XLI CILAMCE
XLI Ibero-Latin American Congress on Computational Methods in Engineering
16-19 November, 2020 FOZ DO IGUAÇU PARANÁ - BRAZIL

ADAPTIVE CONTROL USED IN TWO LINKS OF A ELECTROMECHANICAL ROBOT OF FOUR DEGREE FREEDOM

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Abstract. This work aims to design adaptive controllers to control the position of two links of an electromechanical robot with four degrees of freedom (4 GDL). The control is performed through simulation, using models of the links obtained with real system data, through parameter estimation using the recursive least squares algorithm (MQR). The link identification is carried out in an open loop, using real data collected from the robot. Adaptive controllers are designed and implemented via the imposition of poles to control the position of the two links. The controllers are designed in closed loop based on the models obtained for the links. The control strategy to be used is based on an explicit model of the system. The controllers are implemented through a computer program. The excitation and output curves of the two links are shown, and as a result the output curves of the models of the two links, in open loop and the output curves of the links under the action of the adaptive controllers, in closed loop, are shown too.

Keywords: Robotics, Systems Identification, Adaptive Control.

1 Introduction

This paper aims to control the position, through adaptive techniques, of two links of an electromechanical manipulator robot with four degrees of freedom (4 DOF). The links 1 and 2 to be controlled are shown in Fig. 1. The mathematical model of a system can be obtained by physical laws, known as white box model or parametric identification technique, known as black box model, which relies on real system data. White box models of robot manipulators are nonlinear (Spong and Vidyasagar [1], Craig [2]), while the black box identification generates linear models (Aguirre [3], Astrom & Wittenmark [4], Isermann [5]) that can be used to design and implement adaptive controllers.

The models are obtained in real time, and represent adequately the nonlinear dynamics of the system, since it is evaluated for each instant of time, depending on the sampling time used. The white box models, when used in the design of controllers, demand a high amount of calculations, therefore, they imply the use of large machines, due to computational effort required (Koivo and Guo [6], Shih and Tseng [7]). When using black box models, their structures are defined *a priori*, and thus, the choice of models of the first or second order, which represent well the real systems, and that require the use of low computational effort. As the dynamics of the robot links is coupled and nonlinear, the adaptive controllers are applied, seeking a good performance for the system, since they are obtained at each sampling period and in real time. In this paper, the algorithm of recursive least squares (RLS) is used in real time to obtain the parameters of links 1 and 2 of the robot under consideration, and these are used in projects and implementation of adaptive controllers, aiming to control the position of links 1 and 2 of the robot. The identification of the links is done considering the coupling between them, but the designed adaptive controllers do not take it into consideration. Finally, experimental results are presented showing the performance obtained for the two links of the robot.

2 System description

The manipulator robot, shown in Fig. 1 is a didactic robot, weighing about 7 kg, reference RD5NT, manufactured by Didacta Italy company, consisting of four rotary joints, four links and a claw. The first rotary joint refers to the angular movement of the base, with maximum displacement of 293°; the second rotary joint makes reference to the shoulder, with angular displacement up to 107°; the third rotary joint is related to the elbow, with maximum angular displacement of 284°; the fourth rotary joint pertains to the pulse with maximum angular displacement of 360° and the fifth rotary joint refers to a system crown / worm screw, responsible for the course of the claw, a maximum of 22 mm, clamping capacity load 350 grams and stopped automatically by a micro switch operating with adjustable closing speed. The links of the manipulator robot represent the trunk, arm, forearm and wrist. The transmission of each movement is done by engine block gear, with two reduction stages, and overall gear ratio of 1/500. The engine blocks are DC, reference 2139.906-22.112-050, manufactured by Maxon Motor, with power of 2.5 watts and long life capacitor. The nominal voltage of DC motors is 12 volts and maximum speed without load is 6480 rpm. Reproduction of the angular displacement of joints and claw movement is ensured by means of linear rotary potentiometers, reference 78CSB502, manufactured by Sfernice with resistance of 5 kΩ. A HP Compaq computer with AMD Athlon dual core 985 MHz and 786 MB of RAM is used to send commands to drive DC motors and receive signals from potentiometric sensors. The communication between the robot and the computer is accomplished through two input and output data boards, NI USB-6009, and a computer program in LabView and Matlab platforms. Considering the characteristics of voltage and maximum current capacity of the input and output data boards, it was necessary to introduce a power amplifier to serve as a source of supply for DC motors of the manipulator robot. This amplifier besides providing the power required to drive each motor, supplies the proper polarity for its operation in the desired direction. The decision of the rotation direction depends on the excitation voltage applied at its input terminals.

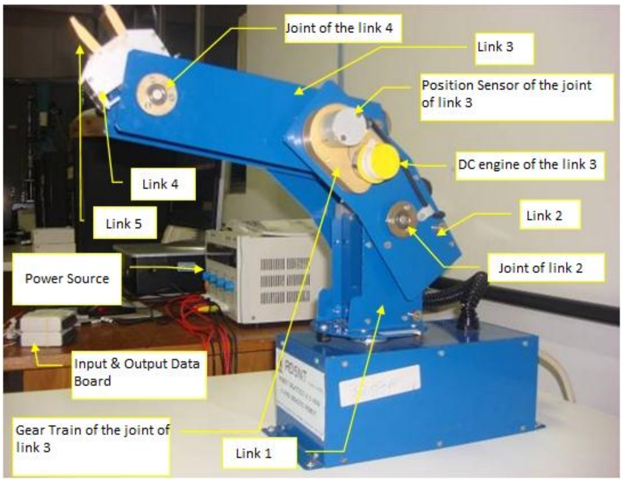

Figure 1. Manipulator Robot of 4 DOF

3 Auto adjustable controller (STR)

The self-adjusting controller (STR) is a type of adaptive controller, which automates the tasks of mathematical modeling, design and implementation of control law. The STR is explicit when the tasks of mathematical modeling, design and implementation of the control law are performed from the estimated parameters of the plant. In the STR, the estimated parameters of the system are determined and updated, at each sampling period, through the MQR. The block diagram of an explicit STR is shown in Fig. 2. The block diagram shows two closed meshes. The lower mesh composed of the system and the output feedback, and the upper one composed by the parameter estimator, by the design of the control law and by the adjustable controller. In the STR, the estimated parameters are considered as the actual parameters of the system. This approach is based on the principle of equivalence to certainty, according to HEMERLY [8].

Controllers such as: Proportional Integral Derivative (PID), Proportional Integral (PI), Proportional Derivative (PD), Minimum Variance (MV), Generalized Minimum Variance (GMV), Linear Gaussian Quadrant (LQG) and Generalized Predictive Controller , can be used for control bill design.

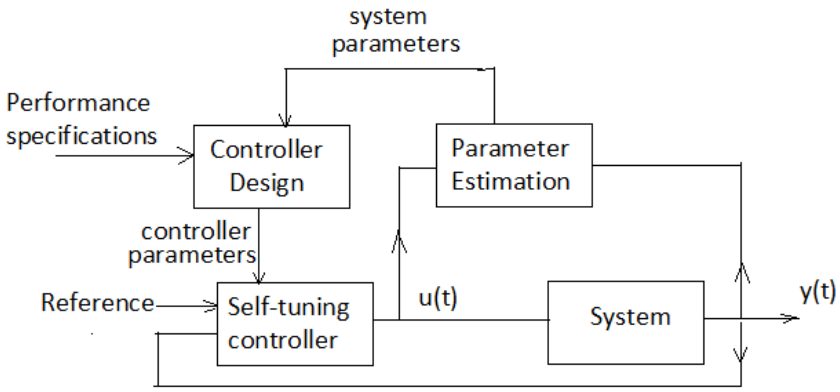

Figure 2. Explicit STR block diagram

The estimation of system parameters is the essence of STR. Among the algorithms that apply to this task are the recursive least squares (MQR) with forgetting factor, according to AGUIRRE [3], LJUNG [9], HEMERLY [8], RÚBIO and SANCHÉZ [10] and COELHO and COELHO [11]. The recursive algorithms use the estimates of the vector, predicted from the instants prior to the instant of time t, to obtain the estimates, as indicated in eq. (1).

$$\hat{\theta}(t) = \hat{\theta}(t-1) + \Delta\hat{\theta}(t) \tag{1}$$

4 Controller PID via síntese de Dahlin

The Equation (2) shows the control action representation of the PID controller in the COELHO et al. [12] .

$$G_c(z) = \frac{U(z)}{E(z)} = \frac{1}{G_P(z)} \frac{[y(t)/y_r(t)]}{[1-y(t)/y_r(t)]} \tag{2}$$

where: $G_p(z)$ is the system transfer function, $G_c(z)$ is the controller transfer function, y(t) is the system output, $y_r(t)$ is the reference, U(z) is the control variable and E(z) is the system output error.

The project proposal of the Dahlin controller, considers that the closed loop system, behaves as first order and with transport delay, according eq. (3).

$$G_c(z) = \frac{U(z)}{E(z)} = \frac{1}{G_P(z)} \frac{[(1-p_1)z^{-(d+1)}]}{[1-p_1 z^{-1} - (1-p_1)z^{-(d+1)}]} \tag{3}$$

where: d is the transport delay.

The system is represented by the following second order discrete transfer function.

$$G_p(z) = \frac{B(z)}{A(z)} = \frac{z^{-(d+1)}(b_0 + b_1 z^{-1} + b_2 z^{-2})}{1 + a_1 z^{-1} + a_2 z^{-2}} \tag{4}$$

Substituting eq. (4) in eq. (3), the eq. (5) of the controller is obtained.

$$G_c(z) = \frac{(1+a_1 z^{-1} + a_2 z^{-2})}{(b_0 + b_1 z^{-1} + b_2 z^{-2})} \frac{(1-p_1)}{[1-p_1 z^{-1} - (1-p_1) z^{-(d+1)}]} \tag{5}$$

Dahlin considers the PID controller in the ideal form according to eq. (6).

$$G_c(z) = k_c \left[\frac{(1+T_s/T_i + T_d/T_s) - (1+2T_d/T_s) z^{-1} + (T_d/T_s) z^{-2}}{(1-z^{-1})} \right] \tag{6}$$

From eq. (5) and eq. (6), we have:

$$k_c = -\bar{k}(a_1 + 2a_2) \tag{7}$$

$$\bar{k} = \frac{(1-p_1)}{(b_0 + b_1 + b_2)[1 + d(1-p_1)]} \tag{8}$$

$$p_1 = e^{\frac{-T_s}{\tau_{MF}}} \tag{9}$$

$$T_i = \frac{-(a_1 + 2a_2) T_s}{(1 + a_1 + 2a_2)} \tag{10}$$

$$T_d = \frac{-a_2 T_s}{(a_1 + 2a_2)} \tag{11}$$

where:

T_s - sampling time;

τ_{MF} - desired closed loop time constant.

Equation (6) represents the PID control in the discretized form, and the difference equation that describes the behavior of the u(t) system control variable is given by eq. (12).

$$u(t) = q_0 e(t) + q_1 e(t-1) + q_2 e(t-2) \tag{12}$$

with:

$$q_0 = k_c(1 + T_s/T_i + T_d/T_s) \tag{13}$$

$$q_1 = -k_c(1 + 2T_d/T_s) \tag{14}$$

$$q_2 = k_c(T_d/T_s) \tag{15}$$

5 Results

The results below were obtained considering a data set of 805 samples collected from the two links of the robot. The estimated parameters of links 1 and 2, from sample 210, were used in the difference equations that represented the links in the design and implementation of PID controllers. The Figures 3 and 4 show the real-time inputs and real outputs and estimated outputs of the links 1 and 2.

Figures 5 and 6 show the outputs of the links with the designed adaptive PID controllers. Outputs were obtained considering pulse sequences as references and the parameters of the controllers were calculated for each sample as well as the control variables.

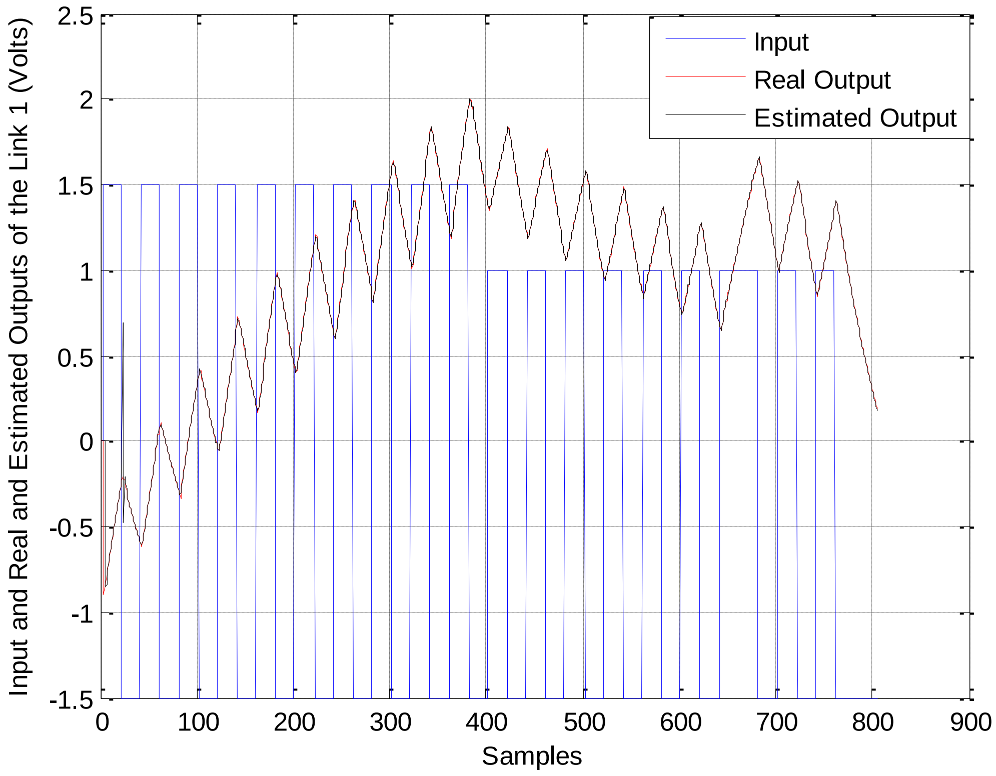

Figure 3. Input and real and estimated open loop outputs of the link 1

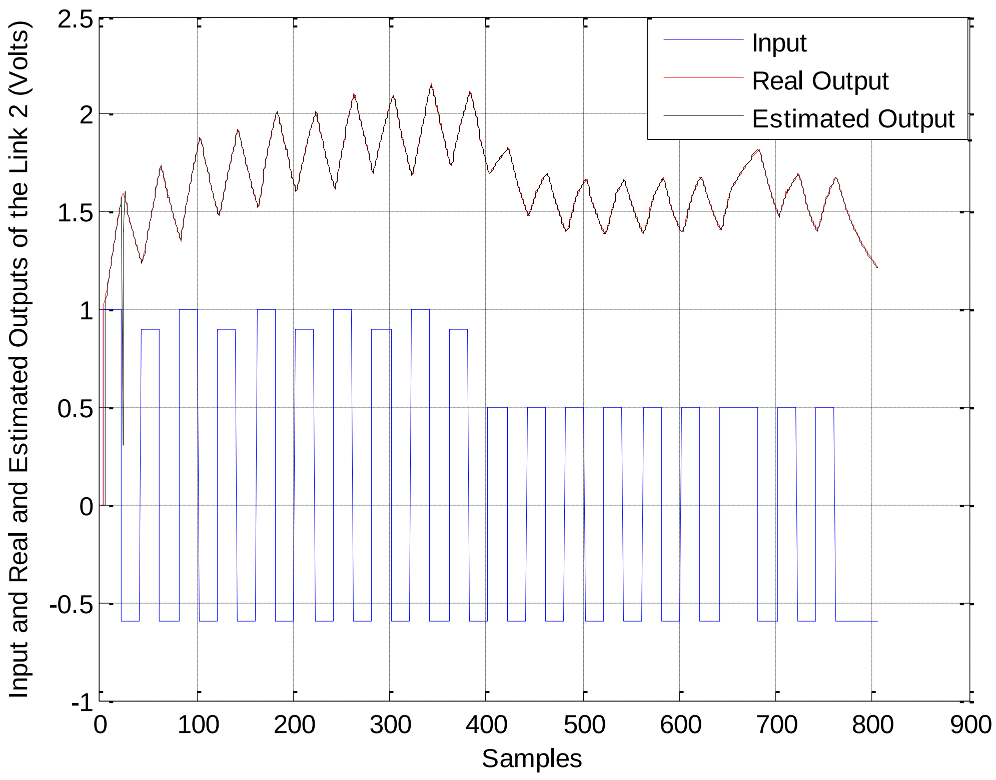

Figure 4. Input and real and estimated open loop outputs of the link 2

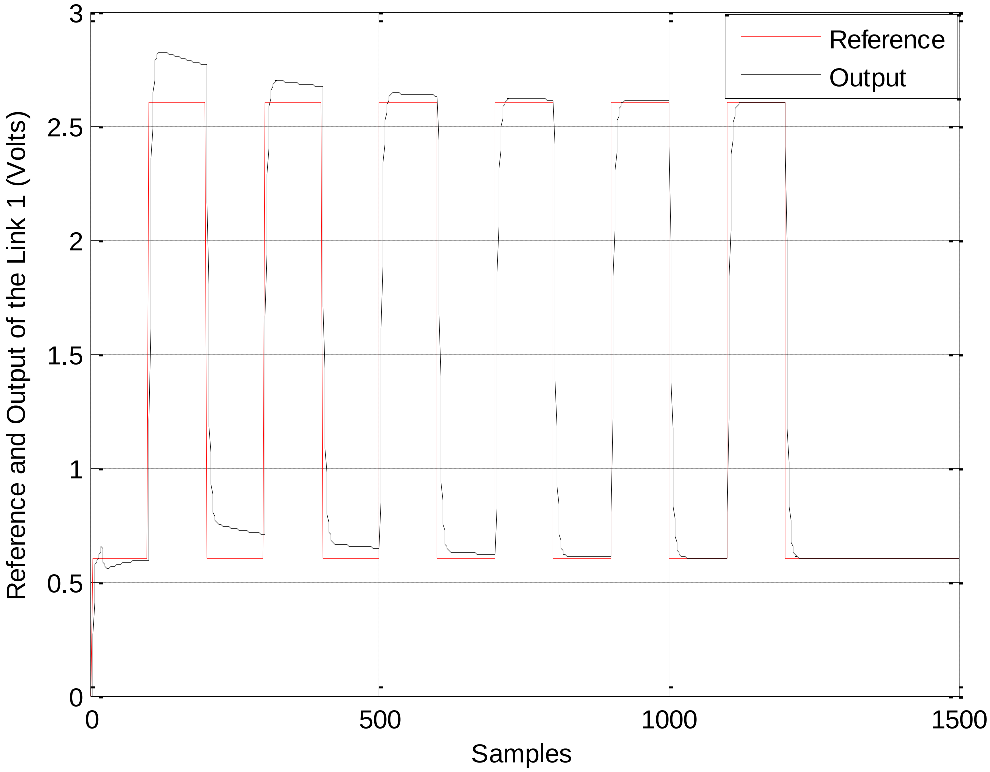

Figure 5. Simulated output of link 1 under the action of the controller

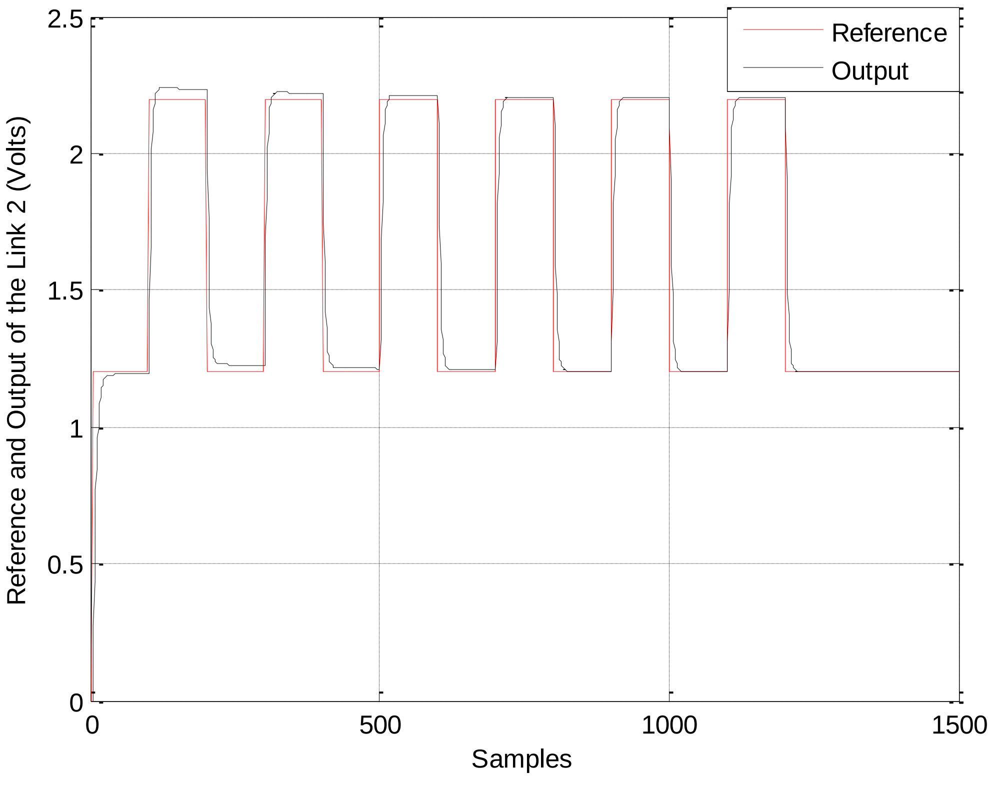

Figure 6. Simulated output of link 2 under the action of the controller

6 Conclusion

This work presented the linear identification technique and the design and implementation of adaptive PID controllers, for two links of a manipulator robot with four degrees of freedom. The identification of the models was carried out using the MQR algorithm, considering the dynamics of the two links of the coupled robot. The designs of the adaptive controllers were carried out through simulation, using the models obtained for the links. The models obtained showed an absolute maximum error of 0,04 volts; and in this way they were considered satisfactory for the design of the controllers. The outputs of the links under the actions of the implemented controllers showed a overshoot of 14% at the beginning of the event, which was reduced over time.

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