cdot \sin(20 \cdot t) \quad (25)$$

Reference Model: γ = 10. Quadratic criterion: α = 1, β = 4, λ = 120. These parameters are selected based on the process dynamics. And we have the following result:

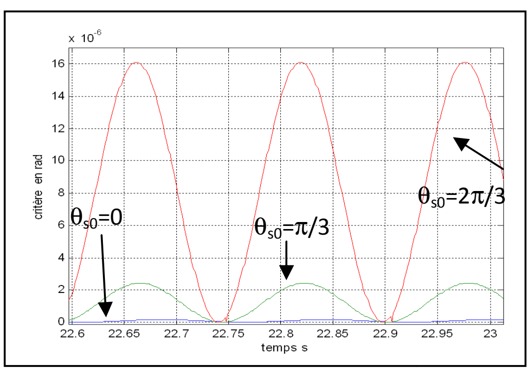

Figure 9: Quadratic criteria.

From the figure 9, we see that the evolution of the quadratic criterion is very low.

In the frank commutation with controllers fixed simulation we use the free switching and the reference signal is:

$$r(t) = \frac{\pi}{3} + \frac{6\pi}{2} \cdot \sin(20 \cdot t) \quad (26)$$

The simulation is done in discrete time, and the result is shown in the following figures:

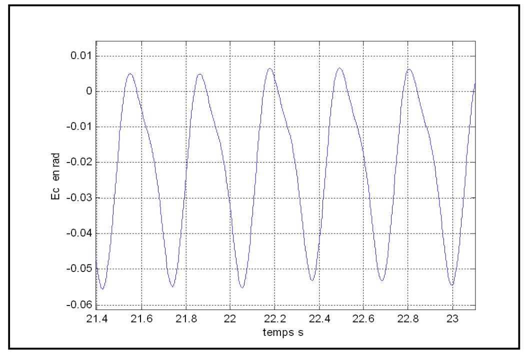

Figure 10: Control error e_c (t) in (rad)

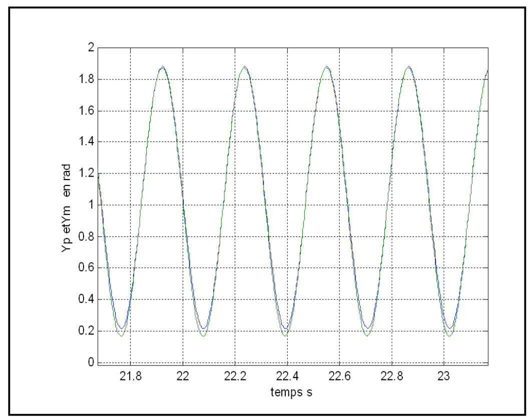

Figure 11: The output of the process and the reference model in (rad).

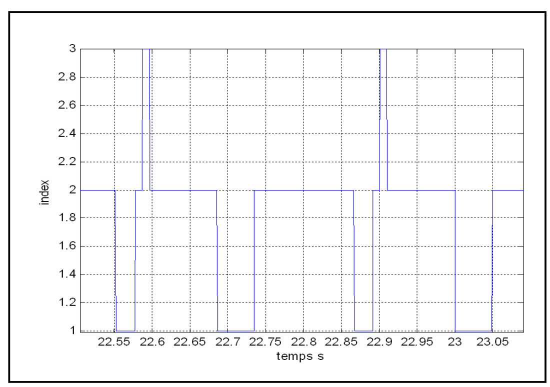

Figure 12: Switching frank local controllers

The figure 10 and figure 11 show the evolution of the error control signal and the output of the process and reference model. The figure 12 shows the commutation signal. We see from the results that the evolution of the criteria is very low. Predictors and the local controllers ensure proper operation of the process around the operating points.

9. RE-INITIALIZED PREDICTOR ADAPTIVE

The re-initialized predictor adaptive with the same structure of the predictor. The parameters of this re-initialized predictor adaptive are re-initialized by the values of the parameters of a fixed predictor who gives the minimum error of the identification (Karimi 1998). The adaptive predictor has as a role to adapt the parameters. The objective to use the re-initialized predictor adaptive is to ensure the good performance of the process between the points of operation.

Considering the fixed predictors give good performances only around the operation points. We used the algorithm of least squares standardized with a factor of lapse of memory to adapt the parameters of the predictors [5]. While using like a reference signal:

$$r(t) = \frac{\pi}{3} + \frac{6\pi}{2}\cdot\sin(20\cdot t) \qquad (27)$$

After simulation wee obtains the following figures:

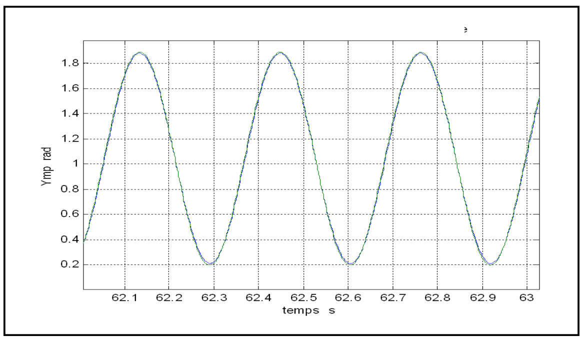

Figure 13: The output of the process and the reference model in (rad).

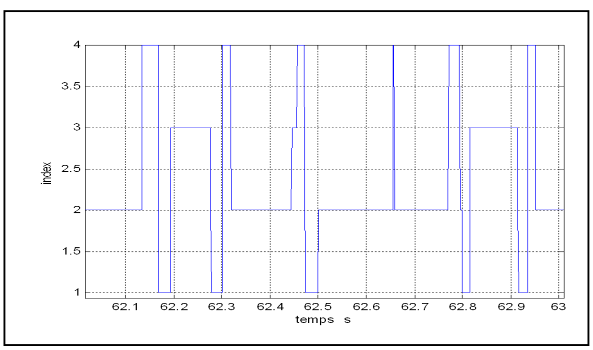

Figure 14: Switching frank local controllers

10. CONCLUSION

In this work, we presented the modeling of nonlinear process. Then, we calculated linear models about operating points considered. Then, we identified the parameters of local linear models. After that, we did a study on the introduction of an integrator.

The results obtained allow concluding that the local controllers give good results around the operating points. But the results are local.

Therefore, we must seek a collaborative approach these local control laws to obtain good results in all operating space. To this end, we presented the different types of control structures multi-controllers with indirect approaches, and the principle of frank switching.

Then we presented the structures of the predictors used. According to the simulation results, we conclude that the predictors fixed premises give good results. It can be seen that the use of the free switching gives acceptable results in the entire space of the system.

It is also concluded that the results obtained by the introduction of a re-initialized predictor adaptive are good compared to the results obtained by frank commutation without the adaptive one.

In the continuation of our work we will study at the first time fuzzy commutation with the indirect approach, then the same category with other type of controller as example numerical PID fractional

REFERENCES

Balakrishnan J. and Narendra S. 1994. *Improving Transient Response of Adaptive Control Systems Using Multiple Models and Switching*. IEEE Trans. on Automatic Control, Vol. 39, n°9, Septembre 1994, pp. 1861-1866.

Balakrishnan J. and Narendra S. 1997. *Adaptive Control using Multiple Models*. IEEE Trans. on Automatic Control, Vol. 42, n°2, Février 1997, pp. 171-187.

Chebassier J.1999. *Méthadologies pour la conception d'un système de commande par calculateur*. Thèse Laboratoire d'Automatique de grenoble (INPG) , 1999.

Duchamp J-M. 1998. *Commutation Floue de lois de Commande applique à la Robotique*. Rapport de DEA , LAMII /CESALP.

Slotine JJE. 1991. *Applied Nonlinear Control*. Prentice-Hall International, ISBN: 0-13-040049.

Karimi A. and Landau I-D. 1998. *Robust Adaptive Control of a Flexible Transmission System Using Multiple Models*. Laboratoire d'Automatique de Grenoble (CNRS-INPG-UJF). Design-CSD, 1998.

Pagès O., Mouille P. and Caron B. 2000. *Two approaches of the multi-model control. Real time Implementation for a wrist of a Robot.* Mechatronics 2000, 1st IFAC Conference on mechatronic systems, Darmstadt, Allemagne, Septembre, 2000.

Pagès O., Mouille P. and Caron B. 2000. *Multi-Model Control by Applying a Symbolic Fuzzy Switcher*. Control Systems Design-CSD 2000, IFAC Conference, Bratislava, République Slovaque, Juin, 2000.

Toscano R., Martin-Calle D. and Passerieu P. 1997. *Adaptation paramétrique floue d'une commande au premier ordre en fonction du point d'équilibre courant.* Laboratoire d'Automatique E.N.I St ETIENNE LFA'97 -Lyon-décembre, pp.3-10.

Foulloy L. and Ramdani M. 1998. *Logique Floue Exercices corrigés et exemples d'applications*. cEpaduEs-EDITIONS, juillet, 1998.