People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific research
M'hamed Bougara University, Boumerdes
Institute of Electrical and Electronic Engineering,
Laboratory of Signals and Systems (LSS)

ALGERIAN JOURNAL OF SIGNALS AND SYSTEMS

ISSN : 2543-3792

Title: **IMC Multi-Controller Strategies applied on a Manipulator Robot**

Authors: **Y. Zennir, E.Guechi, L. Chetioui, R. Bendib**
Affiliation:
Automatic Laboratory of Skikda, Université 20 Août 1955 Skikda, Skikda, Algeria

Page range: **51- 62**

Volume : 2 Issue : 1 (April 2017)
Special Issue of the International Conference on Technological Advances in Electrical Engineering
Skikda, Algeria, 24-26 October 2016

Laboratory of Signals and Systems
Address : IGEE (Ex-INELEC), Boumerdes University, Avenue de l'indépendance, 35000, Boumerdes, Algeria
Phone/Fax : 024 79 57 66
Email : lss@univ-boumerdes.dz ; ajsyssig@gmail.com

IMC Multi-Controller Strategies applied on a Manipulator Robot

Y. Zennir(1)*, E.Guechi(2), L. Chetioui(3), R. Bendib(4),
(1,2,3,4)Automatic Laboratory of Skikda, Université 20 Août 1955 Skikda, Skikda, Algeria
*youcef.zennir@univ-skikda.dz

Abstract: The paper focuses on the use of multi-controller approach to control a robot wrist (STÄUBLI robot RX 90). The descriptions of a nonlinear mathematical model of the process have been presented with the local parametric models around operating points. Controller design of a conventional PID, IMC control, LQG control and H∝ (loop shaping) has been described around each selected operating points for each local parametric models. Finally , in order to show the efficiency of the proposed method, some simulation results in CAO 3D solid-works and MATLAB environments are given.

Keywords: Modeling, Multi-control approach, Multi-controller control, Fractional PID controller, IMC controller, LQG controller, Oustaloup Recursive Approximation method.

1. INTRODUCTION

Invariant linear model for a physical process can only be an approximation. Indeed, a physical process generally has non-linearities [1] that are not taken into account in the modeling of the process. For some operating points of the physical process a local linear model can be determined. Two ways can be used to derive these linear models the first is based on the priori knowledge of the process and the second using identification. We may then seek to enslave the whole process in operational space using the local information [2],[3]. The objectives of this work are to develop a control structure in which control law is deduced from a set of controllers that are working together. The controllers parameters are deduced from the local models of the process. The purpose of the multi-controller command [4] is to control the output of any process in space operation using controls developed by different local controllers. The diagram block of the multi-controllers control approach is represented as follows:

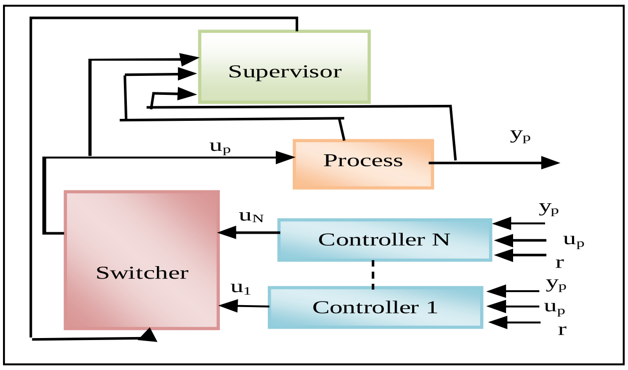


Fig. 1: Multi-controller structure approach.

The multi-controller command is used to specify:

- The controller's structures.
- The switching type [5],[6].

Different solutions are proposed such as:

- Fractional order PID controllers [7].
- Digital RST controller and Adaptive controllers [8],[9].

- Frank or fuzzy switching [8][10].
- Direct or indirect approach to collaboration control law [8][10]. .

In our work we have choose the use of an indirect approach based on comparison between different local controller like fractional order PID controllers, IMC control and LQG control and frank switching for robot wrist control.

2. PROCESS MODELING

The geometric series structure model of STÄUBLI Robot Rx-90 is shown in the figure 2 [11]:

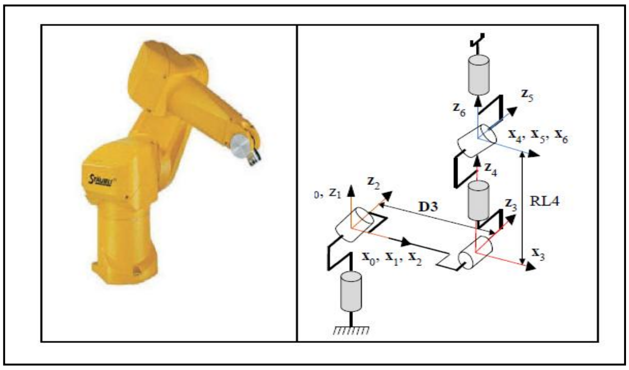


Fig. 2: RX-90 Robot model.

This robot has coupling between axis 5 and 6. The actuators are brushless motors and the engine control uses the rotor position to magnetic flux rotate to achieve desired torque value. Our process corresponds to the robot wrist (axis 6) can be represented by the following figure:

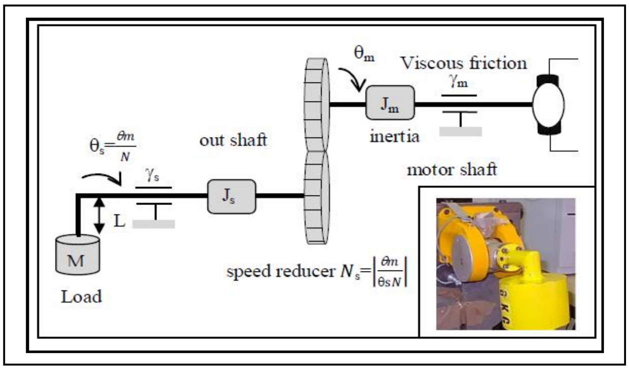


Fig. 3: Process model.

The mathematic dynamic process model is given by the following equations:

$$\Gamma_m - \Gamma_s = \left(J_m + \frac{J_s + M \cdot L^2}{N^2}\right) \cdot \ddot{\theta}_m + \left(\gamma_m + \frac{\gamma_s}{N^2}\right) \cdot \dot{\theta}_m \quad (1)$$

$$\Gamma_s = -\frac{M \cdot g \cdot L}{N} \cdot \sin(\theta_s) \quad (2)$$

with:

$$J_t = \left(J_m + \frac{J_s + M \cdot L^2}{N^2}\right) \quad (3)$$

where:
J_m: inertia moment applied in the motor shaft.
J_s: inertia moment applied in the output shaft (output shaft with mass).

$$\gamma_t = \gamma_m + \frac{\gamma_s}{N^2} \quad (4)$$

γm,γs:: Viscous friction applied to the motor shaft and output shaft respectively.
The motor torque is given by:

$$\Gamma_m = K_e \cdot u(t) \tag{5}$$

Where: Ke is the torque constant and u(t) control voltage.

Then the nonlinear model is given by:

$$X_1 = \theta_m(t);\ X_2 = \dot{\theta}_m(t); X = \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} \tag{6}$$

$$\dot{X} = \begin{bmatrix} 0 & 1 \\ \frac{M \cdot g \cdot L}{N \cdot J_t} & -\frac{\gamma_t}{J_t} \end{bmatrix} \cdot \begin{bmatrix} \sin\left(\frac{X_1}{N}\right) \\ X_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K_e}{J_t} \end{bmatrix} \cdot u(t) \tag{7}$$

$$Y = \theta_s(t) = \begin{bmatrix} -\frac{1}{N} & 0 \end{bmatrix} \cdot X \tag{8}$$

To find the structure of local parametric models, we have used the tangent linearization. The general form of tangent linearization applied on a non-linear system is:

$$\delta_x = \left[\frac{\partial f}{\partial x}\Big| + \frac{\partial g}{\partial x}\Big|.u_0\right].\delta X + g(X_0).\delta u \tag{9}$$

$$\delta Y = -\delta X_1 / N \tag{10}$$

with :

$$\delta X = X - X_0\ ;\ \delta Y = Y - Y_0\ ;\ \delta u = u - u_0 \tag{11}$$

At equilibrium point:

$$f(X_0) + g(X_0)u_0 = 0 \tag{12}$$

$$X_{2_0} = 0 \tag{13}$$

$$u_0 = \frac{M.g.L}{N.k_e}.\sin\left(\frac{X_{1_0}}{N}\right) \tag{14}$$

After the applied the equation (1) around operating point (u0,X0), we have obtained the linear model as a follows:

- State equation:

$$\dot{X} = \begin{bmatrix} 0 & 1 \\ \frac{-M.g.L}{N^2.J_t}.\cos\left(\frac{X_{1_0}}{N}\right) & -\frac{\gamma_t}{J_t} \end{bmatrix}.\delta X + \begin{bmatrix} 0 \\ \frac{K_0}{J_t} \end{bmatrix}.\delta u \tag{15}$$

- Output equation :

$$\delta Y = \begin{bmatrix} -\frac{1}{N} & 0 \end{bmatrix} \cdot \delta X \tag{16}$$

This system has the follows form:

$$\dot{\delta X} = A.\delta X + B.\Delta u \tag{17}$$

$$\delta Y = C.\delta X \tag{18}$$

the process transfer function G(p) can by obtained by the following function:

$$G(s) = C.[s.I - A]^{-1}.B = \frac{\delta Y(s)}{\delta U(s)} \quad (19)$$

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

$$G(s) = \frac{-K_p}{s^2 + a_{p1} \cdot s + a_{p2}} \quad (20)$$

Where:

$$K_p = \frac{K_e}{N \cdot J_t}; a_{p1} = \frac{\gamma_t}{J_t}; a_{p2} = \frac{M \cdot g \cdot L}{N^2 \cdot J_t} \cdot \cos\left(\frac{X_{10}}{N}\right) \quad (21)$$

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:

$$u(t) = 0.2 \cdot [\sin(2\pi t) + \sin(4\pi t) + \sin(8\pi t)] \quad (22)$$

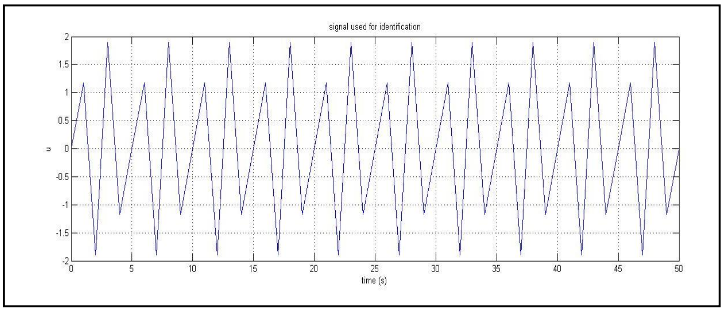


Fig. 4: Structure of FOPID local controller.

After the identification we obtained the following discrete model:

$$G(z) = \frac{-0.0001109 \cdot z}{z^2 - 1.989 \cdot z + 0.9888} \quad (23)$$

This model corresponds to discrete continuous model as follows:

$$G(s) = \frac{-0.05566 \cdot s - 111.5}{s^2 + 11.25 \cdot s + 79.14} \quad (24)$$

The process model (20) contains no zeros. So we obtained the continuous model follows:

$$G(s) = \frac{-111.5}{s^2 + 11.25 \cdot s + 79.14} \quad (25)$$

We deduce:

$$\begin{cases} K_p = 111.5; a_{p1} = 11.25; \\ a_{p2} = C_1 \cdot \cos\left(\frac{X_{10}}{N}\right); C_1 = 79.14 \end{cases} \quad (26)$$

The corresponding continuous linear model is as follows:

- operating points, $\theta s0=0$: $G_1(s) = \frac{-111.5}{s^2+11.25\cdot s+79.14}$ (27)

- operating points, $\theta s0=\pi/3$ and $\theta s0=2\pi/3$ respectively:

$$G_2(s) = \frac{-111.5}{s^2+11.25\cdot s+39.57}\,;\;\; G_3(p) = \frac{-111.5}{s^2+11.25\cdot s-39.57} \qquad (28)$$

3. INTERNAL MODEL CONTROL AND LQG CONTROL

This internal model control (IMC) approach is based on the principle of proposing a control synthesis that acts in parallel to the system and a model perfectly illustrates the dynamic structure of the exogenous signal that the regulator is supposed to control in real time (Figure 5) including additive noise output [1].

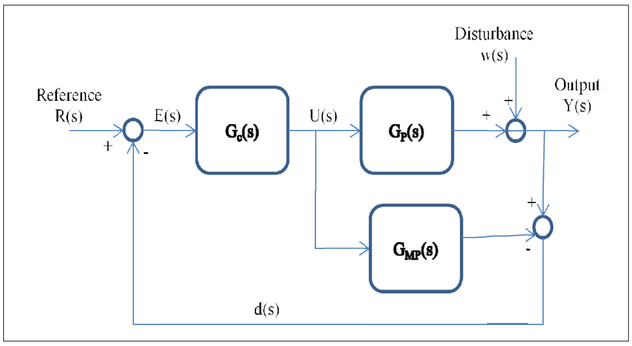


Fig. 5: Structure of Internal model control (IMC)

With : Gp: Procedure transfer function, Gc: controller transfer function, GMP Model of procedure. The closed loop transfer function of IMC is described by the following equation:

$$Y(s) = \frac{R(s)\cdot G_c(s)\cdot G_p(s)+w(s)[1-G_{MP}(s)\cdot G_c(s)]}{1+G_c(s)\cdot[G_p(s)-G_{MP}(s)]} \qquad (28)$$

The aim of system control of a process is eliminating disturbance effect and ensuring the reference tracking. In order to achieve his aim the transfer function of controller and model is given by the following equation:

$$G_c(s) = G_{mp}^{-1}(s)\,;\, G_{MP}(s) = G_P(s) \qquad (29)$$

With process model we can separate the non-invertible and the invertible parts like as follows:

$$G_{MP}(s) = G_{mp+}(s)\cdot G_{mp-}(s) \qquad (30)$$

where $G_{mp+}(p)$ contains all non minimum phase elements in the plant model while $G_{mp-}(p)$ is minimum phase and invertible. Thus the IMC controller can be defined as:

$$G_c(s) = G_{mp-}^{-1}(s) \qquad (31)$$

IMC controller is not only stable and causal, but also proper with using a low pass filter. The low pass filter also helps to minimize the discrepancies between the process and model at high frequency.

$$G_{IMC}(s) = G_{mp-}^{-1}(s) \cdot G_f(s) \quad (32)$$

The transfer function of filter is represented by the following equation:

$$G_f(s) = \frac{1}{(1+\tau \cdot s)^n} \quad (33)$$

The filter order n is selected to make $G_{IMC}(p)$ proper and τ, the timing parameter that has an inverse relationship with the speed of the close loop response. The linear quadratic optimal control the assumed that the mathematical function which is called the cost function or performance index can be written. The term optimal means that the procedure of this technique is to minimize the cost function, however, in most cases the cost function was minimized by trial and error method. The general form of performance index equation [12],[13]:

$$J_N = \sum_{k=0}^{N} x^T(k)Q(k)x(k) + u^T(k)R(k)u(k) \quad (29)$$

In the equation above, k is the sample instant and N is the terminal sample instant. Where matrix Q is a positive semi definite and matrix R is a positive definite matrix. The matrices Q and R determine the relative importance of the error. Then the element of feedback, K is obtained to minimize the performance index. The control law of feedback is according to figure 6.

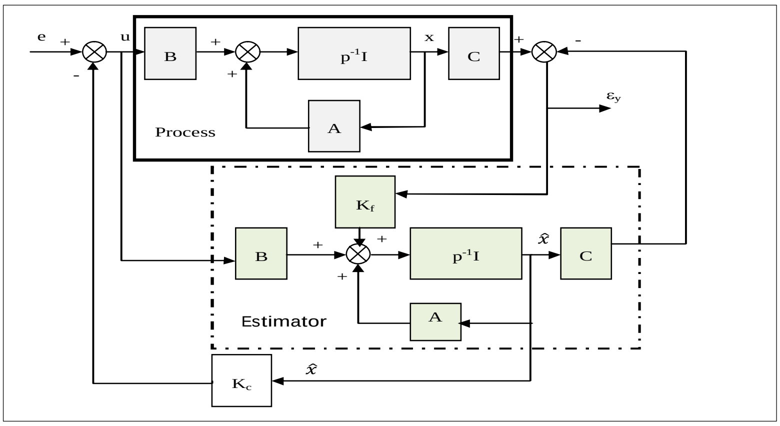


Fig. 6: Structure of LQG control.

The LQG control approach based on the so-called principle of separation of control and estimation. The state-feedback controller K is optimal in the sense of a quadratic criterion, and the Kalman filter K is the optimal state estimator in the presence of white noise disturbances. Taken together controller and filter give a control law which is optimal in the presence of white noise measurement and process noise [14][15]. The IMC and LQG control approach are applied are each operating point (each local linear model)[16].

4. SIMULATION

The synthesis of the controllers is continuous. The simulation is done in continuous time around the following operating points θs0=0rad, θs0=π/3rad and θs0=2π/3rad.The parameter valuesof the reference modelλ0and λ1 are:

$$\gamma = 30\,;\ \lambda_0 = 900;\ \lambda_1 = 60 \qquad (30)$$

The PID controller parameters around the operating points chosen is:

Table 1: Parameters of the local Controller

parameters	K_p	K_i	K_d
Controller(θ_s=0)	-2	-5	-0.7
Controller (θ_s=π/3)	-2	-0.4	-0.4
Controller(θ_s=2π/3)	-3	0.1	-0.4

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. With controller parameters around θs0=0rad and reference signal r (t) is equal to:

$$r(t) = 0.1 \cdot \sin(5 \cdot t) \qquad (31)$$

The simulation results are illustrated in the followings figures:

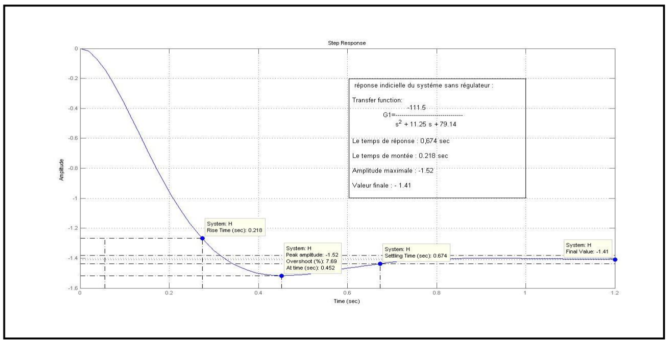


Fig.7: Output of the model G1 without control.

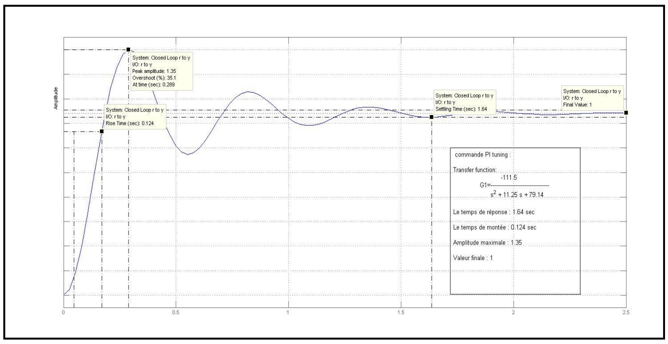


Fig. 8: Output of the model G1 with PI tuining control.

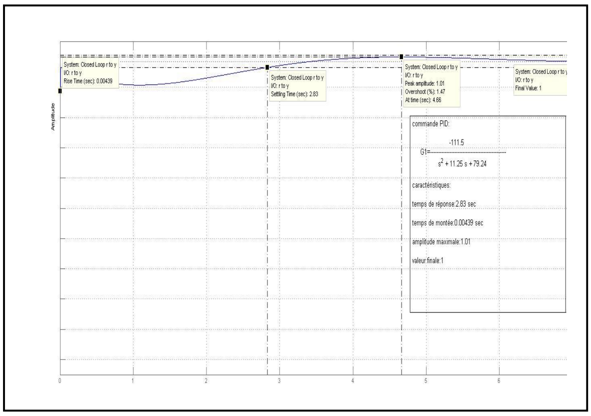


Fig. 9: Output of the model G1 with PID tuining control.

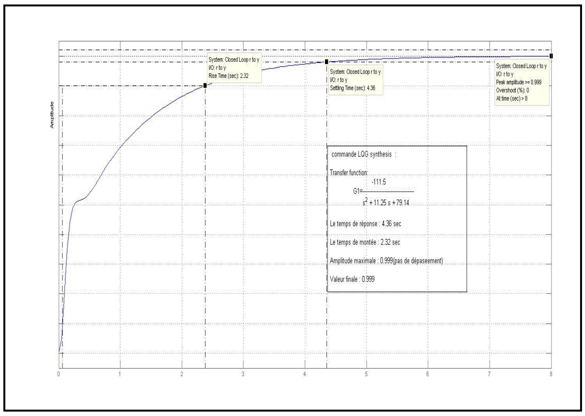


Fig.10: Output of the model G1 with LQG control

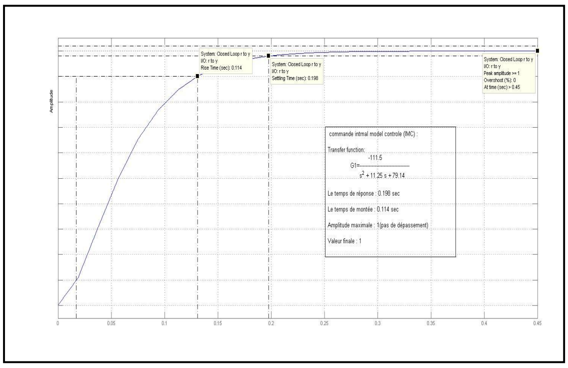


Fig. 11: Output of the model G1 with IMC control.

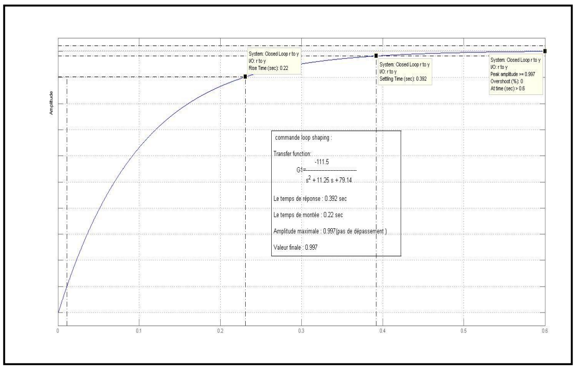


Fig. 12: Output of the model G1 with loop shaping control

The results are illustrated in the following table:

Table 2: simulation results for G1

Control methods	Setting time (sec)	Rise time (sec)	Peak amplitude	Static gain
PI	1.64	0.124	1.35	1
PID	2.83	0.00439	1.01	1
LQG	4.36	2.32	0.999	0.999
IMC	0.198	0.114	1	1
Loop shaping	0.392	0.22	0.997	0.997

We can observe that the best results simulations are obtained with Loop shaping control methods. We have applied the same methods for the second and third model (G2 and G3 local linear model). The obtained results are illustrated in the followings tables:

Table 3: simulation results for G2

Control methods	Setting time (sec)	Rise time (sec)	Peak amplitude	Static gain
PI	2.74	0.22	1.45	1
PID	17.7	0.174	1.05	1
LQG	3.11	1.35	0.995	0.995
IMC	0.216	0.125	1	1
Loop shaping	0.392	0.22	0.997	0.997

For the second linear local model (G2), we can observe that the best results simulations are obtained with Loop shaping and IMC control methods.

Table 4: Parameters of the local Controller

Control methods	Setting time (sec)	Rise time (sec)	Peak amplitude	Static gain
PI	1.88	0.08	1.88	1
PID	260	2.08	1.07	1
LQG	3.85	0.103	1.47	1
IMC	8.99	0.262	5.58	1
Loop shaping	1.77	0.0929	1.25	1

For the third linear local model (G3), we can observe that the best results simulations are obtained with Loop shaping and LQG control methods.

5. ROBOT SIMULATION WITH 3D MODELING

In 90s, the first commercial robotic simulation software has been developed. The software was used to solve complex design and to program robots. All the simulation software used today has an extensive simulation capability where any user can manage the design and can associate this with the manufacturing process. But, any technology has its advantages and disadvantages[18],[19]. In the advantages area, I can include a lower cost, while all of the simulation tools offer the possibility to simulate the robot in different scenarios, the programming code can be tested to determine the compatibility and efficiency with the specifications required, and many more features. To develop a virtual model capable of emulating with small error the real-world process, we have used two software (Matlab and solidworks). There are many tools that can be used in simulation. From free simulation tools and up to software with the license fee, below you can find a complete list with all simulation software that are used today in robotics [20],[21]. Solidworks software used in 3D modeling and rendering in a virtual environment that imitate the real environment of the robot. In the first step we have developing a robot in Malab-Simulink with SimMechanics block library and check the mechanical design according to design proposal request (figure 13) based on mathematical formulas, with a very close behavior than the final product (figure 14).

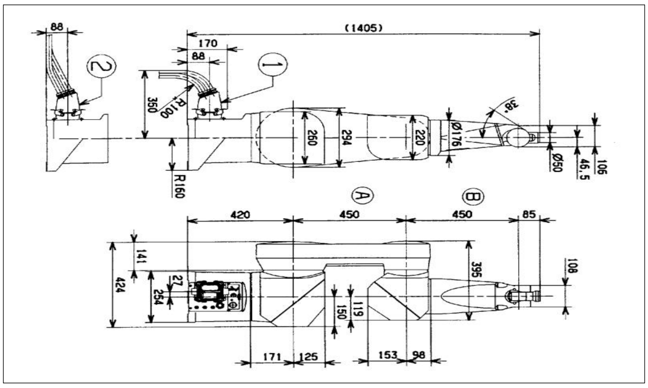


Fig. 13: Manipulator robot

The System (robot) is represented by the following blocks: the body, joints, constraints, and force. The SimMechanics block library provided us the tools to formulate and solve motion equations of complete mechanical system [22],[23],[24].

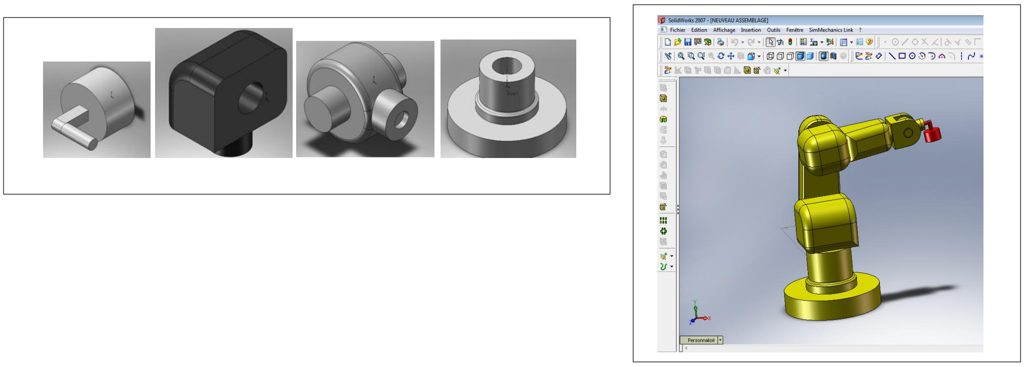
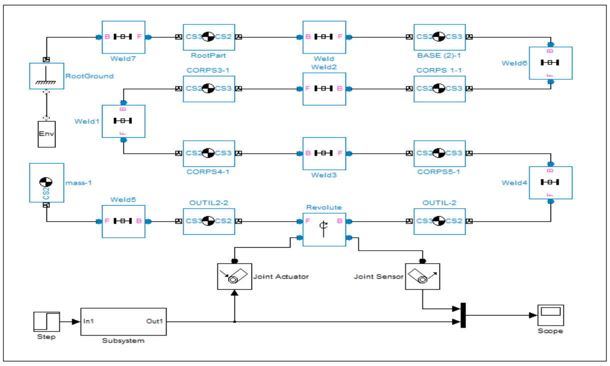


Fig. 14: Different element 3D modeling of robot with solidworks

We used a bridge between solidworks_matlab with same adaptations (SimMechanics 2007) [22] to operate the robot model that we designed with solidworks. To simplify the simulation we have block all robot joints except the terminal element and after we applied a simple control signal. A block diagram of the robot with the actuator and the sensor is illustrated in the following figure:



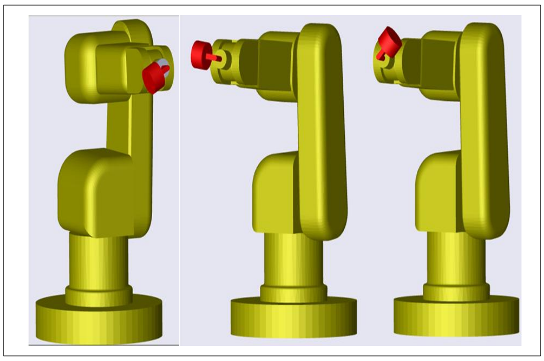


Fig. 15: Control diagram block of robot Rx-90 model

Fig. 16: CAO (Solid Works) 3D robot model.

- The local controller (IMC controller) is more robust compared with other local controller “Fig.7 –Fig.12”.
- In the “Fig.13 -Fig. 17” we have developed RX90 Robot CAO Solid works software and block control for simulation with Matla-Simulink. We can observed too the order of local controller after approximation it’s high for realization.
- For each local linear model around operating points the Loop shaping control methods gives best results.

6. CONCLUSION

Many research work and books in literature have been study on control engineering, describing new techniques for controlling systems, or better ways of mathematically formulating existing methods to solve the ever-increasing complex problems faced by practicing engineers [27]. However, few of these research work and books fully address the applications aspects of control engineering. The necessity of improved and enhanced productivity in industrial applications has necessitated deployment of robot to automate tasks.

Manipulator based articulated robots for today’s industrial applications vary widely in terms of number of Degree Of Freedom (DOF), payload capacity, Range of Motion (ROM), control implementation and mountable configurations [25],[26]. The study of manipulators for diversified industrial applications has highlighted the need of sophisticated algorithms for their control and trajectory planning. The control of industrial manipulator is important for accomplishing tasks requiring high precision, repeatability and reliability by mitigating the effects of disturbances. The trajectory planning is vital for time optimization, energy optimization and collision avoidance to ensure most appropriate trajectory for a given task in an environment.

It is the intention of this paper to answer this situation. In this paper, the modeling of the nonlinear process (Wrist of Rx-90 Stäubli Robot) has been presented. After that the local linear model near each considered operating points has been developed. We have applied IMC, LQG, PID tuining and Loop shaping control methods. According to the Simulation results, we conclude that the application of the local controller model (IMC controller) is very interesting but we need more optimization of parameters.

Effective simulation results have been obtained. They show that the local controllers give good results around the operating points.Therefore, we have to look for a collaborative approach for these local control laws to obtain good results in all operating space. We have developed too Simulator of robot with 3D modeling in solidworks and Matlab software simulated in different scenario similar to the real world. Future work is aimed to test another interesting frank switching with thein direct approach (collaboration between controller) and a Digital Fractional-order PID controller or RST controller. Optimization of our simulator and control parameters with Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC) and Bacterial Foraging Optimization (BFO) for their efficiency and to compare the results.

REFERENCES

[1] Ankit P, Vipin V. Internal Model Control (IMC) and IMC based PID Controller, thesis, National Institute of Technology, Rourkela, 2010, p.52.

[2] 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.

[3] 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.

[4] BensafiaY. and Ladaci,S. 2011. Adaptive Control with Fractional Order Reference Model. IJ-STA, Vol 5, N° 2, pp.1614-1623.

[5] Bagley, R.L. Calico, R.A. 1991. Fractional Order State Equations for the Control of Viscoelastically Damped Structures, J.Guidance, vol. 14, no. 5 pp.304-311.

[6] Bettou,K. 2011. Analyse et réalisation de correcteurs analogiques d'ordrefractionnaire. Mémoire de thèse, Université de Constantine, p.111.

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

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

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

[10] Goto M. and Ishii D. 1975. Semi-differential Electro-analysis, J. Electro anal. Chem. and Interfacial Electrochemical., vol.61, pp.361-365.

[11] 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.

[12] Khalil, W. Lemoine, P. Gautier, M. Erginer, O. 2006. Identification expérimentale des paramètres inertiels de la charge d'un robot Stäubli RX 90. Conférence Internationale Francophone d'Automatique -CIFA'06, Bordeaux, France, 19 Feb2009, p6.

[13] Luo,Y.Chen Y.Q. 2009. Fractional-order [proportional derivative] controller for robust motion control: Tuning procedure and validation. American Control Conference, ACC '09. pp.1412-1417.

[14] Makroglou A., Miller R.K. Skkar, S. 1994. Computational Results for a Feedback Control for a Rotating Viscoelastic Beam, J of Guidance, Control and Dynamics, vol. 17, no. 1, pp. 84-90.

[15] MATLAB® Creating Graphical User Interfaces, September 2010 Online Only Revised for MATLAB 7.11 (Release 2010b)

[16] Oldham, K.B. 1976. A Signal Independent Electro-analytical Method, Anal. Chem., vol.72 pp.371-378.

[17] 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.

[18] 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.

[19] Ragnar E, Per Magne E., Stamsø A., Karimi H.R. LQG Control Design for Balancing an Inverted Pendulum Mobile Robot. Intelligent Control and Automation, 2011, vol. 2, pp.160-166.

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

[21] Sabatier J. Moze M. Farges C. 2010. LMI stability conditions for fractional order systems, Computers & Mathematics with Applications, Volume 59, Issue 5, Fractional Differentiation and Its Applications, March 2010, Pages 1594-1609, ISSN 0898-1221.

[22] SimMechanics 2 User's Guide MATLAB &SIMULIK,TheMathWorks, September 2007 Online onlyRevised for Version 2.7 (Release 2007b)

[23] 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.

[24] Valérie Dos Santos Martins Contrôle frontière par modèle interne de systèmes hyperboliques : application à la régulation de canaux d'irrigation, thèse, Université d'ORLÉANS, 2004, p. 175.

[25] Iqbal, J., Tsagarakis, N. G., and Caldwell, D. G. (2011), 'A multi-DOF robotic exoskeleton interface for hand motion assistance'. 33rd annual IEEE international conference of Engineering in Medicine and Biology Society / Boston, USA, pp. 1575-1678.

[26] Iqbal, J., Islam, R. U., and Khan, A. H. (2013), 'Modeling and analysis of a 6 DOF robotic arm manipulator'. Canadian Journal on Electrical and Electronics Engineering (CJEEE), pp. 300-306.

[27] Robert, J. S. (2009),'Fundamentals of robotics: Analysis and control'. Prentice Hall, Fourth impression.

[28] Djouambi, A., Charef, A., and Bensançon, A.V. (2007), 'Optimal approximation, simulation and analog realization of the fundamental fractional order transfer function'. International Journal Applied Math. Comput.Sci., vol. 17, n° 4, pp.455-462.