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Optimal PSO- $PI^{\lambda}D^{\mu}$ Multi -Controller for a Robotic Wrist

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Abstract: Comparative study between to approach of control based in conventional PID controller and robust Fractional PID controller (FOPID) using PSO algorithm applied to control robotics wrist (Robot RX-90 Staübli). The mathematic model of robot are described follows by design of architecture control. two approximation method of fractional order are used and finally a different simulation study comparative between (PID, PSO-PID, FOPID and PSO-FOPID) with obtained results has been presented discussed and approved the efficiently of the architecture control with PSO-FOPID controller followed by a conclusion and some perspectives for future work.

Keywords : Robotics wrist, Modeling, PSO algorithm, Approximation fractional order method, PID, PSO-PID, FOPID, PSO-FOPID.

1. INTRODUCTION

The robotics has marked the evolution world of the technological. The advent of robots in the industry has made it possible to relieve the man of repetitive and difficult works such as: the displacement of heavy objects, joining spots, micro-welds etc, with more efficiency and precision. Robots are gradually gaining the ability to carry out more and more complex gestures. These developments lead to highly sophisticated machines that can perform increasingly sophisticated tasks, but too often the difficulty in mastering or manipulating these robots increases with the complexity of the system, in order to manage its operations and to support its capacities, Action, adaptation, decision-making, etc. Different architectures and techniques are used to control the manipulator arms. The mechanical design of the manipulator arm has an influence on the choice of control type. A manipulator robot is a complex mechanical structure whose inertias with respect to the axes of the joints vary not only as a function of the load but also as a function of the configuration, the speeds and the accelerations. The physical process (robot arm) behavior has generally many non-linearity [1] that are not taken into account in the modeling process. In the each operating point (equilibrium point) of the physical process we can develop a local linear model. In this work we used multi-controller approach. Then the objective of this approach [1] is to control the process in operational space using the local information [2-9]. The diagram block of the multi-controllers approach is represented as follows:

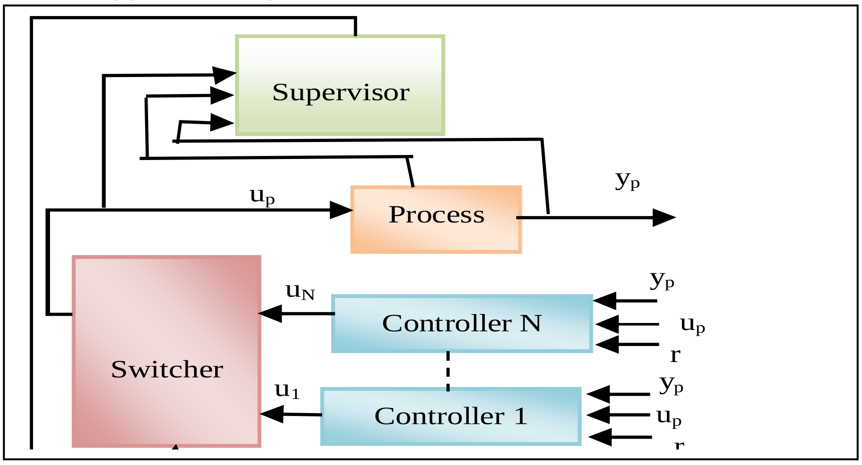


Fig.1.Structureofmuli-controller approach of control.[8].

In this work we proposed the mulit-controller architecture with conventional PID controller and fractional-order PID controller (FOPID) optimized with PSO algorithm to control a manipulator robot wrist (Staubli robot RX 90).

2. PROCESSUS MODELING

The robotics wrist of the manipulator Stâubli Robot Rx-90 can be represented by the following figure:

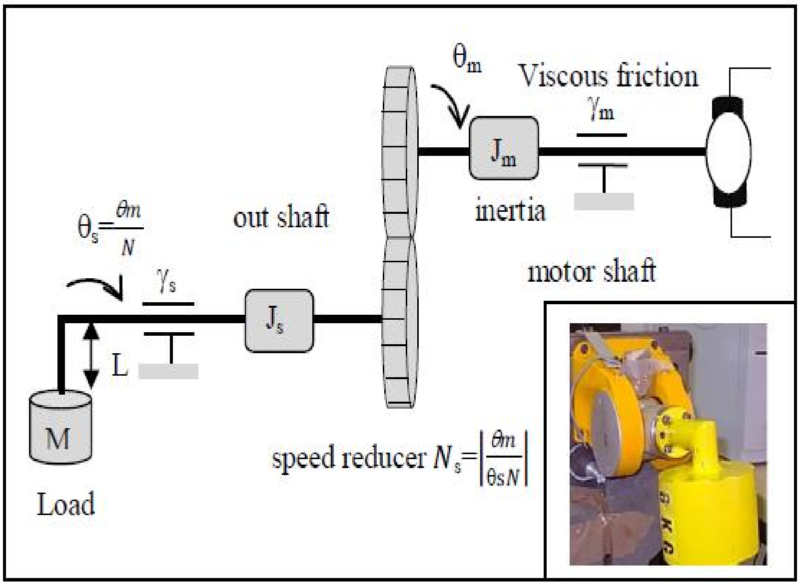


Fig.2. Robotics wrist with Synoptic graph of axes 6.

Mathematic Process dynamic model is given by the following equations:

$$\Gamma_m - \Gamma_s = \left(J_m + \frac{J_S+M.L^2}{N^2}\right)\cdot\ddot{\theta}_m + \left(\gamma_m + \frac{\gamma_S}{N^2}\right)\cdot\dot{\theta}_m \qquad (1)$$

With :

$$J_T = \left(J_m + \frac{J_S+M.L^2}{N^2}\right) \text{ and } \gamma_T = \left(\gamma_m + \frac{\gamma_S}{N^2}\right) \qquad (2)$$

Jm, Js: Inertia moment applied in the motor shaft and the output shaft (output shaft with mass) respectively.

γm,γs: Viscous friction applied in the motor shaft and the output shaft respectively.

The motor torque is given by:

$$\Gamma_m = K_e\cdot u(t) \qquad (3)$$

Ke : is the torque constant and u(t) the voltage applied in process. Then the nonlinear model is given by:

$$X(t) = \begin{bmatrix} x_1(t) = \theta_m(t) \\ x_2(t) = \dot{\theta}_m(t) \end{bmatrix} \; and \;\; \dot{x}_1(t) = x_2(t) \qquad (4)$$

$$y_p(t) = \theta_s(t) = -\frac{\theta_m(t)}{N} = -\frac{x_1(t)}{N} \qquad (5)$$

The corresponding continuous linear local model is as follows [8-9]:

operating points, $\theta_{s0}=0$:

$$G_1(s) = \frac{-111.5}{s^2+11.25\cdot s+79.14} \qquad (6)$$

operating points, $\theta_{s0}=\pi/3$ and $\theta_{s0}=2\pi/3$ respectively:

$$G_2(s) = \frac{-111.5}{s^2+11.25\cdot s+39.57}\ ;\ G_3(s) = \frac{-111.5}{s^2+11.25\cdot s-39.57} \quad (7)$$

3. LOCAL CONTROLLEURS STRUCTURES

The PID controller is the most widely used technique for controlling industrial processes for decades. The main reasons for its wide acceptance in industry are its ability to control the majority of processes, these actions are well understood and its implementation is very simple. The design and adjustment of PID correctors has been a subject of research since the day Ziegler and Nichols presented their method in 1942. Although all existing techniques for adjusting PID corrector parameters, continuous and intensive research work Is still underway for the enhancement of quality and improved control performance. Recently, Podlubny proposed a corrector $PI^{\lambda}D^{\mu}$ of fractional order which is a generalization of the classical PID corrector.

The interest in this type of corrector is justified by a greater flexibility in the design of the control since it has two additional parameters which are the fractional orders of the integration and derivation actions. These parameters can be used to satisfy additional performance in the design of the servo systems. Today, researchers are interested in the development of methods and techniques for adjusting the $PI^{\lambda}D^{\mu}$ corrector. Several methods have been proposed such as the technique based on the ideal transfer function of Bode proposed by Djouambi [10-13]. This technique consists in fixing the fractional orders λ and μ from the frequency behavior of the open loop control and then the estimation of the other parameters by the algorithm of the least square.

A method proposed by Monje [14], which is based on the formulation of the problem of control and robustness in a problem of optimization in five unknowns which are the five parameters of the corrector $PI^{\lambda}D^{\mu}$ of fractional order. An improvement of the previous method was proposed by Valerio [15-21], where an analytical solution of the problem of control and robustness of the corrector $PI^{\lambda}D^{\mu}$ was determined from the index response of the process using the technique of Zigler and Nichols for the conventional PID [9].

The transfer function of a FOPID controller, which was initially proposed by Podlubny in 1999 [17], is given by :

$$G_c(s) = \frac{U(s)}{E(s)} = K_p + K_I\frac{1}{s^{\lambda}} + K_D s^{\mu}, (\lambda, \mu > 0) \quad (9)$$

Where Kp, K_I, $K_D \in$ R and $\lambda,\mu \in$ R+ are the tuning parameters and the controller design problem is to determine the suitable value of these unknown parameters such that a predetermined set of control objectives is met [19]. Many methods in literature have been proposed for FOPID approximation [20]. In this work we used Oustaloup recursive approximation method (ORA) applied in FOPID controller [19-20]. The fractional-order differentiator s^{μ} , μ R+ is approximated as:

$$H(s) = s^{u} \quad , \mu \in R^{+} \quad (10)$$

By a following rational function:

$$\widehat{H}(s) = C\prod_{k=-N}^{N}\frac{1+\frac{s}{\omega_k}}{1+\frac{s}{\acute{\omega}_k}} \quad (11)$$

With: $\acute{\omega}_0 = \alpha^{-0.5}\omega_u;\ \omega_0 = \alpha^{0.5}\omega_u;$

$$\frac{\acute{\omega}_{k+1}}{\acute{\omega}_k} = \frac{\omega_{k+1}}{\omega_k} = \alpha\eta > 1 \quad (12)$$

$$\frac{\acute{\omega}_{k+1}}{\acute{\omega}_k} = \eta > 0; \frac{\omega_k}{\acute{\omega}_k} = \alpha > 0;\ N = \frac{\log\left(\frac{\omega_N}{\omega_0}\right)}{\log(\alpha\eta)}; \quad (13)$$

$$\mu = \frac{\log\alpha}{\log(\alpha\eta)} \quad (14)$$

With ω_u being the unit gain frequency and the central frequency of a band of frequencies geometrically distributed around it .That is, $\omega_u = \sqrt{\omega_h\omega_l}$, where ω_h, ω_l are the high and the low transitional frequencies. The parameters used in the Oustaloup approximation are:

G(s) : Transfer function of local model of process.
N: Approximation order.

$r_1=-\lambda$ & $r_2=\mu$: Integration & derivative order respectively.
$\omega_l=10^{-2}$; low transitional frequency
$\omega_h=10^{3}$; high transitional frequency
$\omega_u=10$; Cutoff frequency

The transfer function in closed loop for rotor's speed is regarded as stable. The problem system's design is thus to regulate the three parameters of fractional controller to guarantee that the transfer function in closed loop behaves the frame of reference which itself answers the specifications of the fractional control system (transfer function in closed loop). The frame of reference fractional model used is:

$$G_d(s) = \frac{1}{1+\left(\frac{s}{\omega_u}\right)^m} \quad with\ 1 < m < 2 \tag{15}$$

The transfer function of reference model is given by the following function:

$$Y_m(s) = \frac{\gamma^2}{(p+\gamma)^2} \cdot R(s) = G_m(s) \cdot R(s) \tag{16}$$

With :

$$G_m(s) = \frac{\gamma^2}{s^2+\lambda_1 \cdot s+\lambda_0} \tag{17}$$

4. PARTICLE SWARM OPTIMIZATION WITH PID

The Particle Swarm Optimization (PSO) is evolutionary computational technique based on the movement and intelligence of swarms looking for the most fertile feeding location; it was developed in 1995 by James Kennedy and Russell Eberhart. This algorithm is simple, easy to implement and few parameters to adjust mainly the velocity. It's inspired by social behavior of birds and fishes and it's combines self-experience with social experience and applies to concept of social interaction to problem solving [23]. The goal of Optimization is to find values of the variables that minimize or maximize the objective function while satisfying the constraints. The optimization needs the good mathematical model of the optimization problem and an algorithm that should have robustness (good performance for a wide class of problems), efficiency (not too much computer time) and accuracy (can identify the error). The optimization is based in population; it has been applied successfully to a wide variety of search and optimization problems. In this technique, a swarm of n individuals communicate either directly or indirectly with one another search directions (gradients)[24].

PSO technique is not only a tool for optimization, but also a tool for representing socio cognition of human and artificial agents, based on principles of social psychology. A PSO system combines local search methods with global search methods, attempting to balance exploration and exploitation[25]. The Population-based search procedure in which individuals called particles change their position (state) with time. The Particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience, and according to the experience of a neighboring particle, making use of the best position encountered by itself and its neighbor. Suppose that the search space is D-dimensional, then the ith particle of the swarm can be represented by a D-dimensional vector $X_i = [x_{i1} x_{i2} \ldots x_{iD}]^T$. The velocity of the particle can be represented by another D-dimensional vector $V_i = [Vi(1) Vi(2) \ldots Vi(D)]^T$. The best previously visited position of the ith particle is denoted as $P_i = [p_{i1} p_{i2} \ldots p_{iD}]^T$. Defining "g" as the index of the best particle in the swarm, where the gth particle is the best, and let the superscripts denote the iteration number, then the swarm is manipulated according to the following two equations[26].

$$V\,i\,(t+1) = w\,.V\,i(t) + c1.\,r1\,.\left(pbesti\,(t) - xi(t)\right) + c2.\,r2\,\left(gbesti\,(t) - xi\,(t)\right) \tag{18}$$

$$xi(\,t+1) = Vi\,(t+1) + xi\,(t) \tag{19}$$

where t = 1, 2, . . . , D; i= 1, 2, . . . , M, and M is the size of the swarm (i.e. number of particles in the swarm); $c1$, $c2$ are the positive values, called acceleration constants; $r1$, $r2$ are the random numbers uniformly distributed in [0, 1].

Typically $w(t)$ is reduced linearly, from w_{start} to w_{end}, each iteration, a good starting point is to set w_{start} to 0.9 and w_{end} to 0.4.

$$w(t) = \frac{(T_{max} - t) \times (w_{start} - w_{end})}{T_{max}} + w_{end} \quad (20)$$

Thought V_{max} has been found not to be necessary in the PSO with inertia version, however it can be useful and is suggested that a $V_{max} = X_{max}$ be used [23-27]. The original procedure for implementing PSO is as follows:

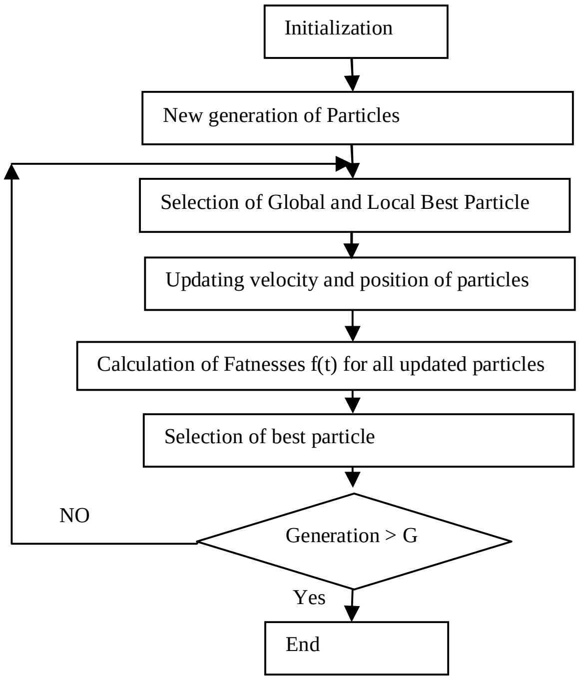


Fig. 3 Flow chart of PSO algorithm [26]

In PID controller design methods, the most common performance criteria are integrated absolute error (IAE), the integrated of time weight square error (ITSE), integrated of squared error (ISE) and Mean Square Error (MSE) [28, 29]. These four integral performance criteria have their own advantages and disadvantages. For example, disadvantage of the IAE and ISE criteria is that its minimization can result in a response with relatively small overshoot but a long settling time because the ISE performance criterion weights all errors equally independent of time. Although the ITSE performance criterion can overcome the disadvantage of the ISE criterion, the derivation processes of the analytical formula are complex and time-consuming.

The essential function of a feedback control system is to reduce the error, e(t), between any variable and its demanded value to zero as quickly as possible. Therefore, any criterion used to measure the quality of system response must take into account the variation of e over the whole range of time. Four basic criteria are in common use:

$$\text{Integral squared erroe (ISE)} = \int_0^\infty e^2 dt \quad (21)$$

$$\text{Integral time squared error (ITSE)} = \int_0^\infty t.e^2(t)dt \quad (22)$$

$$\text{Integral of absolute error (IAE)} = \int_0^\infty |e(t)|\,dt \quad (23)$$

$$\text{Integral time of absolute error (ITAE)} = \int_0^\infty t.e(t)dt \quad (24)$$

In this work we use parallel PID, and the coefficients K_p, K_i, K_d are determined by the PSO algorithm using ITSE performance criteria (figure 3).

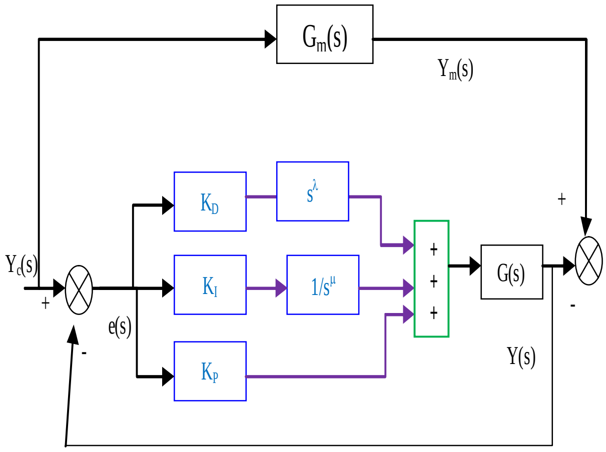


Fig.4. PID parametrs based on PSO

With : J: ITSE performance criteria (fitness function); H(s) : transfer function of process (linear model); Yc: desired input; Y: output system; e: error;

A set of good control parameters K_P,K_I and K_D can yield a good step response that will result in performance criteria minimization in time domain.

5. SIMULATION

The simulation is done in continuous time around the following operating points θ_{s0}=0rad, $\theta_{s0}=\pi/3$rad and $\theta_{s0}=2\pi/3$rad. the parameters (Kp, K_i, K_d) of FOPID and FOPI are by determined with λ=1 and μ=1. The FOPID and FOPI structure is represented by the following figure.

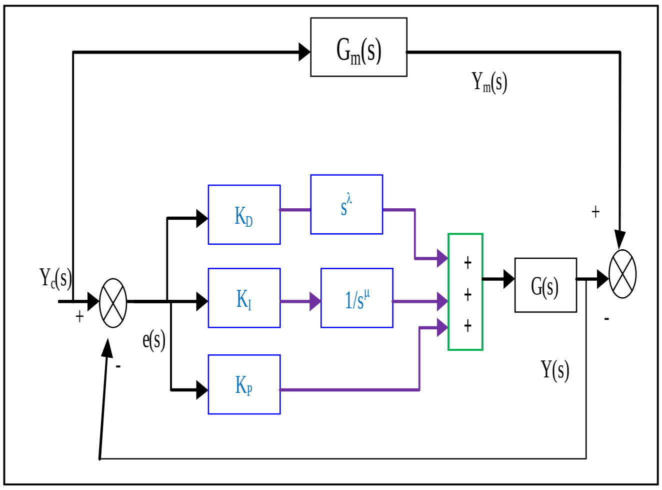


Fig.5. Block Diagram of FOPID controller.

The conventional PID parameters with Ziegler Nichols methods around the operating points chosen are:

PARAMETERS OF THE LOCAL PID CONTROLLER

Paramètre	k_p	k_i	k_d
Sys1 (θ_s=0)	-2	-5	-0.7
Sys2 ($\theta_s=\pi/3$)	-2	-0.4	-0.4
Sys1 ($\theta_s= 2\pi/3$)	-3	0.1	-0.4

The simulation is organized as is:

- Each PID and FOPID applied to control each local linear model.
- Variation of simulation parameter (approximation order) and the Fractional order.
- Optimization of PID and FOPID parameters for each local model.

The object of this simulation is the illustration of fractional order controller efficiency with PSO optimization technique in relation to performances of system in closed loop control. Comparison between PID, PID-PSO, FOPID and FOPID-PSO controllers. The reference signal $y_c(t)$ is step signal is equal to:

$$y_c(t) = 1 \quad (25)$$

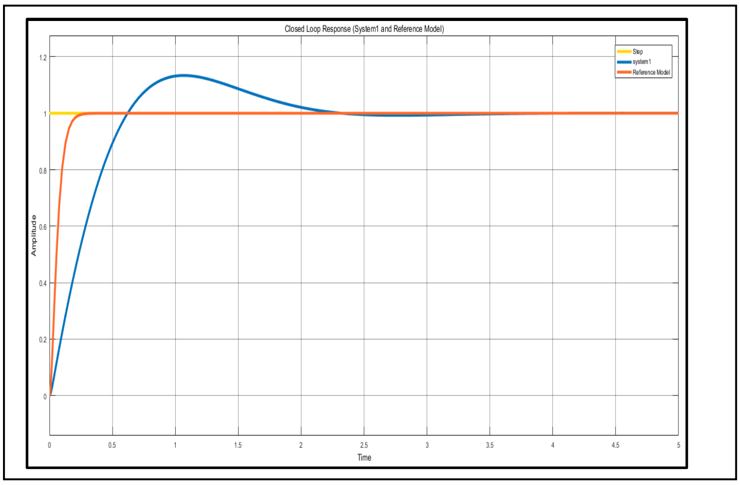


Fig.6. Output linear local model around (θs=0) with PID controller

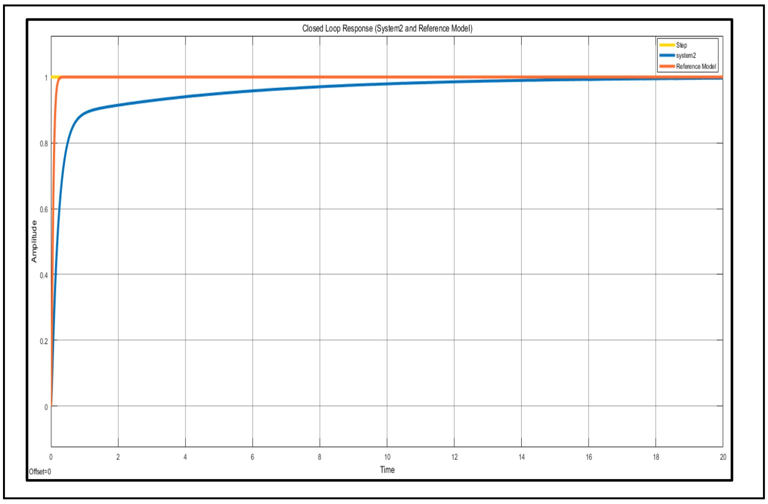


Fig.7. Output linear local model around (θs=π/3) with PID controller.

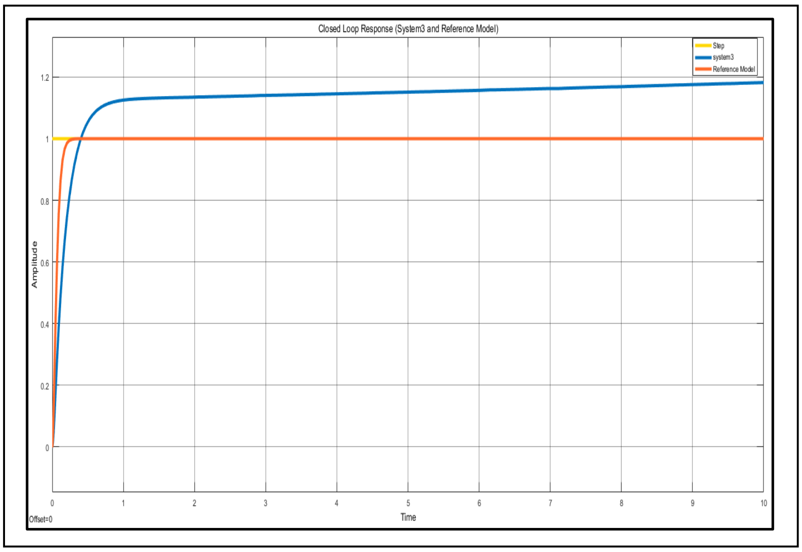


Fig.8. Output linear local model around (θs=2π/3) with PIDr

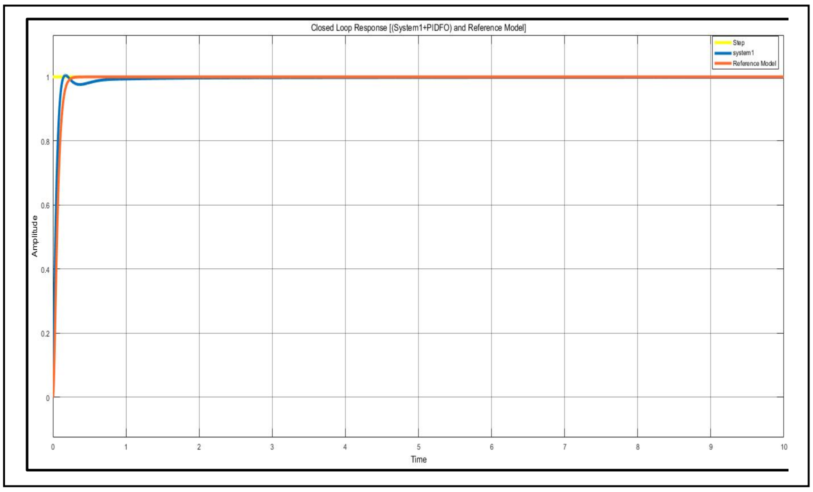
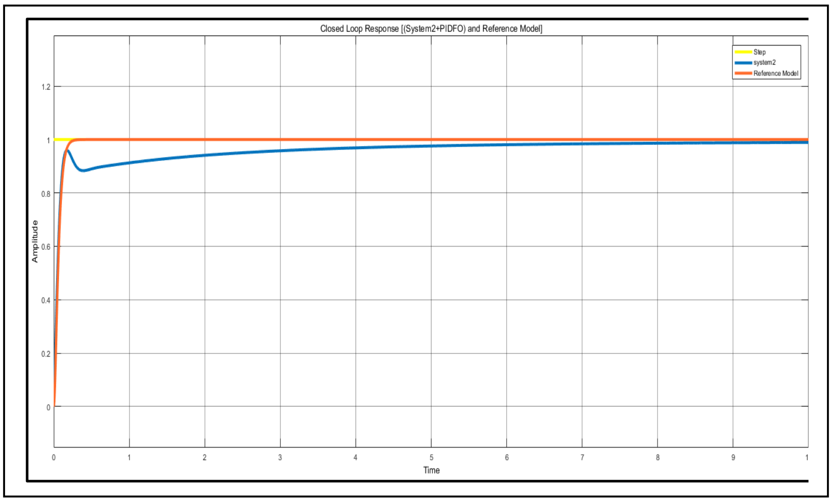


Fig.9. Output linear local model around (θs=0) with FOPID



.Fig.10. Output linear local model around (θs=π/3) with FOPID

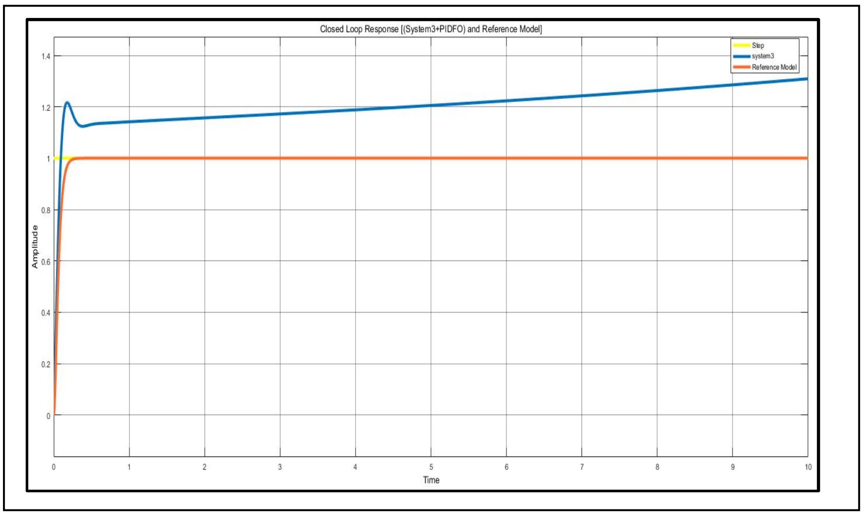


Fig.11. Output linear local model around (θs=2π/3) with FOPID.

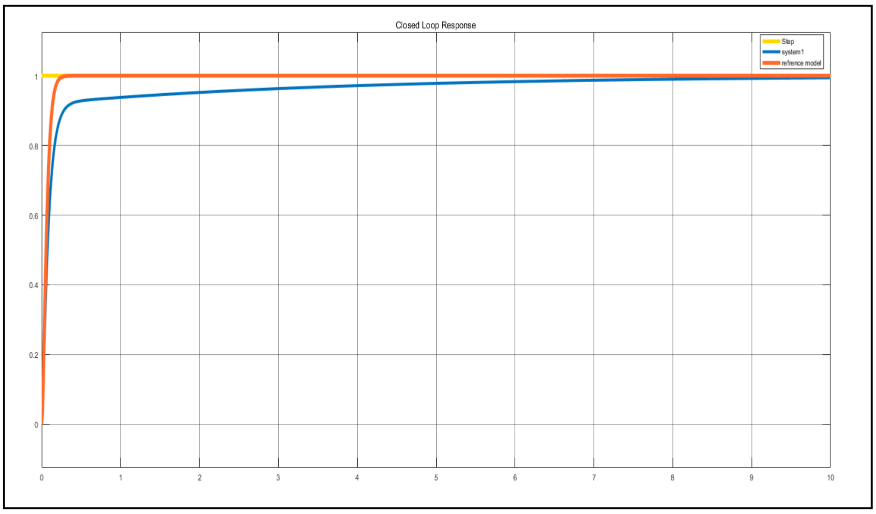


Fig.12. Output linear local model around (θs=0) with PSO-PID.

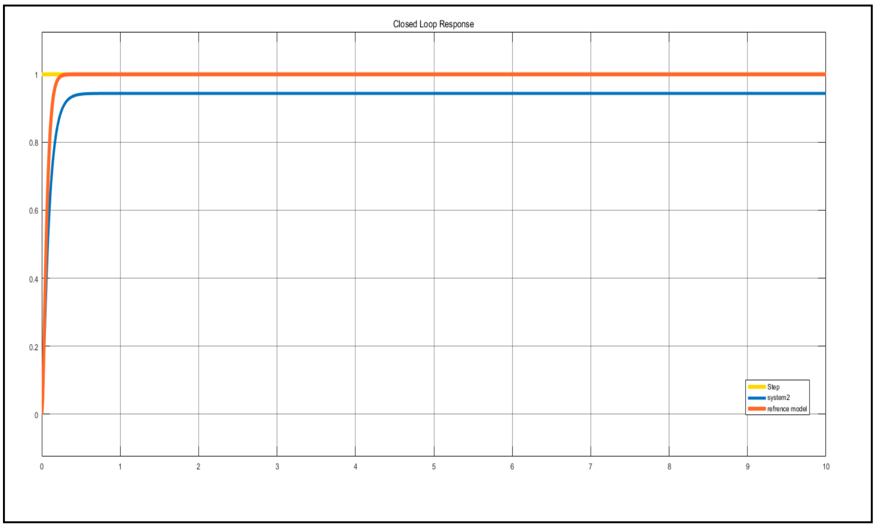


Fig.13. Output linear local model around (θs=π/3) with PSO-PID.

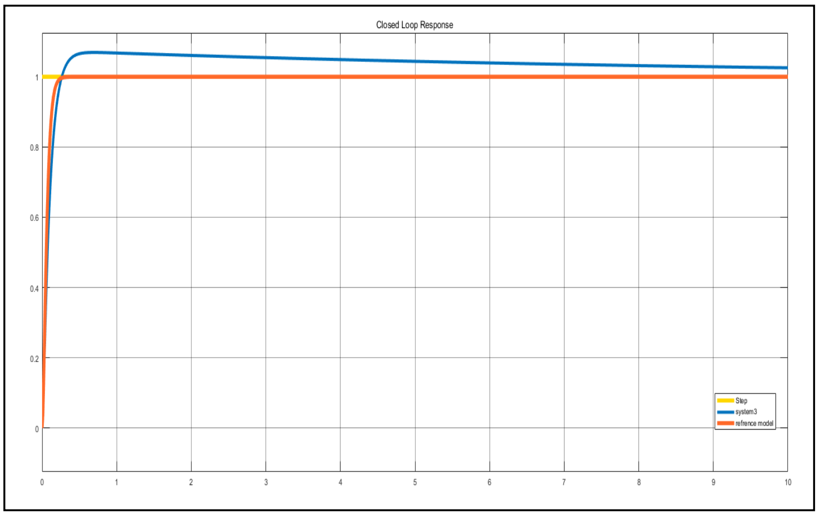


Fig.14. Output linear local model around ($\theta s=2\pi/3$) with PSO-PID.

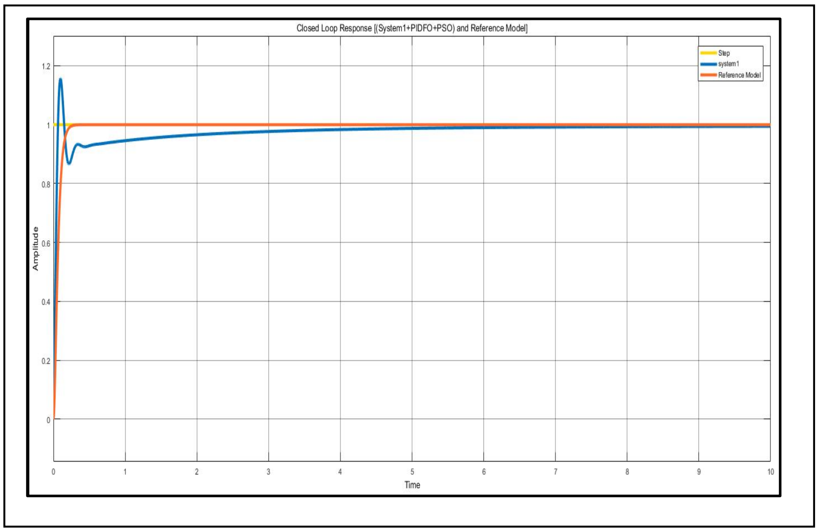


Fig.15. Output linear local model around ($\theta s=0$) with PSO-FOPID.

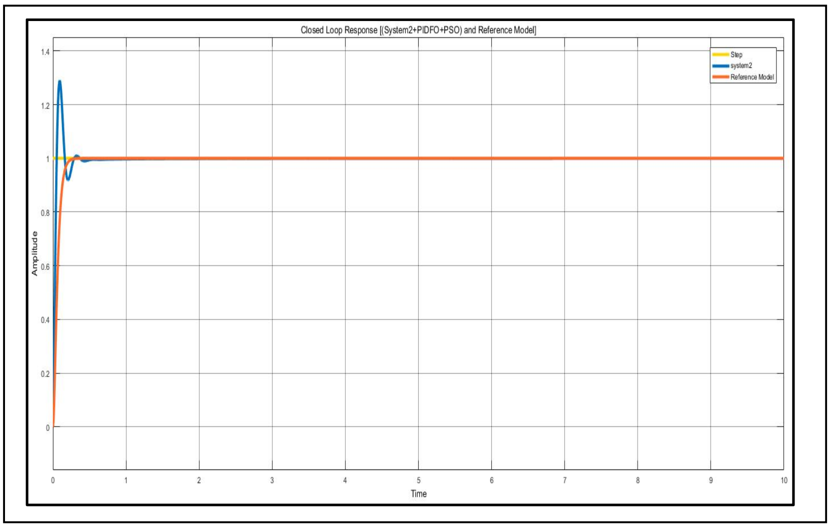


Fig.16. Output linear local model around ($\theta s=\pi/3$) with PSO-FOPID.

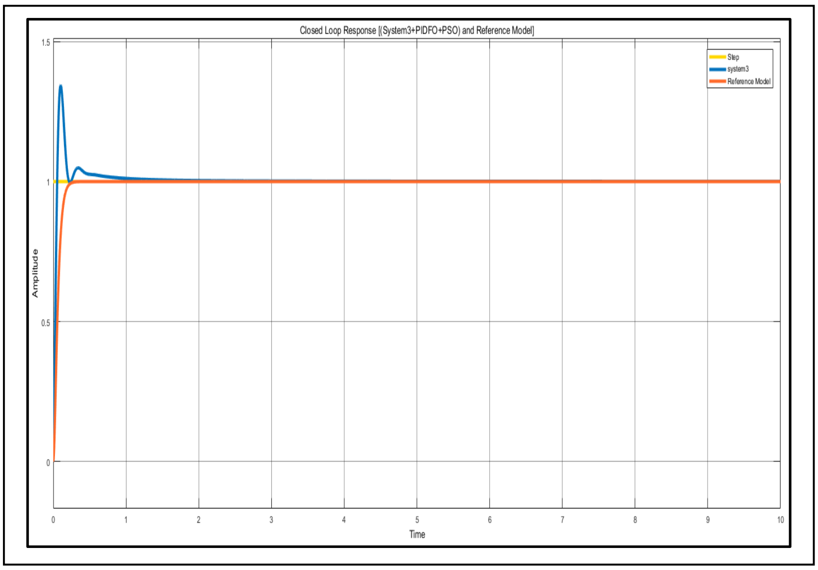


Fig.17. Output linear local model around (θs=2π/3) with PSO-FOPID.

In this part of the simulation, we have varied the parameters of the FOPID controller (λ , μ and the iteration number (N)) in order to find the right compromise between the various parameters for maximum optimization.

ERROR (10^{-2}) WITH VARIATION OF PARAMETER N (ITERATION)

λ = -0.2 μ = 0.2						
N	1	3	5	6	8	10
G_1	-7	-6.836	-6.847	-6.847	-6.847	-6.847
G_2	-1.4	-1.301	-1.306	-1.306	-1.306	-1.306
G_3	2.1	1.962	1.97	1.97	1.97	1.97

ERROR (10^{-2}) WITH VARIATION OF PARAMETER (λ)

N =3 ; μ = 0.2					
λ	0.1	0.3	0.5	0.9	1
G_1	-7.607	-5.957	-3.904	-0.4127	-2.675 x10^{-4}
G_2	-1.716	-0.9447	-0.4149	-0.0224	-1.299 x10^{-5}
G_3	2.475	1.492	0.713	0.04141	2.149 x10^{-5}

ERROR (10^{-2}) WITH VARIATION OF PARAMETER (μ)

N =3 .λ = -0.2					
μ	0.1	0.3	0.5	0.9	1
G_1	-6.768	-6.9	-6.958	-6.987	-6.988
G_2	-1.299	-1.31	-1.315	-1.316	-1.316
G_3	1.955	1.979	1.99	1.994	1.994

After several tests, the optimal values of the parameters are: N = 3, μ = 0.1 and λ = 1.

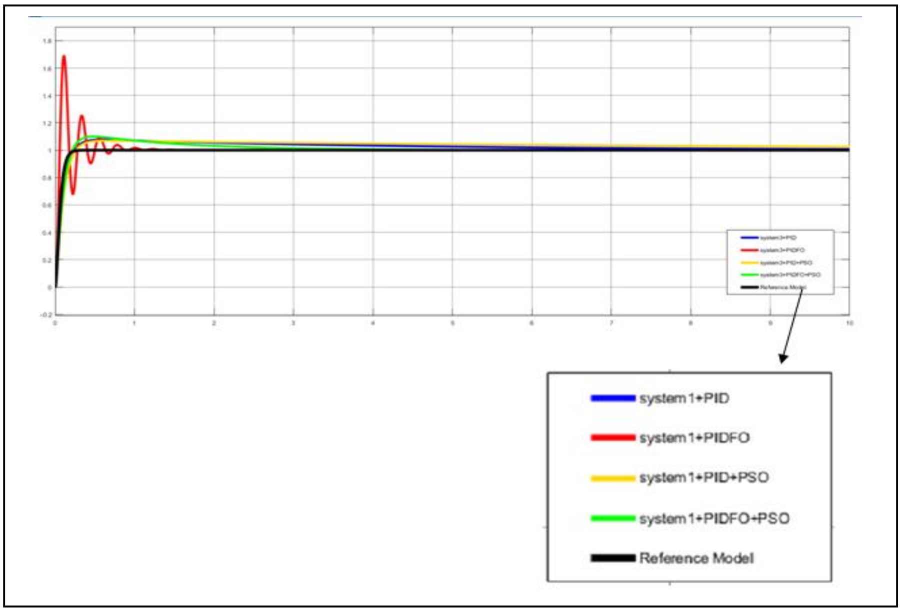


Fig.18. Frequency response of each local Controller type.

ERROR WITH DIFFERENT CONTROLLER

	PID	PSO-PID	PI^λD^μ	PSO-PI^λD^μ
G1	-0.2535	-0.02882	-0.001271	-0.005591
G2	-0.1469	-0.01224	-0.01079	-0.0003801
G3	0.182	0.01871	0.3093	-0.0006587

From the obtained results (figure.6-figure.17), we observe that the three local linear models respond better with the PSO-PID and PSO-FOPID controllers. With a careful choice of the parameters of the FOPID controller, the PSO-FOPID is better than the other controllers (stability, precision and speed) (figure.18).

6. CONCLUSION

In this work, we have presented the modeling of nonlinear process (wrist of RX90 Stâubli Robot). After that the local linear model near each considered operating points has been calculated. We have describe the conventional PID controller and Fractional-order PID controller principal with Oustaloup recursive approximation method (ORA). We have described the Particle Swarm Optimization technique used for optimized parameters of the controllers. After simulation we noted that the application of CRON structure control is very interesting in this case of system but we need more optimal approximation for order minimization and chose of FOPID parameters. The results obtained allow concluding that the local controllers give good results around the operating points. The results obtained allow concluding too that the results obtained with FOPID-PSO are more interesting as compared PID and PID-PSO controllers. Therefore, we must seek a collaborative approach these local control laws to obtain good results in all operating space. Finally we will study at the future work other approximation Fractional-order controller method, and other optimization methods like genetic algorithm. Used Frank and fuzzy switching technique with the indirect approach (collaboration between controllers with same design of control.

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