NONLINEAR CONTROL FOR 3 DOF ROBOT MANIPULATOR

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Abstract:
Using PID with any of the intelligently optimized techniques is one of the latest and most efficient techniques used. This type of hybrid control strategy has advantages of both the conventional and advance intelligent techniques. Multi objective Genetic Algorithm optimizes PID controller is being commonly used these days. Hence, in this paper a MOGA optimized PID controller is developed for the trajectory tracking of a robotic manipulator. Pareto Frontiers have been obtained from the MOGA Optimized PID controller. Obtained results from the developed intelligent PID controller elucidate the efficiency of the proposed controller when compared to conventionally tuned PID controller.

Keywords: PID, Nonlinear control systems, MOGA, Manipulator control.

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I. Introduction:

Today the key competence in robot motion control is the development of the controllers mainly focusing on increasing robot performance, reducing robot cost, improving safety, and stability of the system in presence of uncertainties. Hence, there is a need to continuously improve the control methods used in order to make system robust and adaptive to the changing model parameters of manipulator and uncertainties in the environment. In almost all the practical cases, presence of these model parameters and uncertainties makes the dynamic model of a robotic manipulator known partially. This partial unknown structure of the robotic manipulator leads to the failure of control performance of the classical controllers like PD, PID [1] etc. and hence, shaped the need for the model free intelligent controllers. Moreover, despite the success of modern control theory, it has been recognized that the majority of the controllers used in robotic manipulators are still proportional-derivative (PD) or proportional-integral-derivative (PID) type control [2, 3]. PID controller is a conventional model free feedback control approach and has been extensively applied in industrial application because of its simplicity, easy to implement in hardware or software, and does not require a precise process model to start up and maintain [4-7]. However, PID has major shortcomings, such as: it works best for process that are linear and time invariant. PID has trouble controlling complex systems which are usually nonlinear, time variant, coupled and has parameter or structure uncertainties. Secondly, PID must be tuned correctly; in real applications, tuning of PID controller is often a frustrating experience. The gains of the PD or PID controllers are determined by TAE (Trial and Error) method.

Nowadays genetic algorithm is very commonly used as an effective optimization technique in project planning [8], power plants [9] and PID controllers also [10] and many more [11]. In [11] PSO optiimzed PID has been shown superior to the conventional PID. There is a lot of improvement in rise time and settling time when GA tuned PID is implemented and compared with Ziegler-Nichols tuned PID controller.

In this paper, keeping the above discussion into mind, proposed optimal PID controller has intelligently tuned PID controller gains. MOGA is used here to tune the gains of PID controller. Paper is further divided as: Manipulator dynamics are in Section II; Section III has description about the controllers; Section IV contains simulation example results are described in Section V and; conclusion is given in Section VI.

II. System Model and Dynamics

The dynamics of revolute joint type of robot can be described by following nonlinear differential equation (1) [12],

$$\zeta = M(q)\ddot{q} + V(q,\dot{q}) + G(q) + T_d \qquad (1)$$

with q € R^n as the join position variables € R^n, τ as vector of input torques, M (q) is the inertia matrix which is symmetric and positive definite, $V(q,\dot{q})$ is the coriolis and centripetal matrix, G (q) includes the gravitational forces and T_d is the bounded disturbance torque inserted in the robotic manipulator dynamics.

III. PID Controller

It has been recognized that the majority of the practical applications of motion control use the basic proportional-derivative (PD) or proportional -integral-derivative (PID) type of control, due to of simplicity, easy implementation in hardware and software, and non requirement of a precise process model to start up and maintain [13-16]. Various sources estimate the total share of PID in all the motion control controllers in industry is about 80% [17-21]. PID controller consists of three constant control parameter gains: the proportional, the integral and the derivative gains denoted as K_P, K_I and K_D respectively. Proportional gain control is required to move the process to the right direction i.e. to the desired track. Integral gain term gives the quantity of necessary reset needed to rectify an amount of error and derivative gain is the effort to see that how far a process variable has been from the set point in the past, and analyzing the point at which further rectification will be needed [22, 23]. This controller works well with the unrealistic assumption that the dynamics of the links are uncoupled and linear. This assumption limits the use of PID controllers as they are unable to assure an optimal performance.

One of the remedy provided to that is to increase the gain of the classical linear PID controller. This improves the control performance but with the rise in high order dynamics and noise amplification [24]. Gravity compensation given by Kelly [25] and a method of compensating non linearity in the system by feedback linearization [26] are among a few advance versions of PID controllers. These methods are able to provide optimal controller with the hypothesis that the model parameters of the system are known.

Mathematical formulation given to PID controller is as given below in (2):

$$\tau = K_P e(t) + K_D \dot{e}(t) + K_I \int e(t) \qquad (2)$$

where gains K_P, K_D and K_I are suitable nxn positive definite diagonal matrices. The tracking error is defined as $e = q(t) - q_d(t) \in R^n$ where $q(t)$ and $q_d(t)$ are the actual and desired joint angle positions respectively. Similarly,

$$\dot{e}(t) = \dot{q}(t) - \dot{q_d}(t) \qquad (3)$$

is the velocity error and

$$\int e(t) = \int q(t) - \int q_d(t) \qquad (4)$$

is the integral error.

B tuning the three constants K_P ,K_D and K_I in the PID control algorithm, it can provide control action for specific process requirement. The response of the controller can be described in terms of the responsiveness of the controller to the error; the degree to which controller overshoots the set point and the degree of system oscillation.

Multiobjective Genetic Algorithm (MOGA) based proposed controller:

The heuristic and strategies presented in the previous section target at most one single objective optimization. However in practice we may want to optimize multiple objectives simultaneously. For instance, we may need to maximize the video streams quality while minimizing the bandwidth usage and the energy cost at the client. This multiobjective optimization is challenging, especially when multiple heterogeneous nodes and multiple ways of processing the streams (decoding, trans-coding) are considered. To achieve this, concept of Pareto fronts of solutions have been used. This helps to get a set of Pareto optimal assignment solutions from which a best solution can be choose. In addition, a genetic algorithm is a flexible tool where the target objective can be easily modified.

In this proposed intelligent MOGA based controller, the three parameters of the PID controller i.e. K_p, K_d and K_i have been tuned using the above mentioned MOGA technique. And with this new controller constants in the PID controller, results were obtained and compared with the previous TAE tuned PID controller constants.

IV. Simulation Example:

The dynamics of a 3 link manipulator used in all types of controllers and satisfying Eq. (1) is given as

$$M(q) = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix}$$

$$V(q,\dot{q}) = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$

$$G(q) = \begin{bmatrix} 0 \\ 0 \\ -m_1 g \end{bmatrix}$$

where

$$M_{11} = l_1^2\left(\frac{m_1}{3} + m_2 + m_3\right) + l_1 l_2 (m_2 + 2m_3)\cos(q_2) - l_2^2\left(\frac{m_2}{3} + m_3\right)$$

$$M_{13} = M_{23} = M_{31} = M_{32} = 0$$

$$M_{12} = -l_1 l_2\left(\frac{m_2}{2} + m_3\right)\cos(q_2) - l_2^2\left(\frac{m_2}{3} + m_3\right) = M_{21}$$

$$M_{22} = l_2^2\left(\frac{m_2}{3} + m_3\right)$$

$$M_{33} = m_3$$

$$C_{11} = -\dot{q}2(m_2 + 2m_3)$$

$$C_{12} = -\dot{q}2(\frac{m_2}{3} + m_3)$$

$$C_{22} = -\dot{q}2(\frac{m_2}{3} + m_3)$$

$$C_{13} = C_{22} = C_{23} = C_{31} = C_{32} = C_{33} = 0$$

In which q1, q2 and q3 are the angle of joints 1, 2&3; m_1, m_2, m_3 are the masses of the links 1,2 & 3; l_1, l_2 & l_3 are the lengths of the links 1,2 &3; g is the gravity acceleration.

System parameters of Scara robot are selected as

$$l_1 = 1m \quad l_2 = 0.8m \quad l_3 = 0.6m \quad m_1 = 1kg$$
$$m_2 = 0.8kg \quad m_3 = 0.5kg \quad g = 9.8$$

Values of the controller gains for PID controller by TAE are taken as

$$K_p = \begin{bmatrix} 200 & 0 & 0 \\ 0 & 100 & 0 \\ 0 & 0 & 100 \end{bmatrix}$$

$$K_d = \begin{bmatrix} 1.7 & 0 & 0 \\ 0 & 0.8 & 0 \\ 0 & 0 & 1.0 \end{bmatrix}$$

$$K_i = \begin{bmatrix} 7 & 0 & 0 \\ 0 & 8 & 0 \\ 0 & 0 & 10 \end{bmatrix}$$

For a three-link manipulator path to be tracked is given in (5) and represented in Fig. [1, 2, 3]

$$q_1 = [1 + 0.1\ (\sin(t) + \sin(2t))] \qquad (5a)$$

$$q_2 = [1 + 0.1\,(\cos(2t) + \cos(3t))] \quad (5b) \qquad q_3 = [1 + 0.1\,(\sin(3t) + \sin(4t))] \quad (5c)$$

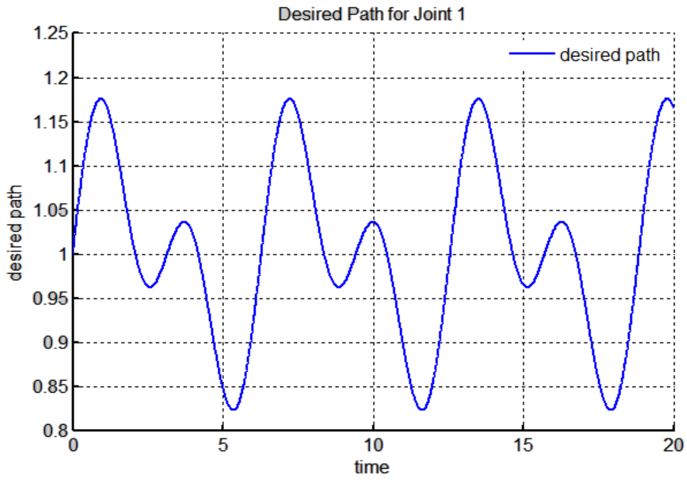

Fig.1: Desired path for Joint 1

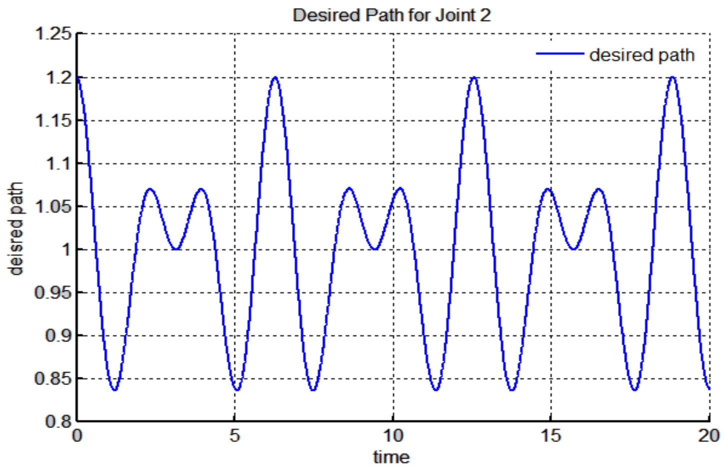

Fig.2: Desired path for Joint 2

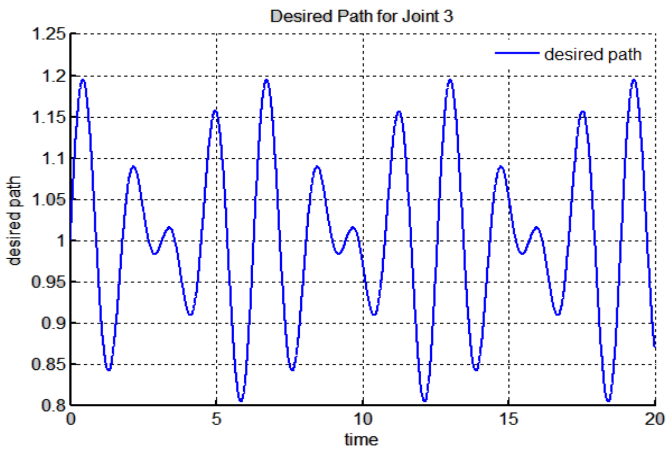

Fig.3: Desired path for Joint 3

***Table1:** Parameters for proposed Controller*

Range of K_d	[0-25]
Range of K_p	[0-200]
Range of K_p	[0-15]

V. Results:

Tracking error for all the joints for all the controllers mentioned in this paper has been calculated. Pareto Front for the MOGA applied for all the constants of PID controller is given below in Fig 2 given below.

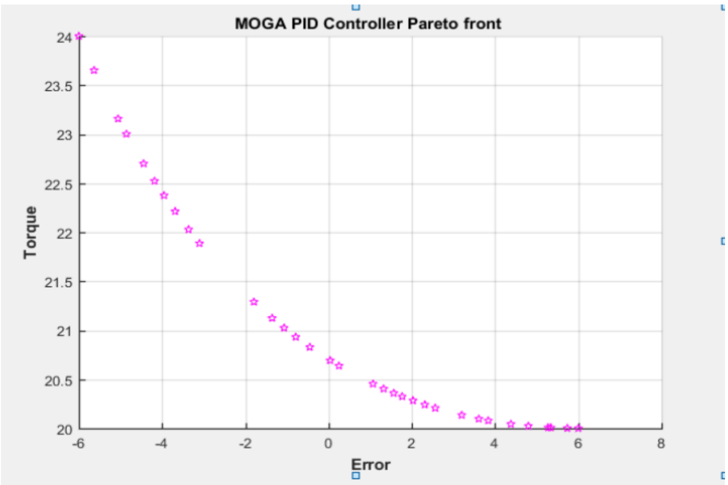

Fig. 4: Pareto Front for MOGA PID controller

These errors have been compared and plotted for all the three joints. Performance indices naming, Mean Square Error (MSE), MEAN error and MAX error for all the three joints have been calculated and compared. These comparative tracking errors have been compared with the tracking performance without any controller and within each other. All the above mentioned errors are tabulated in table 1 given below.

Table 2: Various Types of Errors for Joint 1, 2 & 3 in all the three cases: without any control, with PID controller & with proposed controller

	Joint 1			Joint 2			Joint 3		
	Without any control	PID	Proposed Controller	Without any control	PID	Proposed Controller	Without any control	PID	Proposed Controller
MSE	9.12 e-1	7.11 e-2	7.20 e -4	1.00 e-2	5.07e-5	1.22 e -6	2.34e-1	5.0013 e-3	8.10 e-6
MEAN	1.78 e-1	4.5 e -3	1.11 e -4	1.9 e-3	7.92 e -4	6.79 e -8	8.12e-2	1.406 e-4	6.06 e-5
MAX	8.81 e-1	1.46 e-2	5.01 e-3	3.33 e-1	4.54 e-3	2.34 e-7	2.001 e-1	1.001 e-2	7.2 e-5

It can be observed in the Table 2 that all the errors for all the joints is lowest in the proposed controller. This is followed by the PID controller. MSE, MEAN and MAX tracking errors are found maximum in the case where no controller is used.

Figs. [5-7] represents that the OPD controller has better tracking performance than the classical PD controller. It can be easily observed in the figures given below that the desired trajectory is given in blue colour and the trajectory shown in yellow and red colour are the trajectories obtained when the proposed controller and the PID controller. It can be clearly observed in the trajectories represented in the below given figures that trajectory obtained with proposed controller is closer to the trajectory obtained with PID controller. Hence, the proposed controller in which PID constants are optimized using MOGA are giving the better results.

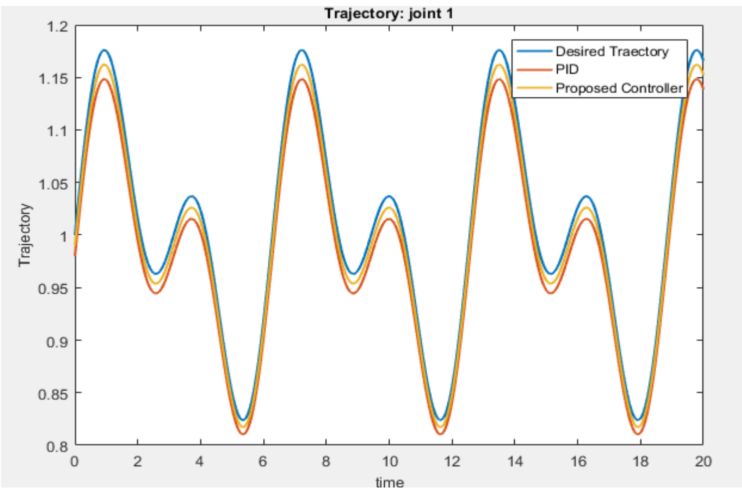

Fig. 5: Trajectory tracked by Joint 1 with PID and Proposed controller.

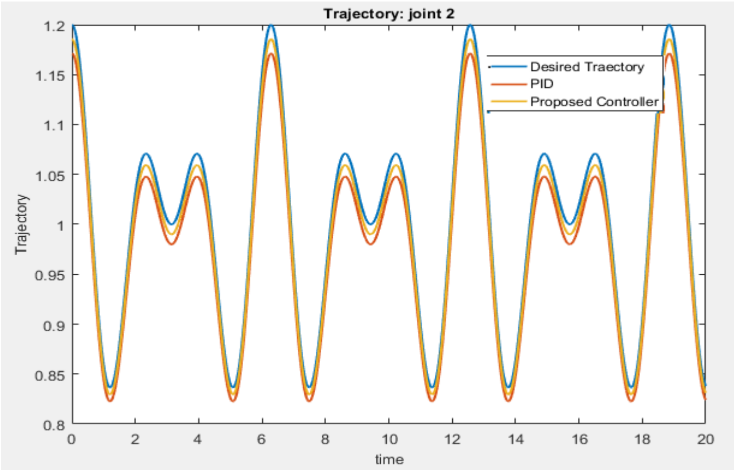

Fig. 6: Trajectory tracked by Joint 2 with PID and Proposed controller.

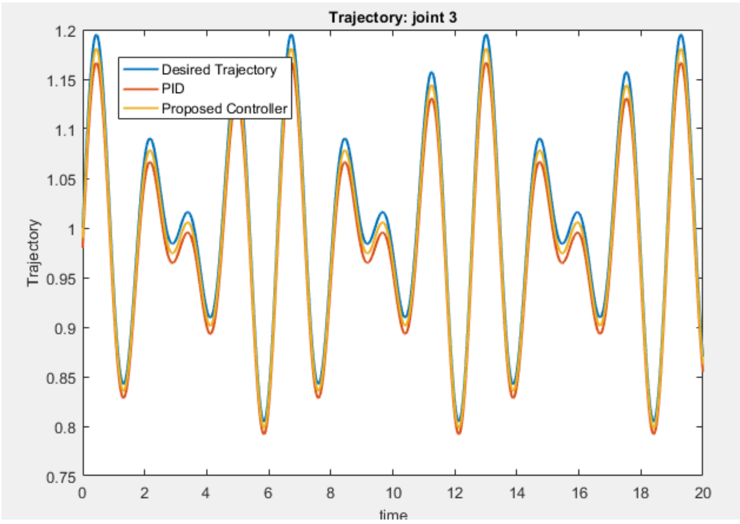

Fig. 7: Trajectory tracked by Joint 3 with PID and Proposed controller.

VI. Conclusion:

A novel hybrid control scheme having MOGA optimized PID constant parameters have been proposed in this paper. This intelligent proposed controller is used for a robotic manipulator for a tracking a pre- defined trajectory. It has been observed from the results obtained that the proposed intelligent controller has less numeric tracking errors when compared with TAE tuned PD controller. Trajectory tracked with the proposed controller is closer to the trait is giving better performance. This hybrid controller can further be used for other robotic manipulators moving on other paths.

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