Control of a hydraulic servoactuator using an automated algorithm generator

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Abstract

The paper presents an application of techniques and methodologies of automatic control design - already developed and successfully experimented by EICAS in automatic control design - to the control of the MAESTRO hydraulic arm. The application has been developed within the ACODUASIS Project, a three-year project founded by the European Commission in the frame of the Innovation Program aiming at transferring to the robotics sector the EICAS methodology by means of the high professional EICASLAB software tool. The following innovative aspects can be highlighted: "*automated algorithms and code generation*", "*model identification*", "*control parameters numerical optimization*" and "*default fine model class*". The use of EICASLAB reduces time spent in the design phase, increases companies' competitiveness and reduces the time to response.

Keywords: Automatic Control Design, Automated Algorithm and Code Generation, Model Identification, Control Parameter Numerical Optimization.

1 Introduction

The EICAS methodological approach has been developed along 20 years starting from the theoretical results obtained by Donati, Carlucci and Vallauri [1-2].

On the basis of the theory, presented in both previous references, the EICAS approach to the control design of "*almost-linear plants*" is developed according to the following ordered steps:

1. Through the analysis of the *"control design requirement specifications"* the designer states the necessary feedback control frequency band (called *"low frequency band"*).
2. A plant linear model ("*simplified model*") and a related state observer are built, with a frequency pass band sufficient for getting the required control performance, so that it results:
   a. plant-model uncertainty is *norm bounded*,
   b. accurate modeling within the required operating field.
3. The designer builds a *"plant fine model"* (typically non-linear), which should give an *"accurate"* description of the plant dynamics within a frequency band at least 10 times larger than the simplified one,
4. Through numerical simulation, comparing the fine model output filtered through the observer and the simplified model outputs, the result 2.b. is assessed.
5. A feedback control is designed on the basis of the *"simplified model"*, without considering the plant-model uncertainty. In order to get the best control performance, the plant control is typically designed to include:

a. the estimation of future equivalent additive disturbances acting on the plant inputs so that their effect can be directly compensated,
b. an open loop control action, which is computed by means of the "reference generator", together with the required state values,
c. the feedback state control.

6. The control is tuned and its performance assessed by means of the EICASLAB simulator, where the fine model is used to simulate the plant.

3 Test case description: MAESTRO hydraulic arm

3.1 Plant description

The Maestro is a hydraulic arm for heavy load work in nuclear power plants applications. It consists of 6 axes (Figure 1), each of them equipped with position and pressure sensors. The arm is also equipped with a grip for the manipulation of objects.

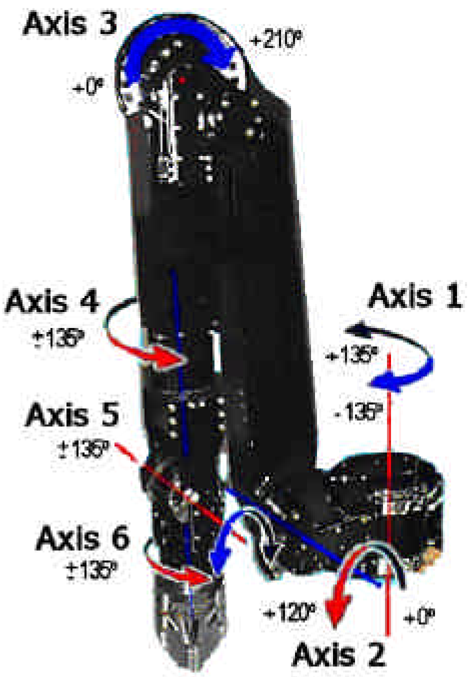


Figure 1. – Maestro arm axes definition.

3.2 Technical specification requirements

The following table indicates some of MAESTRO's more important characteristics:

Number of axes		6 + griper
Load Capacity	(max.)	1000 N
	Griper	2500 N
Rotation range	Axis #1	-135° to +135°
	Axis #2	0° to +120°
	Axis #3	0° to +210°
	Axis #4	-135° to +135°
	Axis #5	-135° to +135°
	Axis #6	-135° to +135°
Griper range		150 mm
Weight		90 kg
Hydraulic pressure		120, 210 and 260 bars

Table 1 – MAESTRO Arm Characteristics

Each axis is a combination of electrical, hydraulic and mechanical parts. The hydraulic servo-actuator is composed by a servo-valve and a rotary actuator.

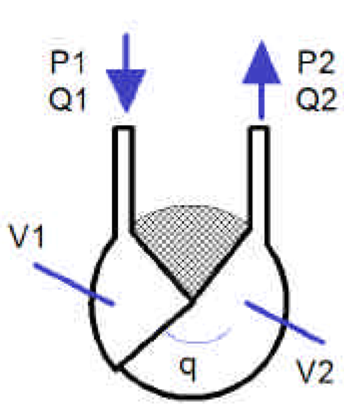


Figure 2 – Hydraulic rotary actuator

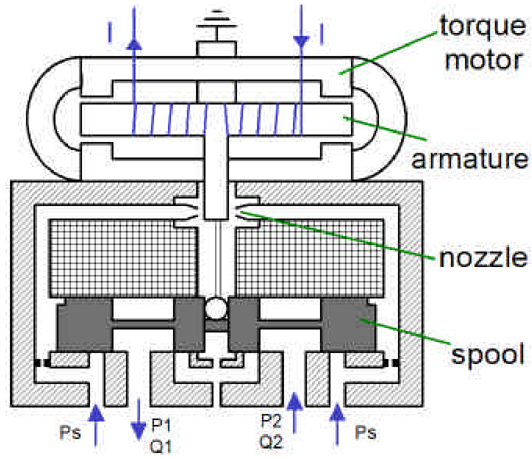


Figure 3 – Electro-hydraulic servo-valve

The electro-hydraulic servo-valve, used to drive flow from the hydraulic power supply to the hydraulic rotary actuator (Figure 2 and Figure 3), is composed by a permanent magnet torque motor and a spool mechanism, which controls the flow to the actuator. Physically, the current reference sent to the torque motor causes the armature deflection and armature flapper displacement. The armature flapper position determines the pressure levels in the nozzles. The difference of pressures causes displacement of the spool.

3.3 Fine model of the plant

The dynamic model of the hydraulic servo-actuator computes the servo-valve current reference of the armature coil, as a function of actuator pressures, position, velocity and acceleration [3].

$$\frac{C_y}{4b_e}\dot{P}_L + C_{tm}P_L = Q_L - D_m\dot{q} \quad (1)$$

$$J_m\ddot{q} + C_{fv}\dot{q} + C_{fs}sign(\dot{q}) = D_mP_L \quad (2)$$

$$Q_L = K_{qi}\ i \tag{3}$$

where:

q	Angular position of motor shaft;
P_L	Pressure difference across the motor (P_L=P_1-P_2);
Q_L	Average flow for the two chambers;
i	Electric current for command;
D_m	Volumetric displacement of the motor;
C_y	Motor's total compressed volume;
b_e	Effective bulk modulus of the system;
C_{tm}	Inter-chamber leakage coefficient;
J_m	Moment of inertia of the motor and load;
C_{fv}	Viscous friction coefficient;
C_{fs}	Static friction coefficient;
K_{qi}	Servo-valve gain.

3.3.1 Model parameters (estimated experimental values)

Estimated values of the dynamic parameters are given in Table 1, together with the respective standard deviations values.

Parameters	Value	Std Dev (%)	Units
D_m	3.27×10^{-5}	0.12	m^3
$C_y/4ß_e$	5.20×10^{-14}	1.18	$m^3.Pa^{-1}$
C_{tm}	1.17×10^{-12}	0.75	$m^3.s^{-1}.Pa^{-1}$
J_m	19.1	0.26	$kg.m^2$
C_{fv}	52.1	0.75	$Nm.s^{-1}$
C_{fs}	16.8	0.80	Nm
K_{qi}	15×10^{-3}	-	$m^3.s^{-1}A^{-1}$
Q_{L0}	-1.23×10^{-6}	0.47	$m^3.s^{-1}$
P_{L0}	1.28×10^{5}	1.64	Pa

Table 2 - Estimated model parameters

Note: some of the presented values in table 2 are very small due to the fact of their representation in the International System units.

3.4 Fine model validation results

The direct validation of the estimated values is carried out comparing the model simulation results with the experimental data (Figure 4).

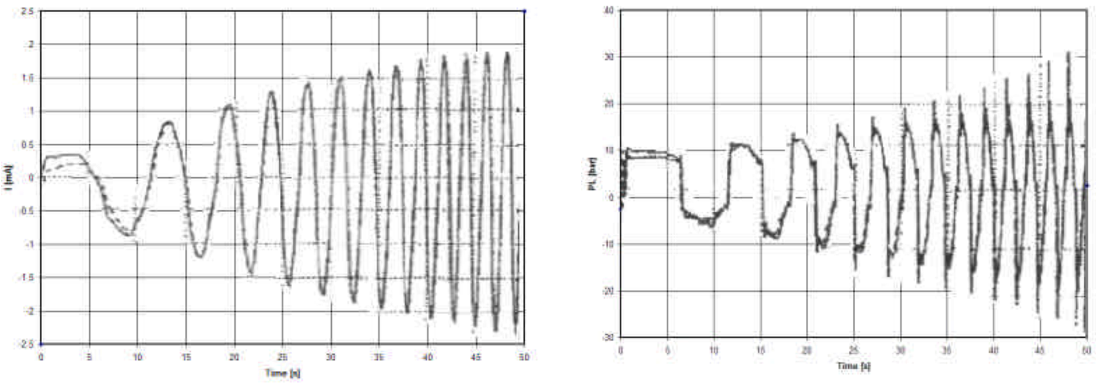


Figure 4 – Inverse dynamic model simulations on I and P_L (-- experimental; — simulation)

3.4.1 Implementation in EICASLab

Figure 5 shows the implementation of the Maestro model (Eq. 1 to 3) in the EICASLab software application.

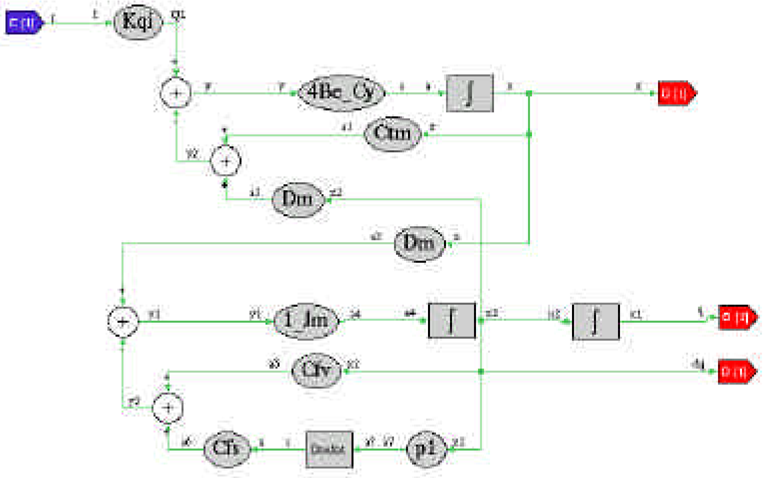


Figure 5 – Implementation of the Maestro model on the EICASLab.

3.5 Simplified Model

The Simplified Model used in EICASLab for control purposes is shown in the following figure:

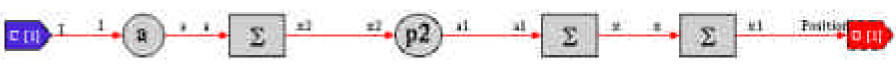


Figure 6 – EICASLab Simplified Model

4 Control design using EicasLab

4.1 Control Goal

The control should allow a quick and accurate following of the changing target-angle [5]. Moreover it is also required the inexistence of overshooting.

The control action must be able to allow the existence of two operating modes: (1) automatic Mode and (2) master-slave mode. The first one is the basic control mode; used for joystick remote command or autonomous movements. In the second one the arm (that becomes the slave) follows the movements of a Master arm, i.e., all the movements of the master are transmitted to the slave, and all the effort is fed back to the master. Movements can be given in axial or cartesian coordinates. In this mode, the command is done either by a master arm or a joystick.

The master and slave arms are not identical. The master is a simpler electrical one and, despite it has the same number of axes, its geometry is different. Moreover there are also some axis rotation mismatches between both arms. Thus, when working in cartesian space, direct and inverse geometric models must be used.

4.2 Original Control Structure

Figure 7 shows the proposed control structure proposed by [4] to control each axis of the Maestro arm, consisting in a cascade of three control loops. The axis speed is controlled ($v = \dot{q}$) in the innermost loop, with the speed reference being generated by a torque (effort) controller. The torque value is inferred through the measured pressure at the actuator chambers. In the outer loop, a PID controller sets the desired torque in order to regulate the axis position.

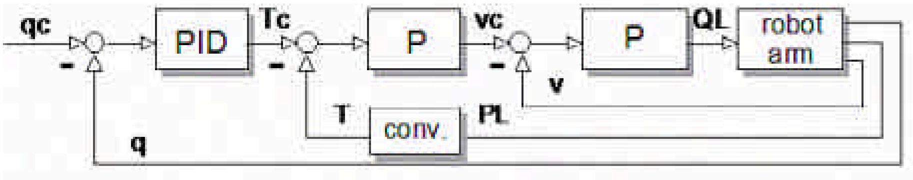


Figure 7 – Proposed control structure for the Maestro arm (one axis)

4.3 EICASLab Control Structure

The control structure proposed here is based on the Automatic Algorithm Generation (*AAG*) feature, as can be seen in Figure 8. The aim of *AAG* is to provide sophisticated control techniques in a reduced time without requiring a specific know-how. The *AAG* is a particular way for programming a control function, so it is an alternative to the C and the graphical mode. The user can choose among a set of predefined feedback control architectures or state estimators and forecasting models.

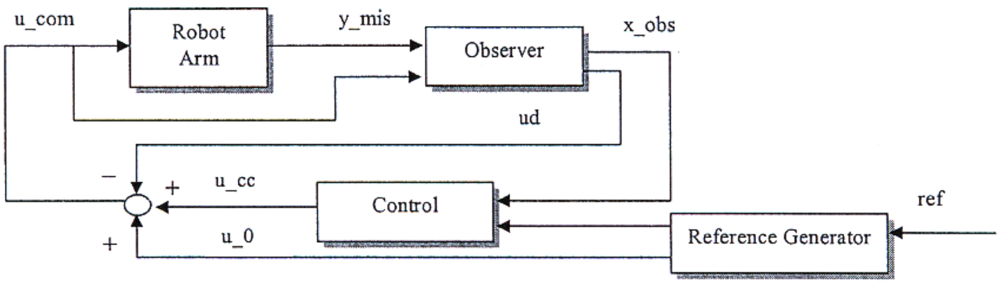


Figure 8 – Control Structure Proposed by EICAS

5 Simulation results

5.1 Results of the Original Control Structure

Simulations were carried out in Matlab's Simulink to evaluate the control structure originally proposed:

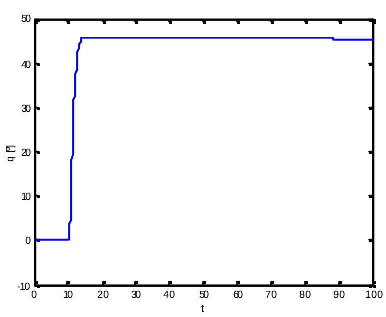


Figure 9 – Position in º

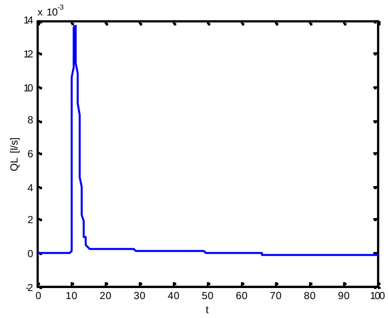


Figure 10 – Average flow in l/s

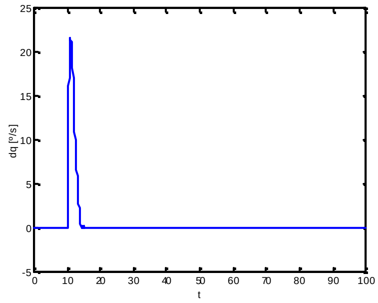


Figure 11 – Speed in º/s

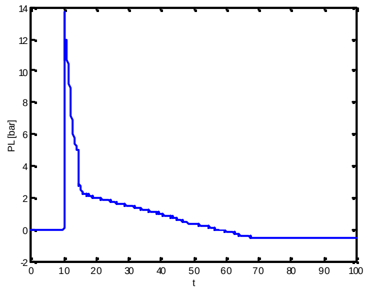


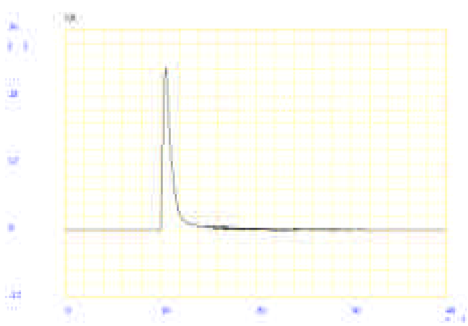
Figure 12 – Pressure in bar

5.2 Results of the EICASLab Control Structure

A similar task was performed in EICASLab, to observe the behaviour of the control structure proposed here. The following figures show the obtained results:

Figure 13 – Position in rad

Figure 14 – Speed in rad/s



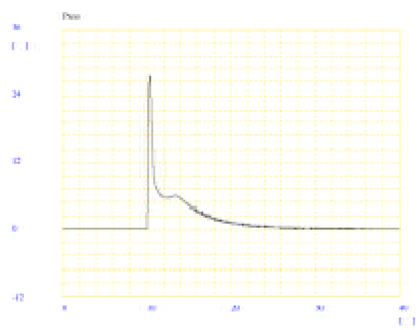


Figure 15 – Flow in ml/s **Figure 16 – Pressure in bar**

6 Conclusions

This paper presents the application of the EICAS methodology, through the use of the EICASLab software tool, to the control of a hydraulic arm as a test case. The necessary steps for the control design are here stated and some simulation results with the plant fine model are shown, illustrating its potentialities.

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