EICASLAB: The software tool for the automatic control design

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Abstract

EICASLAB is a professional software tool for automatic control design, that has been suitable customized and used within the ACODUASIS project to allow the technology transfer to the robotic sector of the EICAS innovative methodology on automatic control design.
The paper starts with an overview of the software tool concept and its main features. Then the paper goes on with the description of EICASLAB functional architecture. The use of EICASLAB significantly helps the designer along all phases of the design process of the control strategy, from the system concept to the production of the control software to be transferred in the plant control processors. The tool offers sophisticated control techniques without requiring a deep mathematical knowledge for their applications.
The note is concluded with a mention of the major advantages and benefits offered, which have been proven in concrete cases within the ACODUASIS Project.

Keywords: automatic control design, professional software tool, automated algorithm generation, automatic code generation.

1 Introduction

Since the Eighties EICAS follows the control system design methodology presented in [1] (see also [2] and [3]), that allows to design plant control systems on the basis of plant simplified models and aims at avoiding the experimental control system set-up performed by actual plants.
The basic idea followed by EICAS lies in the fact that the design of the control system has to be considered as the design of any engineering work. It has to be developed on the basis of the customer requirements and of the plant design data. When the control system, with its algorithms and related software is delivered to the customer, the achievement of the requested performance has to be guaranteed, without the need of experimental tuning performed by the actual plant.
Control systems have been designed for the space and operate at present in orbit on board of satellites. Control systems have been also designed for industrial processes, for machine tools, for the automotive sector.
During this experience it has been found out that the control design effort was very considerable. In fact the designers must have a deep knowledge of sophisticated mathematical techniques together with experience and know-how in the specific sector in which they operate.
In order to make it easier for the designer and to reduce the necessary time for the project development, the automatic control design is supported at EICAS by software tools, all conceived and mainly developed by the author. Such software tools became over the years more and more sophisticated, following the progress of digital control: from the old PID single-processor single-loop controllers to the multi-loop multi-processor controllers, which implement sophisticated intelligent control logics, including different control modes automatically selected, fault diagnosis and auto recovery. At the basis of the approach there is the *Automated Algorithm*

and Code Generation methodology, a way of making available to the designer sophisticated mathematical methodologies, without requiring from him a deep knowledge of them: he only needs to know how and when it is convenient to use those techniques.
A family of software tools, called "EICASLAB family", was born: it is made up of highly professional custom-made software tools, each one specifically oriented toward a well defined control design area, such as "Spacecraft attitude determination and control system design", "Automotive control system design", "Vehicle crash prediction and avoidance system design".
The ACODUASIS Project [4] stems from the above mentioned experience and it has the goal of technology transfer design to the robotic field of the powerful methodology on automatic control. The final output of the project is the EICASLAB tool in a version customized for the robotic sector, shortly illustrated in the following paragraphs. At first the software tool concept is presented, then the EICASLAB functional architecture is described. The note is concluded with a mention of the major advantages and benefits offered.

2 EICASLAB: the software tool concept

The problem considered is the "plant" control design, where "plant" is a physical object belonging to the real world such as an industrial robot. Such a problem, see Fig. 1, is typically split in two steps.

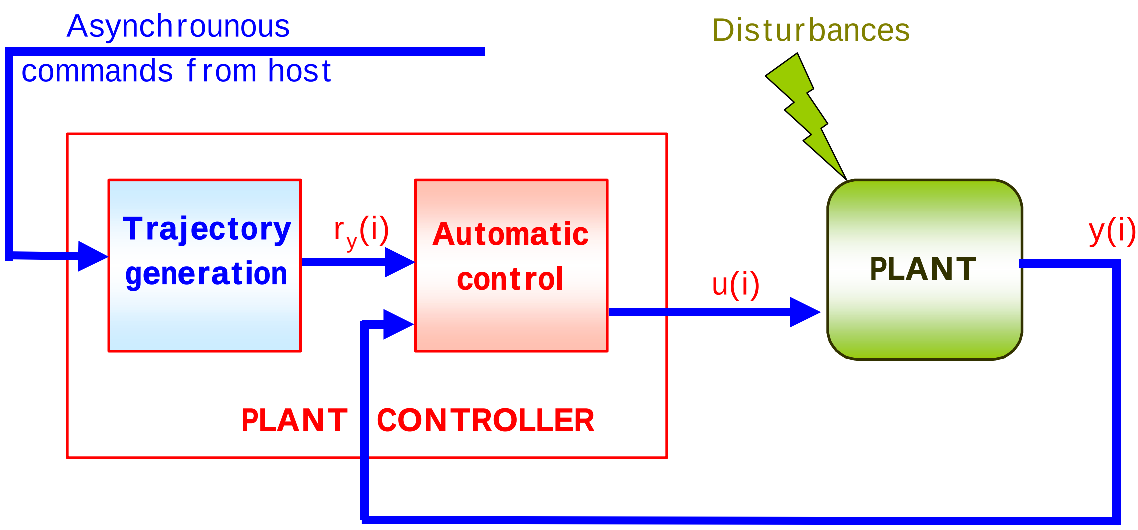

Fig. 1 The "plant" control design problem

The first step is the design of the automatic control of the plant, intended according to the classic meaning of the term, that is, the design of an algorithm to determine a sequence of values of the plant input variables in order that the plant output variables track stated output reference signals within stated accuracy limits. Such a step includes both closed loop and open loop automatic control design. The subject of this design step is represented in Fig. 1 by the "automatic control" block.

In robotics, typically, the host does not send to the plant controller the above output reference signal, but, by means of asynchronous commands, it requests point-to-point robot movements or more complex operations. Then, the second design step aims at determining the plant output reference signals in such a way that the plant, tracking the determined output reference signals, performs what has been required by the host. The subject of this second design step is represented in Fig. 1 by the block "trajectory generation".

The EICASLAB is an environment where the designer can develop, optimize and test all the algorithms and software related to the "plant controller", including both the "automatic control" and the "trajectory generation". To perform such a task three different working areas are available as follows.

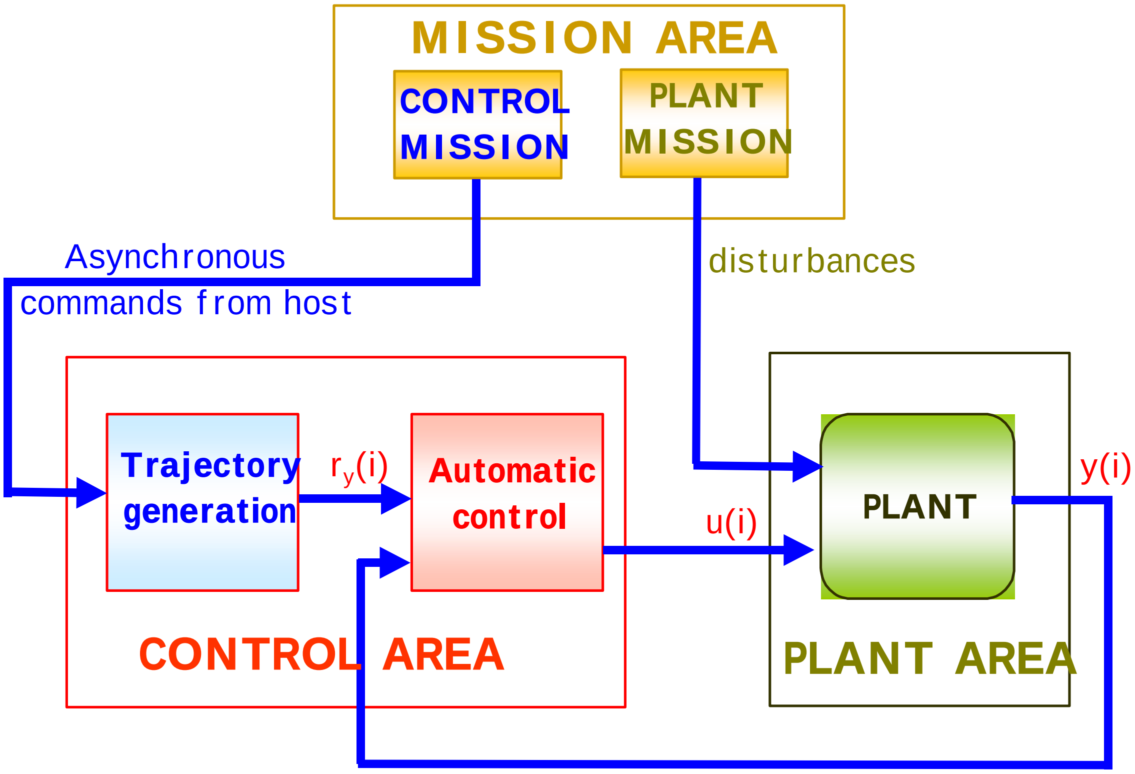

Fig. 2 The three working areas in EICASLAB: PLANT, CONTROL and MISSION area

The PLANT area to be used to simulate the plant dynamic behavior by means of the "plant fine model". The CONTROL area to be used to design the functions related to the automatic control and the trajectory generation.
The MISSION area to be used in order to plan the simulated trials. It is split in two sections, respectively, the *Plant Mission* and the *Control Mission*. The first one has to be used to generate the disturbance acting on the plant during the simulated trials and to schedule any other event concerning the plant performance, like plant parameters variations. The second one is devoted to generate the host command to be sent to the plant control during the simulated trials.

The final result of the designer work is the "application software" in C language, debugged and tested, ready to be compiled and linked in the plant control processors. The "application software” includes the software related to the “automatic control” and the “trajectory generation” functions.

The first outstanding characteristic of EICASLAB is to be a professional tool with a special attention devoted to the control hardware and software architecture.
Hardware architectures including multi-processors and software architectures including multi-level hierarchical control are considered. The control software is subdivided into functions allocated by the designer to the different processors. Each control function has its own sampling frequency and a time window for its execution, which are scheduled by the designer by means of the EICASLAB scheduler.
Data can be exchanged among the control functions allocated to the same processor and among the different processors belonging to the plant control system. The delay time in the data transmission is considered.
The final “application software” generated in C language is subdivided into files each one related to a specific processor.

Another outstanding characteristic of EICASLAB is the support given to the designer in the control algorithm development, in the identification of the simplified model parameters and in control parameter tuning by simulated trials. All the functions, which are available to support the designer, implement fully original algorithms developed by EICAS and not available outside of EICASLAB. A short overview of the above available functions is now given.

The ***Automated Algorithm Generation*** is an option, which starting from the “plant simplified model” generates the control algorithm. The designer can choose among three control basic schemes and for each one he has the option of selecting control algorithms at different level of complexity. The Automated Algorithm Generation is specifically oriented to implement the innovative methodology described in [2] and a particular relevance is given to the plant state observer, the task of which may be extended to estimate and to predict the disturbance acting on the plant.
In synthesis, the control is performed by the resultant of three actions:

- the *open loop action*, which is given by the commands necessary to track the reference signals computed on the basis of the plant simplified model;
- the *plant disturbance compensation*, which is computed on the basis of the disturbance predicted by the plant state observer;
- the *closed loop action*, which is computed as the action necessary to correct the plant state error with respect to the reference one.

The *plant disturbance compensation* is an original control feature, which allows to reduce significantly the control error. It is the result of a sophisticated control algorithm developed by EICAS and widely tested successfully in many applications. Such a feature can be used only as a part of the innovative methodology described in [2] or other equivalent, which does not require experimental control tuning in field. Indeed, it enlarges significantly the control degrees of freedom, so that the number of the control parameters to be tuned became so large that does not appear possible to do it experimentally in field.

The ***Model Parameter Identification*** is an option which allows the identification of the most appropriate values of the simplified model parameters from simulated trials performed by using the “plant fine model”.

Let us point out that the above parameter "true" value does not exists. Indeed, the model is an approximated description of the plant and then, the parameter "best" value is depending on the cost functional adopted to evaluate the difference between model and plant.
Because the "plant simplified model" must be used to design the plant control, then EICAS has developed an original identification method, which estimates the best values of the simplified model parameters from the point of view of the plant control design.

The ***Control Parameter Optimization*** is an option which allows to perform the control parameter tuning in simulated environment. The optimization is performed numerically over a predefined simulated trial, that is for a given mission (host command sequence and disturbance acting on the plant and any other potential event related to the plant performance) and for a given functional cost associated to the plant control performance.
The optimization is performed by a powerful numerical optimization algorithm, originally developed by EICAS, which allows in a very reasonable computing time to get the optimum value of a large number of parameters (it has been already used to optimize the control system with up to about 100 parameters).

Another outstanding characteristic of EICASLAB is the support given to the designer in setting up the control on the plant and assessing the control performance. Two facilities have been conceived: ***Rapid Prototyping*** and ***Slow Motion View.*** The first one is a classic feature of the professional software tool, at present it is in phase of development and the expected performance is described in paragraph 5. The second one is an original feature of EICASLAB and it is here shortly mentioned.

The ***Slow Motion View*** is a feature to be used in the phase of setting up of the plant control. The plant input and output and the host commands sent to the controller are recorded during experimental trials and then they can be processed by EICASLAB as follows. The recorded plant input and output variables are used in the Plant Area inside of the input and output variables obtained by the plant simulation. The recorded host commands are used in the Control Mission area inside of the host command generated by the Control Mission function.
Then, when a simulated trial is performed, the control function receives the recorded outputs of the actual plant and the related recorded host commands inside of the simulated ones. Because the control function running in the EICASLAB is strictly the same one, which is running in the actual plant controller, then, the commands resulting from the simulated control function and sent from the simulated control to the simulated plant should be strictly the same of the recorded plant inputs (unless there are numerical errors depending on the differences between the processor where the EICASLAB is running and the one used in the actual plant controller, but the experience has shown that the effects of such differences are negligible). Then, the recorded experimental trial performed by the actual plant controller is completely repeated in the EICASLAB, with the difference that now the process can be performed in slow-motion and, if useful, step by step by using a debugger program. All the working variables of the control software can be recorded and then analyzed by means of the POST tool (see next paragraphs) available in EICASLAB.
The aim of the Slow Motion Facility is precisely the above mentioned one: to allow, step by step and variable by variable, the analysis of the control software performance during experimental trials performed by means of the actual plant.

3 EICASLAB: The functional architecture

The use of the software tool envisages three different phases of work:

- Automatic control and simulated environment *programming*
- Control trials *performing* in the above simulated environment
- *Post-processing* and analysis of the results obtained in the simulated trials.

A unique program, called *MASTER*, manages all the *programming*, *performing* and *post-processing* phases running specific tools for each phase:

- *SIMBUILDER* is the tool which helps the user in developing control algorithms and related codes and in programming the simulated environment for testing the above control design. It includes the *Automated Algorithm Generation* functions which help the user in the control algorithm design.
- *SIM* is the tool which enables the performance of simulation trials. A customized SIM program is created by means of the *SIMBUILDER* for each specific control design project. It includes the simulation of the plant, of its environment and of the control system. It includes also the algorithm for the model *identification* and the algorithm for the control *optimization*, when these options are required by the user.
- *POST* is the tool which allows the analysis off-line of the simulation trial results.

3.1 SIMBUILDER features

The SIMBUILDER offers a pre-defined architecture to design the three distinct areas above mentioned: the *PLANT* area, the *MISSION* area and the *CONTROL* area.
Each area has at its disposal graphical layouts organized in hierarchical levels (see Fig. 3) and customized libraries oriented to its design.

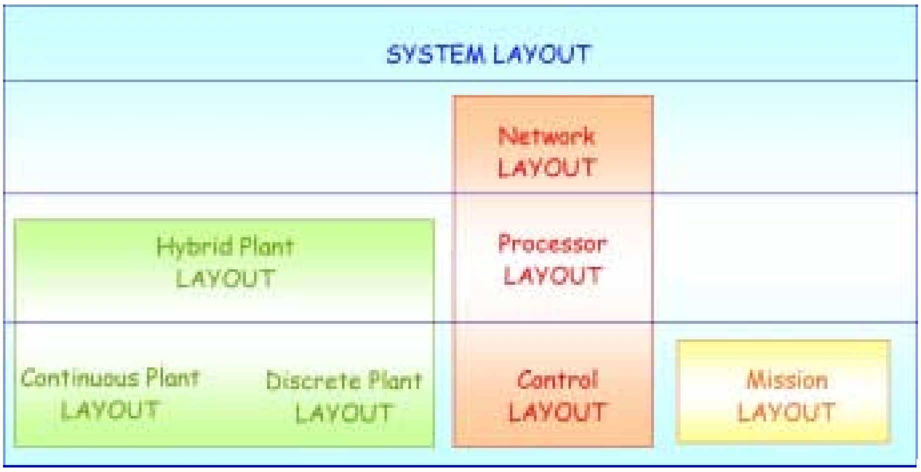

Fig. 3 The hierachical graphical layouts

The PLANT, MISSION and CONTROL areas are included in the *System* Layout which is the highest level of the project representation and it appears when the user runs the SIMBUILDER tool.
The **PLANT area** is used to program the simulation of the plant and its environment. Continuous or discrete or hybrid plants can be simulated. It is also possible to use data recorded

in experimental trials performed in actual plants by means of the *Slow Motion View* option. The graphical layouts available in the PLANT area together with oriented libraries are the *Continuous Plant* layout, the *Discrete Plant* layout *and the Hybrid Plant* layout.
It is available a set of macro-blocks, which have been developed within the ACODUASIS project , specifically oriented to robotics. They allow to simulate from the most common components used in robotics, such as electric motor or mechanical gear, up to single mechanical axes and complete industrial robots.
The **MISSION area** is used to program the disturbances acting on the PLANT area and the references of higher hierarchical levels (host simulation) for the control.
The **CONTROL area** is used to design the plant control system, conceived as a potential multi-processor system, where each processor may perform multi control functions.
The graphical layouts available in the CONTROL area together with oriented libraries are the *Network* layout, the *Processor* layout and the *Control* layout. Each control function has its own sampling frequency and the user must schedule it by means of a suitable scheduler. Data can be exchanged among the control functions running within the same processor and among different processors. The data transmission is simulated and the transmission time is simulated.
Automated Algorithm Generation functions are available to help the user in the control algorithm design. The user can choose within a set of predefined feedback control architectures or state estimators and forecasting models, all related to linear dynamic models. The use of the *Automated Algorithm Generation* functions requires that a plant linear model be available and that the required control or forecasting performance be stated according to defined standard performance indicators. Algorithm and related code are automatically generated, which are strictly in conformity with the stated performance indicators.
In order to be practically useful, the automated algorithm and code generation techniques have been conceived in such a way to be specifically oriented towards given technological sectors.
Three software packages are available, which are oriented to the robotic field and have been tested within the ACODUASIS project.
The options, which activate the algorithms for the model *identification* and/or control *optimization*, are selected at the *SIMBUILDER* level. The identification and optimization activities are then performed by the *SIM* tool.

The layout is a graphical concept, and it is always applied to the first three levels of the above structure; the representation of the lower level, that must contain the description of the plant, the control function and the mission, that instead depends on the programming mode.
The available programming modes are:

- the *Graphical mode:* it allows the user to build his own block by using a block diagram representation. The scheme will be composed by elementary blocks, available in the library window, connected by means of wired links,
- the *C mode*: it gives the possibility to directly write and insert the user C code into a pre-defined structure of files *.c* and *.h* whose templates are automatically generated and provided by the EICASLAB,
- the *Automated Algorithm Generation* devoted to the plant control design according to the EICAS methodology as above described,
- the *Library mode:* the user has to insert the parameters requested in special block graphical user interface.

The *Continuous Plant,* the *Discrete Plant,* the *Control* and the *Mission* layouts are available when the user decides to program them in *Graphical mode.*

3.2 SIM features

The *SIM* tool enables to assess the control and/or forecasting algorithm performance by means of simulated trials, which can be performed both by varying the plant and the environment parameters, that is by modifying the testing conditions, as well as by varying the control parameters, that is by performing an experimental control tuning .
When the related option has been selected, the *SIM* tool performs the identification of a model parameter set stated by the user. The identification can be performed both from input and output data recorded during trials carried out on the actual plant, as well as from input and output data obtained by simulating the plant using a fine model, more sophisticated than the one which has to be identified.
An identification algorithm is implemented which is specifically oriented toward the identification of models suited for the control design. The above algorithm has been originally developed by EICAS.
Similarly, when the related option has been selected, the *SIM* tool performs the optimization of the control parameter set stated by the user. The optimization is carried out by repeating the same simulated trial and varying the control parameters according to a numerical algorithm which optimizes the cost function defined by the user.
The above algorithm, originally developed by EICAS, implements an approximation of the "conjugate gradient" method.

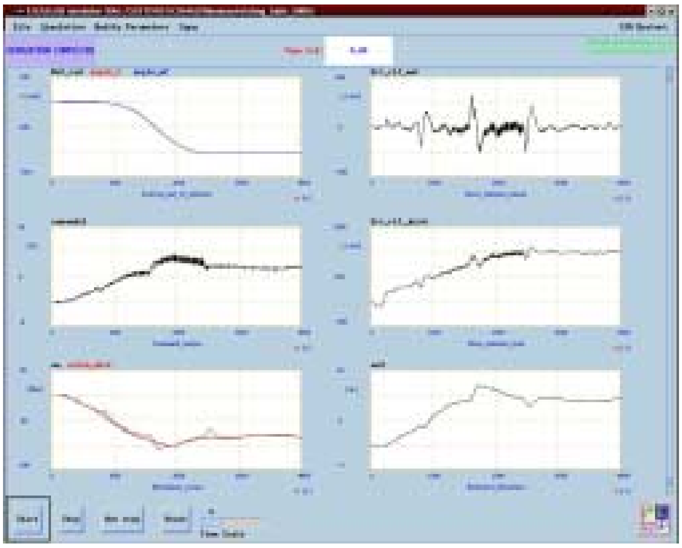

Fig. 4 The SIM program

3.3 POST features

The POST program (Fig. 5) enables to visualise and analyse the variables resulting from the simulation, which have been selected with the aid of the SIMBUILDER during the programming phase. The POST offers in a very friendly way all typical functions of a plotting program and moreover some other functions which are often very useful for analysing the result of a simulation test. Among the classical post-processing functions (like sum, product, division of variables, raising to a power, logarithm..), it is relevant to mention the availability of tools for:
the statistical analysis of the behaviour of a variable in time, with calculation of average value and standard deviation

- the Discrete Fourier transform
- the Auto and Mutual correlation
- the harmonic analysis and power spectrum.

The POST program is also a useful tool for preparing technical reports. In fact it allows to capture images in the desired format for printing or being included in word processors. Such images are created starting from diagrams of variables on video, adding captions, arrows and notes according to the user wish.

Fig. 5 The POST program

4 Rapid-prototyping : an activity under development

A cooperation between EICAS and SUPSI (University of Applied Sciences of Southern Switzerland) is going on with the aim of developing a rapid-prototyping in Linux RTAI environment of the plant control software developed by EICASLAB.

5 MAJOR ADVANTAGES AND BENEFITS

The main advantages and benefits obtained with the use of the EICASLAB software tool are below described.

- **To avoid the need of deep mathematical knowledge.**
  The use of the software tool and specifically of *Automated Algorithm Generation techniques* relieves the designer of the need of specific know-how necessary to develop complex computations, such as those required for the design of a multi-input multi-output closed-loop control, and of spending a significant part of time in solving them iteratively. EICASLAB relieves the designer of the need to possess the mathematical background necessary for the control design according to the sophisticated and complex methodology set up by EICAS over the years.

- **Larger Freedom to the Designer.**
  The designer is allowed to focus on engineering aspects of the project, like the sensor and actuator selection, the system architecture, the control sampling frequency and the frequency bands within which the control loop has to work.
- **To reduce the time demanded by control algorithm design**
  The use of the software tool and specifically of *Automated Algorithm Generation techniques* reduce the time necessary for developing the control system design with respect to standard control design techniques (a person trained to use the tool can typically execute the design of a 3-axis machine tool of standard type in 5-10 days)

- **To reduce the costs of the control design**
  It reduces the time necessary for developing the control system design, improves the result quality and allows to approximate the maximum possible technological limits.
- **To design only starting from plant datasheet**
  The control design is only executed starting from the plant datasheet with guaranteed performance
- **No set-up in field**
  the control is tuned and its performance assessed by means of the EICASLAB. The control does not require set-up in field.
- **To increase the performance also in complex control cases**
  The performance obtained with the use of the innovative technology is on the average better than the one reached by using traditional control techniques.

6 Acknowledgements

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7 References

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