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Computed Torque Control of a Puma 600 Robot by Using Fuzzy Logic

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Abstract *– The strong dependence of the computed torque control (CTC) of the dynamic model of the robot manipulator makes this one very sensitive to uncertainties of modelling and to the external disturbances. In general, the vector of Coriolis torque, centrifugal and gravity is very complicated, consequently, very difficult to modelled. In order to improve the performance of this control, we propose in this paper a simple and more robust technique based on the fuzzy logic control (FLC) while retaining the architecture of this method. The contribution of this technique was shown by simulation results.*

Keywords*: Computed torque control, Puma 600 robot, Fuzzy logic control.*

Nomenclature

Γ	The $n \times 1$ vector of actuator joint torque
$M(q)$	The $n \times n$ symmetric positive-definite inertia matrix
$C(q, \dot{q})\dot{q}$	The $n \times 1$ vector of Coriolis and centrifugal torque
$G(q)$)	The $n \times 1$ vector of gravitational torques
$q, \dot{q}, \ddot{q}$	The joint displacement, velocity, and acceleration vectors
$F(\dot{q})$	The $n \times 1$ vector of actuator joint friction forces
n	The number of degrees of freedom of the robot.
$e = \tilde{q} = q_d - q$	Vector of the position error
$\dot{e} = \dot{\tilde{q}} = \dot{q}_d - \dot{q}$	Vector of the velocity error
$\ddot{e} = \ddot{\tilde{q}} = \ddot{q}_d - \ddot{q}$	Vector of the acceleration error
$q_d, \dot{q}_d, \ddot{q}_d$	are respectively the vectors of desired position, desired velocity and desired acceleration.
Γ_0	Auxiliary input of the select controller
K_p, K_v	positive definite diagonal matrices gains
G_1, G_2	the gains of normalization
$G_1^{'}$, $G_2^{'}$	the gains of denormalization
P, PP, Z, PN, N	are linguistic variables which mean respectively: positive, small positive, zero, small negative and negative.

I. Introduction

The control of robot manipulators presents nowadays a major concern of research in robotics. Indeed the majorities of the tasks entrusted to the robots are delicate and require great precision in the fast trajectories. The use of the control by nonlinear decoupling constitutes a good approach in this direction. Such control is also known as dynamic control or computed torque (CTC) because it is based on the use of dynamic model of the robot [1].

Implementing this controller requires knowledge accurate and complete model of the robot. In such a situation, this control is perfect. However, in practice this requirement is very difficult to satisfy considering the external disturbances acting on the robot. Under such conditions, this control technique is very sensitive and inefficient [2].

These drawbacks of the linearization control have motivated researchers to develop new versions and strategies of intelligent and adaptive control to limit their effects and to regain the effectiveness of this method [3-4] [5].

In this sense, we present a simple technique and more robust based on the fuzzy logic control (FLC) while retaining the architecture of the computed torque control (CTC) to limit the effects of disturbances and element non-modelled acting on the dynamics of the robot.

The originality of our work is to apply this technique in the joint space for 5 rules contrary to what has been previously applied by [6] in the operational space with 4 rules. The improvement made with this alternative is validated by simulation results.

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II. Model motion of the Robot Manipulator

A robot manipulator consists of a mechanical structure, usually a set of rigid bodies connected in series by joints, with an end on the ground, which is the base of the robot, and the end body or effector.

The model of motion (or dynamics) of such a mechanism is usually described by the following matrix equation:

$$\Gamma = M(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) + F(\dot{q}) \qquad (1)$$

We pose in the following:

$e = \tilde{q} = q_d - q$: Vector of the position error,

$\dot{e} = \dot{\tilde{q}} = \dot{q}_d - \dot{q}$: Vector of the velocity error,

$\ddot{e} = \ddot{\tilde{q}} = \ddot{q}_d - \ddot{q}$: Vector of the acceleration error.

To ensure the linearization and the decoupling of the nonlinear system describes by the equation (1) in closed loop, we introduce a linearization control (CTC) based on exact knowledge of the robot model and its implementation allows us direct. The loop of the linearization is achieved by choosing a torque Γ applied to the robot, as follows:

$$\Gamma = M(q)\Gamma_0 + C(q,\dot{q})\dot{q} + G(q) + F(\dot{q}) \qquad (2)$$

Substituting Γ in expression (1) and taking into account $M(q)$ that is a regular matrix, we have n decoupled linear systems:

$$\ddot{q} = \Gamma_0 \qquad (3)$$

Where Γ_0 is an auxiliary input of the select controller. A proportional derivative control (*PD*) is a typical choice for Γ_0, given by the equation:

$$\Gamma_0 = \ddot{q}_d + K_v(\dot{q}_d - \dot{q}) + K_p(q_d - q) \qquad (4)$$

By the replacement of (4) in (3), we get the following error equation:

$$\ddot{e} + K_v\dot{e} + K_p e = 0 \qquad (5)$$

The error equation (5) is a linear differential equation of second order.

Where K_p and K_v are positive definite diagonal matrices, so the closed loop system becomes linear decoupled.

This equation has solution for an error $e(t)$ that exponentially tends to zero. The closed-loop system with this controller, where the model of the robot is known with accuracy, is asymptotically stable. In the case of an imprecise knowledge of parameters of the robot and/or presence of some unmodelled dynamics, the computed torque control (CTC) shows its limits.

The solution we propose is to use a fuzzy controller (FC) whose role is to adapt the values of coefficients K_p and of K_v to compensate for neglected parts of the dynamic model while keeping the architecture of the method.

III. Computed Torque Control Based on Fuzzy Logic

In order to keep the robot, in joint space, a desired trajectory $q_d(t)$ and its successive derivatives $\dot{q}_d(t)$ and $\ddot{q}_d(t)$, which describe respectively the desired velocity and desired acceleration, the strategy of the fuzzy control consists to give to values of corrector gains in a progressive manner differing to the classical corrector that are fixed [7-10].

The fuzzy controller (FC) comprises the three following blocks:

Fuzzification of input variables by using triangular functions, then the inference that these variables are fuzzifiate compared with presets to determine the appropriate response. And finally the defuzzification to convert the subsets fuzzifies into actual values by using the centroïd defuzzification. The basic structure of our fuzzy controller is given by figure 1.

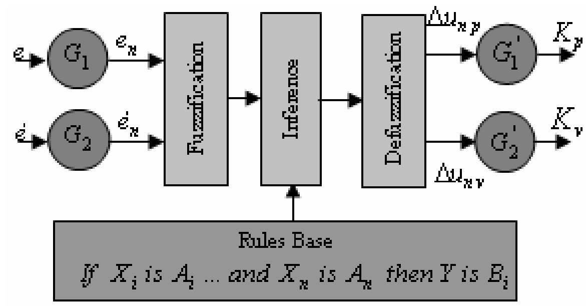

Fig.1. Basic structure of the fuzzy logic controller

With: G_1 and G_2 represent the gains of normalization (scale factors) transforming the physical values $(e,\ \dot{e})$ of inputs in the normalized values $(e_n,\ \dot{e}_n)$ belonging to the interval $[-1\ \ 1]$. Gains $G_1^{'}$ and $G_2^{'}$ allows denormalized the values normalized of the variables control $(\Delta u_{np}, \Delta u_{nv})$ in actual values (K_p, K_v).

III.1. Inference Method

The rules of inference that we have adopted for our controller are the following:

Rule 1: If e is P Then K_i is P.

This means that: If the trajectory of the robot moves away from an significant way, in the positive direction, of the desired trajectory Then to increase to the maximum the gain control (the same reasoning for the other rules).

Rule 2: If e is PP Then K_i is PP
Rule 3: If e is Z Then K_i is Z
Rule 4: If e is PN Then K_i is PN
Rule 5: If e is N Then K_i is N

We have chosen in our case the method of inference Max / Min of Mamdani [11], who consists to realizing the operator "**AND**" and the conclusion " **THEN** " of each rule by the Min function and the operator "**OR**" of the connection between all the rules by the Max function and defuzzification by center of gravity (centroid).

Figure 2 shows the membership function used in a fuzzification of inputs and defuzzification of the outputs linguistic variables.

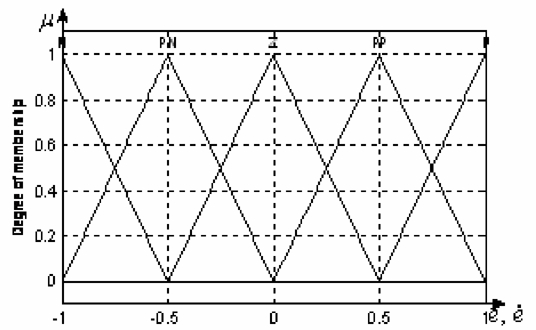

Fig.2. Membership function of the inputs and the outputs of the fuzzy controller

IV. Simulation Results

To show the contribution of the control by fuzzy logic (FL) and its improvements compared to the classical method, a simulation was approved on a model of a robot manipulator puma 600, for the first three DOF, whose parameters are presented on table I [12]. We considered a reference trajectory, ensuring continuity in position, velocity and acceleration, given by:

$$\begin{cases} q_{d1} = 3 + 6(\sin t + \sin 2t) \\ q_{d2} = 2 + 4(\cos t + \sin 2t) \\ q_{d3} = 4 + 5(\sin t + \cos 2t) \end{cases}$$

For the classical method, we took the following parameters:

$$K_p = diag\,(300,\ 300,\ 300);\quad K_v = diag\,(35,\ 35,\ 35)$$

TABLE I
PARAMETERS OF THE PUMA 600 ROBOT MANIPULATOR USED IN SIMULATION

Parameters	Values
Mass of the first body m_1	10.521 Kg
Mass of the second body m_2	10.236 Kg
Mass of the third body m_3	8.767 Kg
Coefficient of viscous friction f_1 of the 1st body	$2.52\,N.m.s/rd$
Coefficient of viscous friction f_2 of the 2nd body	$7\,N.m.s/rd$
Coefficient of viscous friction f_3 of the 3rd body	$1.75\,N.m.s/rd$
Coefficient of dry friction f_4 of the 1st body	$3.6\,N.m.s/rd$
Coefficient of dry friction f_5 of the 2nd body	$10\,N.m.s/rd$
Coefficient of dry friction f_6 of the 3rd body	$2.5\,N.m.s/rd$
Length of the first body $l_1 = r_2$	$0.149\,m$
Length of the second body $l_2 = d_3$	$0.432\,m$
Length of the third body $l_3 = a$	$0.431\,m$

Figure 3 (a, b, c), shows the behaviour of the robot in pursuit of the desired trajectory in both cases of the computed torque control (CTC), classical and by fuzzy logic (FLC). We see clearly that the control performances by fuzzy logic (FL) are better than those in the classical computed torque control (CTC); this is interpreted by the faster convergence of position tracking error to zero, in the case of fuzzy controller. The robot reaches the desired trajectory in a time less than that of classical control. We found similar results for the case of the pursuit in velocity and acceleration.

V. Conclusion

In this article, we have presented a simple technique of control by fuzzy logic that contributes to improved performance of the linearizing control applied to robot manipulators.

The interest offered by the use of a fuzzy controller has been clearly demonstrated by the simulation results. The strategy of determination of gains control (with FLC) presents, compared with fixed gains (conventional CTC), the following benefits:

- A high gain is applied only when the variation is very important;
- If the variation is low, the gain is also low.

The robustness of this control (FLC) lies in its adaptive character to the determination of gains from the regulator, which means a direct adaptive control. These adaptive gains allow smoothing control signals thus, avoiding any solicitation of actuators.

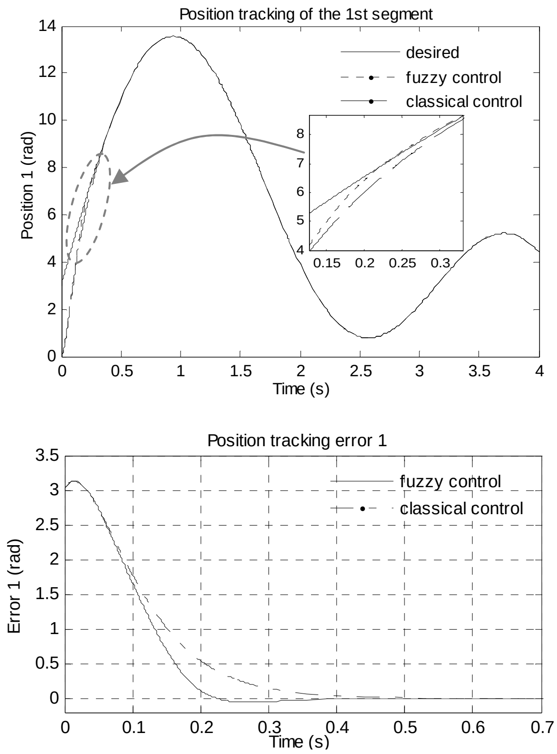

Fig. 3(*a*) First segment

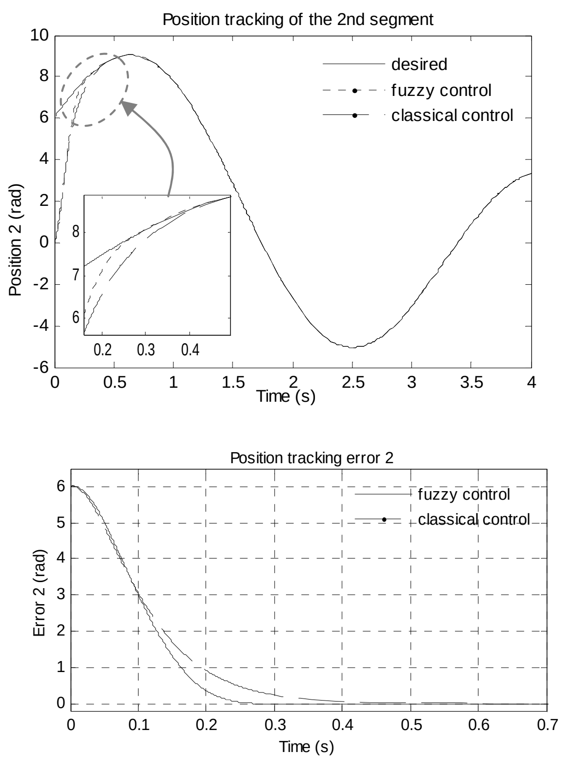

Fig. 3(*b*) Second segment

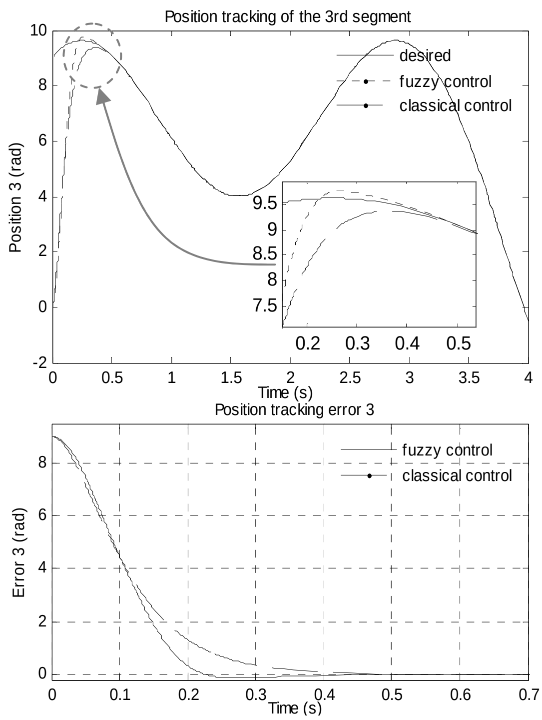

Fig. 3(*c*) Third segment

Figs. 3. Trajectory pursuits of position and position errors with the computed torque control law and that by the fuzzy logic

References

[1] Spong M. W. and M. Vidyasagar, Robot Dynamics and Control. *John Wiley and Sons*, Inc., 1989.

[2] Egeland O., On the robustness of the computed torque technique in manipulator Control, *Proc.IEEE. Intern. Conf. Robotics and Automation*, p. 1203-1208, 1986.

[3] SUFIAN Ashraf Mazhari., Surendra Kumar Member IEEE, Heuristic Search Algorithms for Tuning PUMA 560 Fuzzy PID Controller. *International Journal of Computer Science*, pp. 277-286, Jun. 2008.

[4] Hala Bezine., Nabil Derbel and Adel M. Alimi., Fuzzy control of robot manipulators: some issues on design and rule base size reduction. *Engineering Applications of Artificial Intelligence*, vol. 15, Issue 5, pp. 401-416, Sep 2002.

[5] G. Mkhoury, M. Saad, H. Y. Kannan, C. Asmar., Fuzzy PID control of a Five DOF Robot Arm, *Journal of intelligent and robotic systems*, vol. 40, pp. 299-320, ISSN: 0921-0296, July 2004.

[6] Ben Ghalia M., Alouani A. T., A Robust Trajectory Tracking Control of Industrial Robot Manipulators Using fussy logic. *IEEE Trans. Robotics and Automation*, 1995.

[7] Tang, Kwok L., Mulholland, Robert J., Comparing Fuzzy Logic with Classical Controller Designs. *IEEE Trans. on SMC*, *Vol.* 17, *no.*6, *pp.* 1085-1087, 1987.

[8] Rakesh K Arya., Analytical Structures and Analysis of Simplest Fuzzy PD Controller with Asymmetrical/Symmetrical, trapezoidal/Triangular/Singleton Output Membership Function, *international journal of computational cognition*, *vol. 5, no.* 2, *pp.* 10-24, June 2007.

[9] Moon B. S., Equivalence between fuzzy logic controllers and PI controllers for single input systems - Fuzzy sets and Systems, 69: 105-113, Elsevier Science, 1995.

[10] Petr Pivonka. May, Comparative analysis of fuzzy PI/PD/PID Controller Based on Classical PID Controller approach,

Proceedings of IEEE international conference on fuzzy systems, vol. 1, pp.541-546, 2002.

[11] Mamdani E. H., Application of Fuzzy Algorithm for Control of a Simple Dynamic Plant. *Proc. Inst. Elect. Eng. Contr. Sci*, Vol. 121, pp. 1588-1588, 1974.

[12] Kaddour E. L. , Simulation de la commande dynamique d'un bras manipulteur à 6 ddl appliqué au robot puma 600, USTO, 1995.

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