ARM MANIPULATOR POSITION CONTROL BASED ON MULTI-INPUT MULTI-OUTPUT PID STRATEGY

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Abstract:
A robot manipulator is a multi-articulated mechanical system, in which each articulation is driven individually by an electric actuator. As the most used robot in industrial application, this system needs an efficient control strategy such as the classical PID control law by means of which each articulation is controlled independently. This kind of control presents a lot of inconvenient, such as error of each articulation isn't taken account into others. In this work we present a Multi Input Multi Output (MIMO) PID controller to ensure the articulation robot control strategy, the results obtained present satisfactory and shows clearly the efficiency of the present PID-MIMO controller.

Keywords: *robot, articulation, PID, Control, MIMO*

1. Introduction

The robot arm manipulators in recent years had a slight growth in the industry. Because in standard industrial the controllers don't include the non-linearities between the joints of the robot and the problem of modelling the dynamics and motion control arise the complications of the system when computing the inertia tensor of a moving rigid body [1, 4]. The purpose of robot arm control is to maintain the dynamic response of a computer-based manipulator in accordance with some pre specified system performance and goals. Most of the robot manipulators are driven by electric, hydraulic, or pneumatic actuators, which apply torques (or forces, in the case of linear actuators) at the joints of the robot [1, 4,12]. Conventional robot control methods depend heavily upon accurate mathematical modelling, analysis, and synthesis [4]. Dynamic modeling of manipulators is a very active field of research, it's can be used to investigate the system responses and system properties, like finding the stability of the system [11].

Robot control is the spine of robotics. It consists in studying how to make a robot manipulator do what it is desired to do automatically; hence, it includes in designing robot controllers. Typically, these take the form of an equation or an algorithm which is realized via specialized computer programs. Then, controllers form part of the so-called robot control system which is physically constituted of a computer, a data acquisition unit, actuators (typically electrical motors), the robot itself and some extra "electronics". In this work two types of control problems was studied feed forward control and computed torque control [11, 13].

In this work after the system modeling, simulation and control robot manipulator using two articulations for motion using MatLab/Simulink software were carried, when the proposed MIMO PID controlled is used to improve the articulation robot stability. Two types of control PID and PID-MIMO were studied and analysed, and comparative studies were made.

The reminder paper was structured as follow: the robot modelling is presented in second part of this paper, in the third part of this paper the PID-MIMO is detailed, the results discussion are presented in the last part of this paper and finally conclusion was given.

2. Robot Description

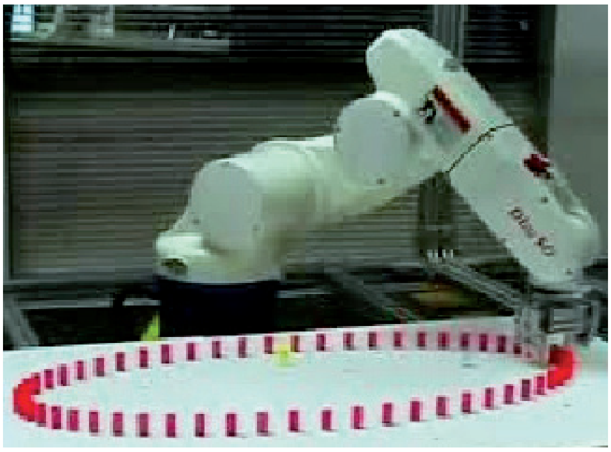

Fig. 1. Pick and Place Robot manipulator

Motion control: for some applications, such as simple pick-and-place assembly, the robot needs merely to return repeatedly to a limited number of pre-taught positions. For more sophisticated applications, such as welding and finishing (spray painting), motion must be continuously controlled to follow a path in space, with controlled orientation and velocity.

Most robot manipulator employed in industrial are controlled by PID algorithms independently at each joint. This kind of control present a lot of inconvenient, for instance the error of each articulation isn't taken into consideration. This can affect the performance of the system such as the precision, the rapidity and the quality of the product. So, in this work we propose a new approach of control to resolve this problem.

3. Robot Dynamic Modelling

The dynamical equation of manipulator robot of n solids articulated between us is given by the following Lagrange method [12]:

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

Where:
$q,\dot{q},\ddot{q} \in \mathbb{R}^n$ denote the joint angle, the joint velocity and the joint acceleration, $M(q) \in \mathbb{R}^{n\times n}$ denote the inertia matrix, $C(q,\dot{q}) \in \mathbb{R}^{n\times n}$ denote the centrifugal and Coriolis force matrix, $G(q) \in \mathbb{R}^n$ denote the gravitational force vector and $\tau(t)$ is the torque.

In the Figure 2 a schema of a two degree of freedom of arm manipulator is given.

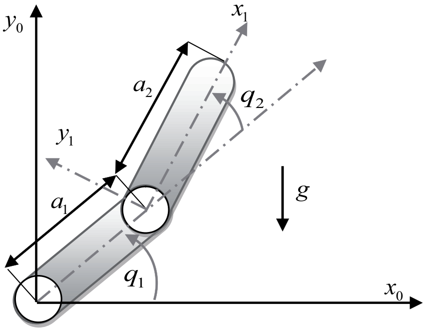

Fig. 2. Structure of manipulator robot of two degree of freedom

The robot dynamics is defined as:

$$M(q) = \begin{pmatrix} (m_1+m_2)a_1^2 + m_2a_2^2 + 2m_2a_1a_2c_2 & m_2a_2^2 + m_2a_1a_2c_2 \\ m_2a_2^2 + m_2a_1a_2c_2 & m_2a_2^2 \end{pmatrix} \qquad (2)$$

$$C(q,\dot{q}) = \begin{pmatrix} -m_2a_1a_2(2\dot{q}_1\dot{q}_2 + \dot{q}_1^2)s_2 \\ m_2a_1a_2\dot{q}_1^2 s_2 \end{pmatrix} \qquad (3)$$

$$G(q) = \begin{pmatrix} (m_1+m_2)ga_1c_1 + m_2ga_2c_{12} \\ m_2ga_2c_{12} \end{pmatrix} \qquad (4)$$

$$\tau = \begin{pmatrix} \tau_1 \\ \tau_2 \end{pmatrix} \qquad (5)$$

With:

$$c_1 = cos(q_1);\ c_2 = cos(q_2);\ s_1 = sin(q_1);$$

$$s_2 = sin(q_2);\ c_{12} = cos(q_1+q_2);\ s_{12} = sin(q_1+q_2)$$

The Table 1 presents the used robot manipulator simulation parameters.

Tab. 1. Used Robot Parameters

	Weight : m_i (kg)	Height : a_i (m)
Arm 1	0.432	1.5
Arm2	0.432	1.2

4. Control Law Used (PID MIMO)

Generally, a classical PID controller of each articulation controlled independently is given with the main following formula [6, 7, 8, and 10]:
The classical PID control law of first articulation is given by:

$$\tau_1(t) = K_{p1}\varepsilon_1(t) + K_{d1}\frac{d\varepsilon_1(t)}{dt} + \frac{1}{K_{i1}}\int \varepsilon_1(t)dt \qquad (6)$$

When the classical PID control law of second articulation is given by:

$$\tau_2(t) = K_{p2}\varepsilon_2(t) + K_{d2}\frac{d\varepsilon_2(t)}{dt} + \frac{1}{K_{i2}}\int \varepsilon_2(t)dt \qquad (7)$$

Where: ε_1 and ε_2 are the main position errors of each articulation controlled independently.
The multivariable PID (MIMO-PID) controller of the two motors is given by the following formula:

$$\tau_i(t) = \left[K_{pi}\right]\varepsilon_i(t) + \left[K_{di}\right]\frac{d\varepsilon_i(t)}{dt} + \left[K_{ii}\right]\int \varepsilon_i(t)dt \qquad (8)$$

Where the terms K_{pi}, K_{ii}, and K_{di} define:

* The proportional term: providing an overall control action proportional to the error signal through the all pass gain factor [8, 9, 10].
* The integral term: reducing steady state errors through low frequency compensation by an integrator.
* The derivative term: improving transient response through high frequency compensation by a differentiator.

And
$\varepsilon_i = q_{di} - q_i (i = 1,2)$ represent the error signal, q_{di} is the input reference signal and K_{pi}, K_{ii}, K_{di} are respectively the gain proportional, integral and derive.

There MIMO PID computations parameters is based on the try and error and our controllers have two important considerations: the position references of the two articulations, and the second articulation have take into account the error position of the first articulation

Our PID-MIMO parameters are given as follows:

Tab. 2. The PID-MIMO Parameters

	Articulation 1	**Articulation 2**
K_p	1200	1200
K_i	400	400
K_d	2500	2500

5. Simulations Results

SISO control based on classical PID model and MIMO model based on multi input multi outputs PID were tested to sinus response trajectory. This simulation applied to two degrees of freedom robot arm was implemented in Matlab/Simulink. Trajectory performance, torque performance and position error are compared in these controllers.

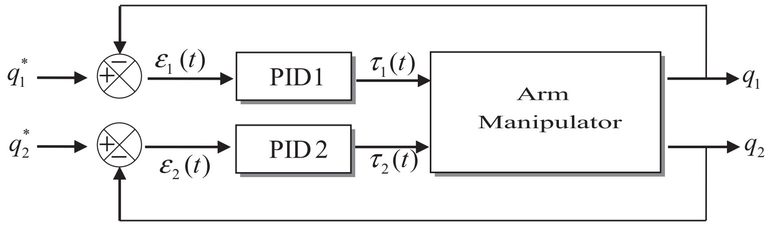

Fig. 3. Arm manipulator robot classical PID Control

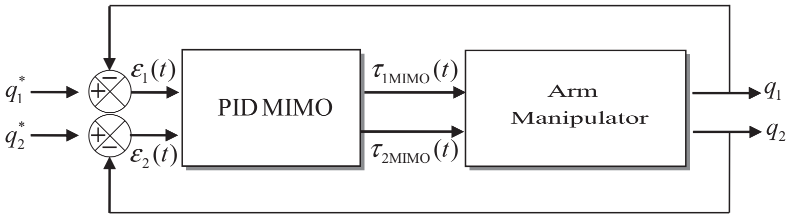

Fig. 4. Arm manipulator robot PID-MIMO Control

The trajectory performances:

Figures (5, 6, 7) are show tracking performance for first and second arm (link) with PID and PID- MIMO for sinus trajectories.

By comparing sinus trajectory with PID and PID-MIMO:

For the first link controlled by PID, the output does not coincide with the reference (Fig.5) but by the PID-MIMO they coincident as shown in (Fig.5) PID's overshoot (3%) is higher than PID-MIMO (0%).

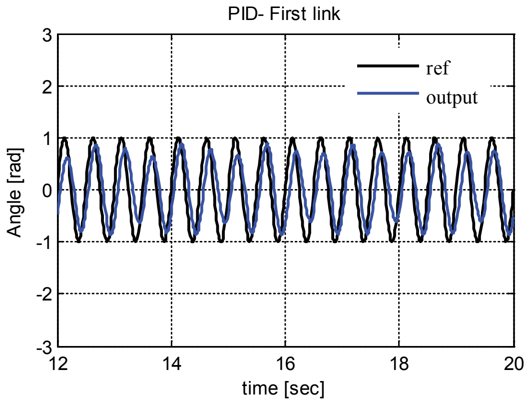

Fig.5. PID (First link trajectory)

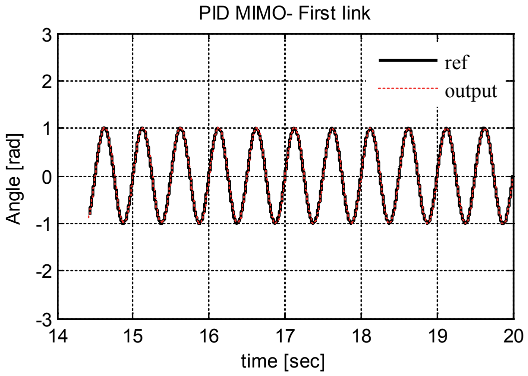

Fig. 6. PID-MIMO (First link trajectory)

For the second link controlled by PID, the output does not coincide with the reference (Fig. 6) but by the PID-MIMO they coincident after t=2s as shown in (Fig. 8).

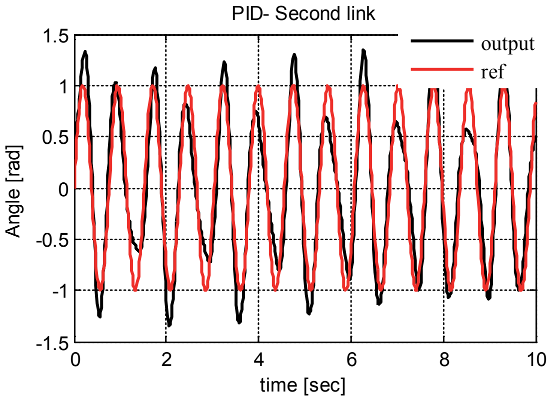

Fig. 7. PID –Second link trajectory

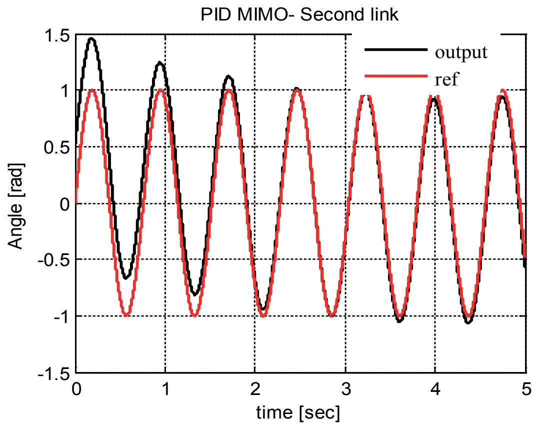

Fig. 8. PID MIMO (Second link trajectory)

Error computation compare:

Figures 9 and 10 are showes error performance, by comparing position error for the first and second link; PID's error is higher than PID-MIMO.

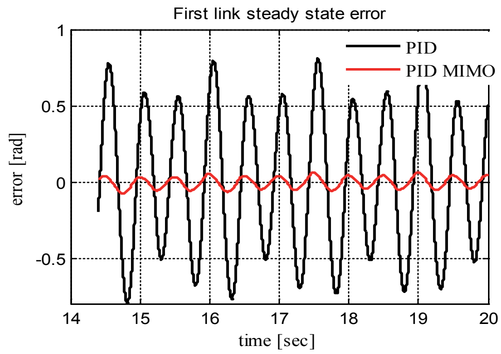

Fig. 9. PID and PID-MIMO for the first link compared error

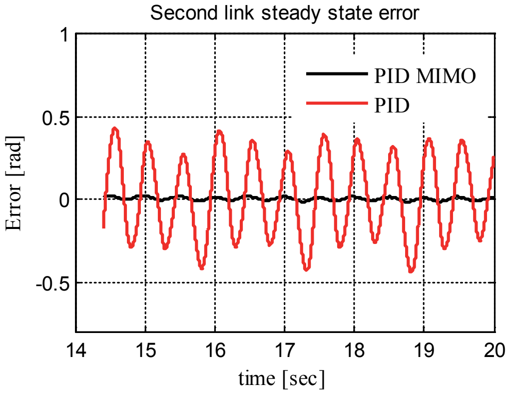

Fig. 10. PID and PID-MIMO for the first link compared error

We can summaries all the obtained results in the Table 2:

Tab. 3. PID and PID MIMO Results

Controller	PID		PID-MIMO	
Links	**Link1**	**Link2**	**Link1**	**Link2**
Position error[rad]	0.519	0.265	0.045	0.014
overshoot [%]	–	3%	0%	0%
Torque [Nm]	1108	315.5	170.5	238

6. Conclusion

In this present work an arm manipulator robot using two degree of freedom was controlled using two types of controls strategies, SISO control based on classical PID model and MIMO model based on multi inputs multi outputs PID controller (PID-MIMO) , this last one present maximum control structure of our control model and give more and more efficiency for the robot model with more position stability and good dynamical performances with no overshoot so industrials would take into account the efficiency of the developing control model for the futures two freedom robot design considerations.

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