Industrial robots control with EICASLAB approach: industrial prototyping and experimentation results

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Abstract

Automation is more and more part of our everyday life. The trend is to automate the control of equipments so as to increase people's safety, quality of life and scientific knowledge. That explains the increasing demand to have more efficient, reliable and safe automated systems in a short time-to-market. In line with these considerations European Community approved the ACODUASIS project, whose aim is to experiment an innovative control design methodology in the robotic field. The new approach has been applied to a COMAU industrial robot by means of the EICASLAB software tool. The experimentation covered all the phases from the control design to the tests on the actual plant, and allowed to demonstrate both the advantages of the innovative methodology and the benefits obtained by using the EICASLAB.

Keywords: automatic control design, robotic control application, experimentation results, industrial prototyping.

1 Introduction

ACODUASIS (Automatic COntrol Design Using Advanced SImulation Software) is a project founded by the European Community aimed at transferring the EICAS innovative methodology to the robotic field through a professional software tool (EICASLAB) which can help a user in designing control system algorithms.
During the project several test cases have been developed in order to demonstrate the potentials of such an innovative methodology. In particular this paper describes the results obtained within the experimental activity related to the test case proposed by COMAU: control of the motor positions of a six axes industrial manipulator (COMAU NH4).
The first section of the paper introduces the robot application and what the project expects from this experimentation. Then a description of the implemented control algorithm is given. And finally the results in term of performance, cost reduction and easiness of control design are reported and analysed.

1.1 Description of the application

The robot set at disposal by COMAU for the experimentation was the COMAU NH4 200-2.7. It is a six axes manipulator with 200Kg of maximum payload, the maximum extension is 2.7m horizontally and 3.25m vertically. It is characterized by the hollow wrist, a particular COMAU patented solution for avoiding problems due to the cable twisting during movements. It has been designed for applications like spot-welding and handling.

Fig. 1. COMAU devices: NH4 robot, C4G controller, TP4i

The NH4 robot was controlled by the last generation of COMAU controllers: the C4G. It is a PC Processing Unit with 2 CPU Boards on Bus Compact PCI, able to control up to ten axes. The HMI (human-machine interface) is the Teach Pendant TP4i, through which the user can perform all the task and movements foreseen for the robot.

1.2 Aims and objectives

The experimental activity performed on the COMAU NH4 robot consisted in the development of a closed loop control algorithm controlling the motor position. The sensors used to measure the angular position of the motor rotors are encoders. Fig. 2 shows a scheme of the structure of the system composed by the robot with the joints control.

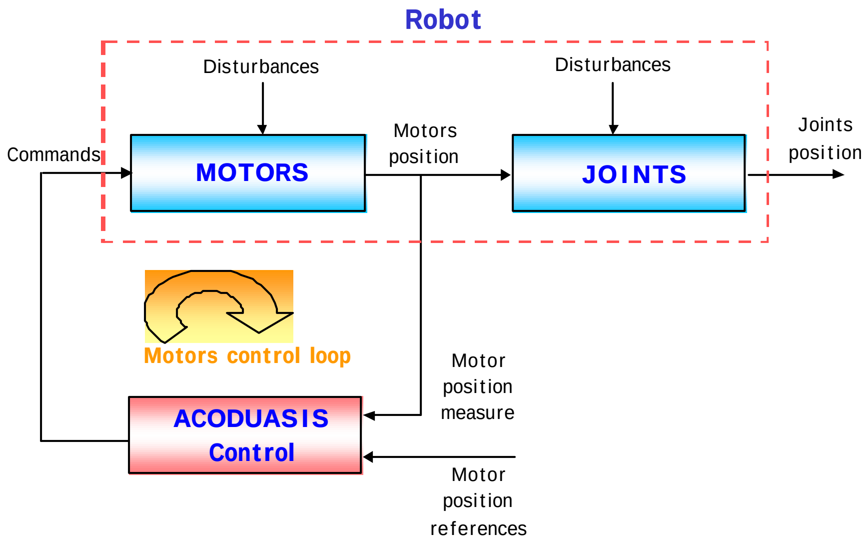

Fig. 2. Robot control scheme

The objectives of this activity was to demonstrate that, through the EICAS methodology, it is possible to develop control algorithms:

1. designed just using plant project data, without requiring any additional experimental measures;

2. robust and able to work properly since the first plant start-up without requiring any tuning in field of the control parameters;
3. able to offer performance better than or equal to the ones obtained with control systems designed by means of classic methodology and setting-up through an expensive experimentation in field.

2 Control Algorithm

The EICAS methodology represents a new approach for designers working in the sector of automatic controls. It has been developed by EICAS during its twenty years of experience, and has been tested in many different industrial fields: digital control, signal processing, vehicle control, spacecraft control, handling of flexible materials.
The detailed description of the methodology is beyond the purpose of this paper, so in this section we will just resume the most important characteristics of the control algorithm structure. For better understanding the problems characterizing the plant modelling (fine model and approximate model) we suggest [1] and [2], then [3] and [4] for analysing the mathematical basis of the methodology (theorem of uncertainty).

2.1 Architecture

The structure of the controller proposed by the EICAS approach is reported in Fig. 3, and it is composed by three blocks: the state and disturbance observer, the closed loop control and the reference generator.

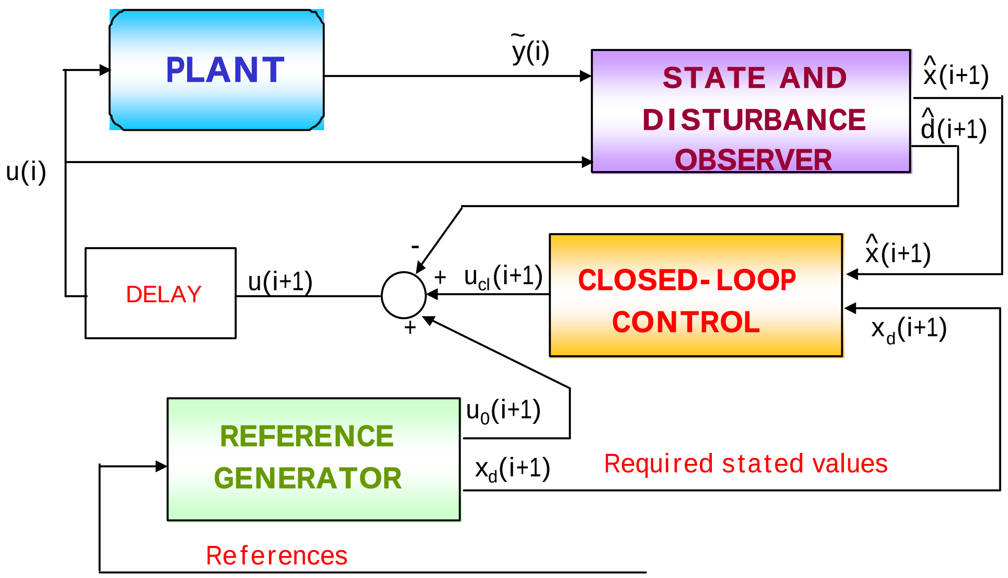

Fig. 3. Structure of the EICAS control algorithm

The observer is composed by two parts: the state observer and the disturbance observer.
The **state observer** is the most important part of the scheme because it is responsible of the stability of the whole structure. It can be realised in many different ways, but it is always based on the approximate model of the plant. Moreover, by means of an internal feedback, it is able to generate an estimation of the states which model in a good way the behaviour of the plant.

The **disturbance observer**, on the contrary, analyses the contribution on the measures due both to the model uncertainty and to the disturbances acting on the plant. The idea is to build a model of foreseeable disturbances and to analyse the difference between the measures of the plant and the outputs of the approximate model, in order to obtain an estimation of the equivalent disturbance at the input of the plant.
The feedback action of the controller is done by the **closed loop control**; it generates a closed loop command by analysing the difference between the estimated and the desired states.
The last block to be considered is the **reference generator;** it is the block necessary to get the reference of trajectory compatible with the dynamics of the plant. The idea is to take a signal from a higher hierarchical level and, by means of an internal feedback on the approximate model, to obtain the desired states necessary for that reference.
The final command obtained by the controller is composed by a combination of three contributes:

- an open loop contribute, obtained by the reference generator block, corresponding to the command that would perfectly generate the desired states in the case in which the plant was perfectly described by the approximate model;
- a closed loop contribute, generated by the closed loop control block, that is responsible of the corrections to be applied to the plant in order to make it stable and to obtain good performance;
- an estimation disturbance contribute, generated by the disturbance observer block, that compensates the disturbances present in the plant and the model uncertainty.

2.2 Development

Once the structure of the control algorithm according to the EICAS methodology (as described in the previous paragraph) has been defined, the work effort has been oriented towards the study of the architecture of the COMAU C4G controller: the aim was to understand its characteristics in terms both of hardware (microprocessors and network communication) and software (real-time tasks and data processing at any hierarchical level).
As a consequence of this task, it was possible to develop a simulation project in the *EICASLAB environment* of the whole robotic system under test, composed by the dynamic model of the COMAU NH4 robot (see [5]), the sensors, the actuators and the COMAU C4G controller.
The simulation phase is a basic step in the EICAS methodology, because it allows:

- *to set the parameters* (poles of observer, close loop control and reference generator) of the control algorithm in laboratory, without the need of any tuning in field on the actual plant.

Moreover the characteristics of the simulation environment (EICASLAB, see [6]) improved and made faster the translation of the control algorithm into the final C code for the COMAU C4G controller. In fact it allowed:

- *to perform a deep and complete debug* of the code (instruction by instruction, verifying all the internal variables) by importing in the simulator exactly the same source code files implementing the EICAS control algorithm in the C4G numerical controller (it would not be possible to perform this debug in other ways);
- *to import the same reference* trajectories applied to the actual robot;
- to import the experimental data acquired in field, in order *to perform comparisons between measured and simulated data*.

At the end of this phase, having designed the control algorithm according the EICAS methodology, and having debugged the C code, we expected (as actually verified) that the robot could work properly at the first start-up of the plant, with the performance foreseen in simulation.

3 Experimentation results

The experimentation in field and especially the trials performed by the robot with the ACODUASIS control algorithm allowed to concretively understand and demonstrate the benefits of the EICAS methodology. We can consider three main aspects already explained in the paragraph 1.2, that will be analysed in this section.

3.1 Control based on a simplified model

According to the EICAS methodology, the control algorithm has been designed on the basis of the approximate model of the plant (see [2] and [5]). Each axis has been considered as rigid and independent from the others, so each one is modelled by means of a discrete second order model (see Fig. 4).

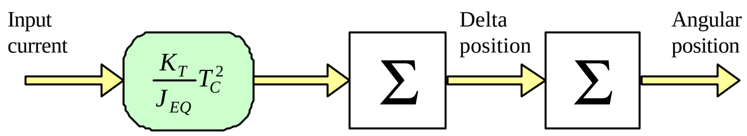

Fig. 4. Approximate model

The *only two parameters* requested for such kind of model are the average inertia (J_{EQ}) and the torque constant of the motor (K_T). They are data taken directly from the datasheet of the system under test and *no identification phase was necessary* on the actual plant.
Moreover some indications about how the dynamic response of the plant changes were available by means of particular algorithms already implemented in the COMAU C4G controller. Nevertheless this information was not strictly necessary for the EICAS methodology and it has not been used in the control algorithm.

3.2 System start-up

One of the most important advantages of the EICAS methodology is the minimization of the time needed to obtain the final version of the control algorithm application completely tested and working with the requested performance. More in details the approach avoids at all any tuning in field of the control parameters. This has been verified within the experimentation.
At the *very first start-up* of the whole system *the robot worked properly and in a safe way*, the control algorithm demonstrated its stability and robustness. *The set of parameters used in field was the same defined theoretically* and verified by means simulations. The performance was as expected (see paragraph 3.3) and *it was not necessary to perform any tuning in field* of such parameters.

3.3 Performance

The performance of the ACODUASIS control algorithm has been analysed by considering the class of COMAU reference signals, that are typical trajectories for robotic applications.

The control system implemented for the COMAU NH4 robot is a motors control loop, in other words a servo-system controlling the position of the motors in order to make them follow as close as possible the reference trajectories received as input. For this reason the parameter to be analysed was the *tracking error*, that is to say the difference between the input reference and the position of the motor, in the joint space.

In order to quantify the performance of the ACODUASIS control algorithm, two indexes have been considered: the mean value and the standard deviation of the tracking error defined above.

- the *mean value* indicates whether the system is affected by a systematic error,
- the *standard deviation* is strictly related to the maximum obtainable error.

Moreover the performance has been analysed in two different operative conditions: static trials and dynamic trials.

Static trials allow to verify the ability of the control system to keep the desired position. Different positions all around the operative work space have been considered; Fig. 5 shows the tracking error for the six axes in the robot calibration position.

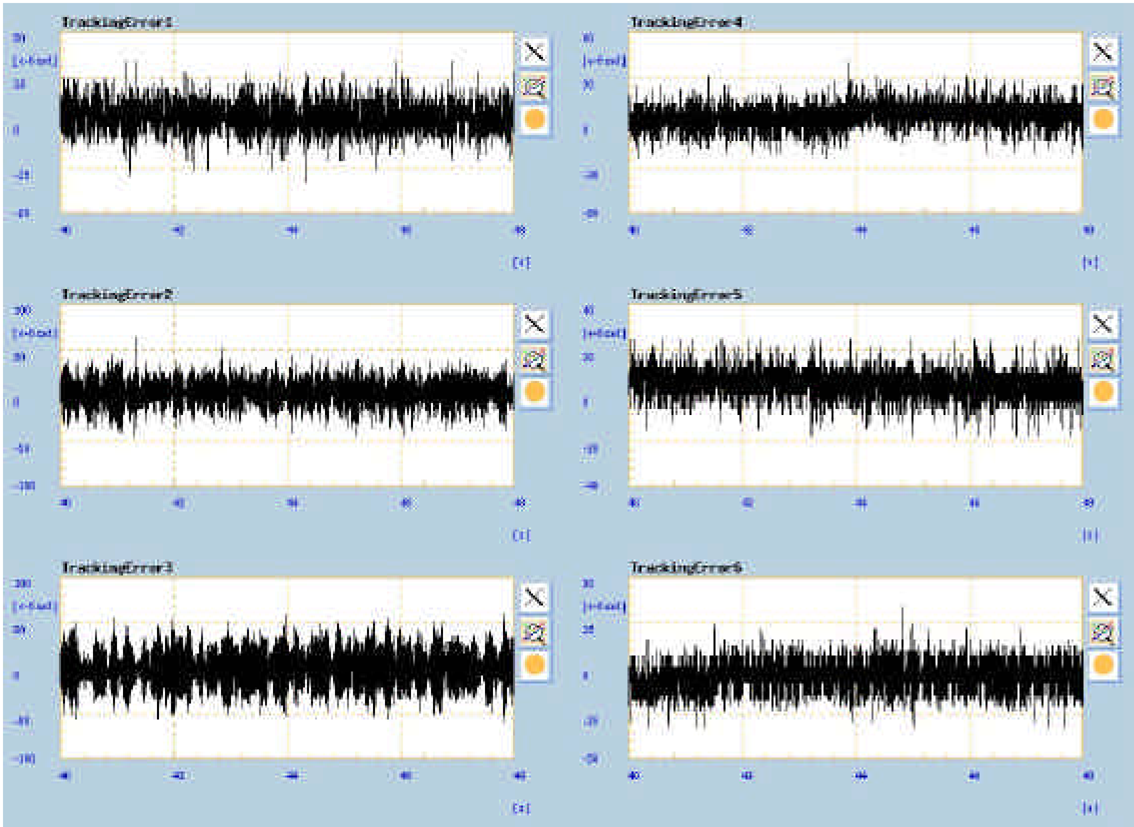

Fig. 5. Tracking error in static trial (calibration position)

The dynamic trials allow to verify the goodness of the behaviour of the system in performing typical movements for industrial applications of NH4, for example: spot welding, handling etc…

Fig. 6 shows the tracking error for the running in cycle (LAVNH4 trajectory) performed at the maximum speed.

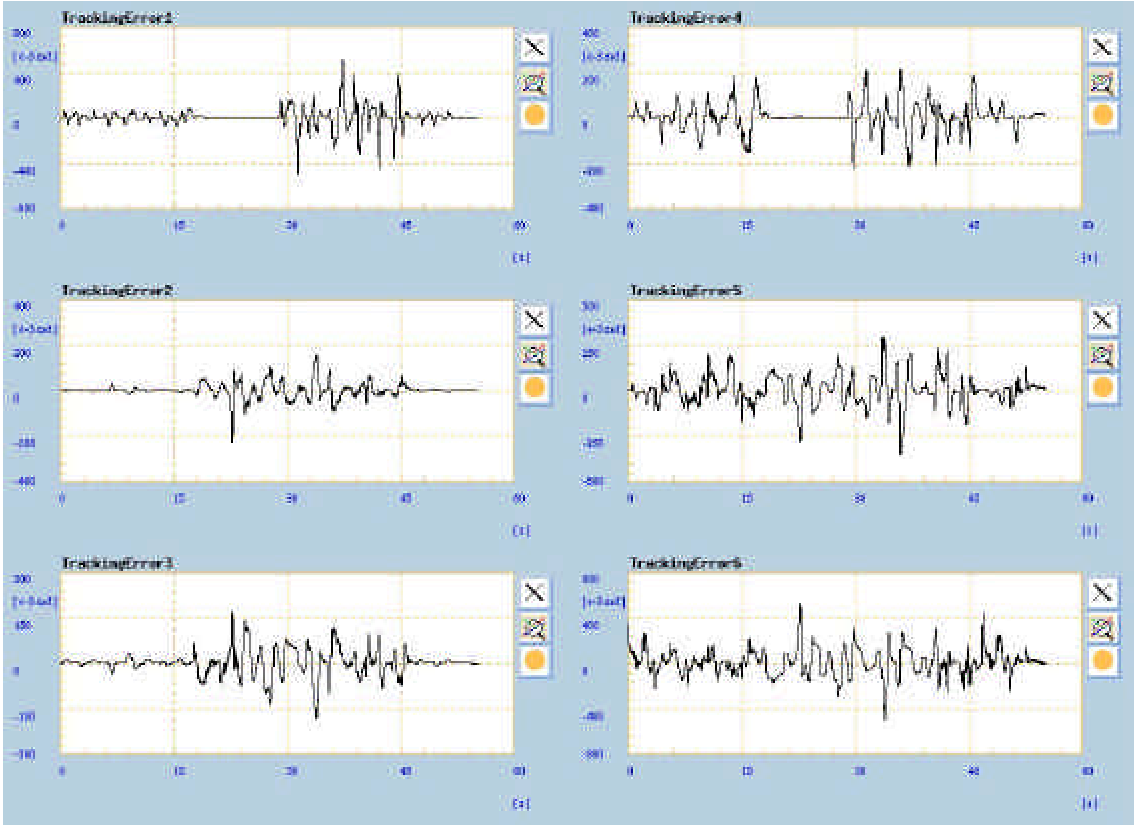

Fig. 6. Tracking error for the LAVNH4 trajectory

The results of the experimental trials are resumed in Table 1. For each trial and for each axis the mean value and the standard deviation have been calculated. Then the arithmetical mean among all the axes and the trials has been computed.

For static trials the indexes are respectively of the order of 1e-6 and 1e-5 radians; this means that, in the worst case (robot at its maximum extension), in the Cartesian space the error committed is about 1e-7 meters, absolutely negligible with respect to the requirements needed for the robot positioning in industrial applications.

In dynamic trials the errors are just a little bit higher, they are respectively of the order of 1e-4 and 1e-2 radians. Again, in the worst case, this corresponds to a Cartesian error of the order of 1e-3 meters, that is still a good result for dynamic trials. In fact the analysis of this result must take into account that the dynamic trials performed are movements at the maximum speed, typically used for moving the robot tool from one working position to another one. So for these movements the most important requirement is to perform them as quick as possible, while the required accuracy is lower than for static trials.

Table 1. Performance of the ACODUASIS control algorithm

	Mean value [radians]	*Standard deviation [radians]*
Static trials	1.13e-6	1.70e-5
Dynamic trials	3.83e-4	3.70e-2

Considering the operative requirements of the COMAU robots, it is possible to conclude that, *in the context of the class of references used for such robots, the ACODUASIS control system error can be considered negligible* both as mean value and as standard deviation.

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