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Multi-Disciplinary Tutoring for Project-Based Mechatronics Learning

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Abstract: A project-based learning experience has been recently developed at the University of Bologna within the second-level degree in Automation Engineering. The most relevant aspect is a co-tutoring activity jointly performed by teachers both from the mechanical area and from the automatic control area. The project was related to the design of an automated assembly system, developed for a local company that is leader in the production of technical cases. After a description of the educational goals, the paper discusses the phases of the activity and the main methodological aspects, then briefly presents the adopted tools for the design and simulation of the developed mechatronic system and finally discusses the achieved results.

Keywords: Control education

1. MECHATRONICS EDUCATION AT THE ENGINEERING SCHOOL OF BOLOGNA

The industrial area around Bologna is known worldwide for the high density of companies that are leaders in the production of automated systems, especially packaging machines. Most of these companies were founded by ingenious technicians very skilled in mechanical design and became world leaders thanks to their capability to provide a quick and efficient response to a market characterized by the need of extreme customization. Small-medium enterprises best coped with the required design capacity and organizational flexibility.

Inside these companies design roles were covered at the beginning mainly by people coming from a practical mechanical education, at the best with high-school degree or simply with machine-shop experience, later by mechanical engineers. Electronic and information technology skills became progressively necessary with the development of new generation automation (in particular with the massive advent of electromechanical drives and programmable controllers) but, in most cases, they were integrated into design teams with a subsidiary function, seldom participating to the conceptual design of the automatic machine. Nowadays too in most of the automatic machinery companies the basic task of conceptual design is performed mainly by people with dominant mechanical background.

It is widely demonstrated that in most cases such an approach cannot fully exploit the potential that rising mechatronic technologies can provide. In particular, there are valid evidences that people with a mono-disciplinary education, even if open-minded and informed about complementary available technologies, tend to apply to problem solving (and therefore to the growth of innovation) a point of view that is heavily conditioned by their dominating cultural background.

New educational profiles are under definition and testing world-wide, starting from the shared opinion that a balanced multidisciplinary education can help to approach design problems that involve the integration of so many technologies in a more creative way. Mechatronics are rising to the role of a self-standing discipline whereas education in mechatronics is considered a very specific goal worthy to be achieved, Isermann [2005].

In Italian engineering schools, in particular at the University of Bologna, an educational curriculum explicitly oriented to integration and synergy of different cultural domains (mechanics, electronics, information science) has been proposed only in recent years. A slowing factor, apart the difficulty to harmonize contributions coming from academic partners traditionally not trained to cooperate, were the many doubts about the consistence of such a professional figure (the mechatronic engineer risks to be one who owns knowledge in multiple fields, but has no actual operating capacity in any of them) and about the capability of the industrial world to really accept and exploit such a professional figure. In Bologna the new professional figure has been called "automation engineer": elsewhere a quite similar curriculum originates a "mechatronic engineer". Even if mechatronics and automation are not synonyms, in terms of educational curricula, substantial differences behind these denominations are difficult to be identified: a malicious interpretation says that mechatronics were introduced in those engineering schools where mechanical people were dominating, while, on the opposite, people coming from electronics and automatic control area imposed the name of automation engineering. We think that, whatever the denomination, the added value of a multidisciplinary

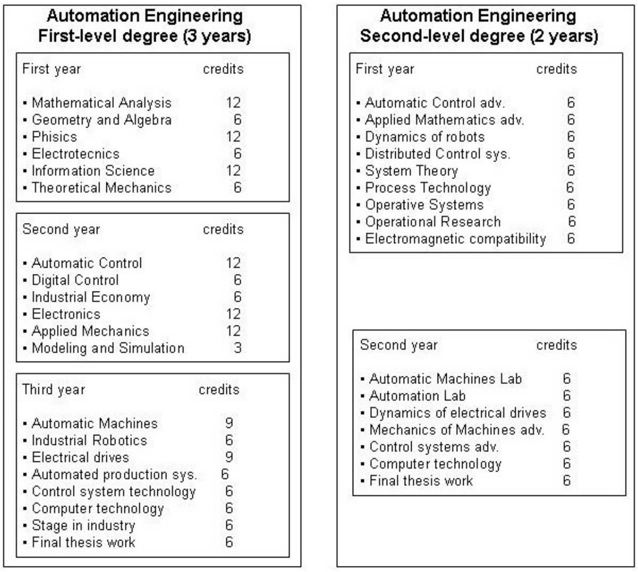


Fig. 1. Overall curriculum in Automation Engineering at the University of Bologna.

curriculum is the acquisition of a project capability, that is to achieve a consistent education to synthesis. The main vocation of a mechatronic engineer must be to develop innovation, that is to approach design problems from a point of observation as wide as possible, not conditioned by the prevalence of a particular cultural domain, but, on the contrary, educated to a simultaneous vision of problems and skilled in the use of synergistic tools.

In Fig. 1, a scheme of the overall curriculum in Automation Engineering at the University of Bologna is presented. It can be seen that even at the basic level (the three-year degree) courses characterized by multidisciplinary integration (e.g. Industrial Robotics and Automatic Machines) represent a consistent part of the didactic offer. Systematic contents concerning design of mechatronic systems however are not consistent and emphasis is put mainly on the acquisition of basic knowledge in the different disciplinary areas. Probably an unbalance in favor of -tronics is present, and the mecha- part should be powered.

The activities planned for the second level degree (*laurea magistralis*) are explicitly oriented to encourage the growth of design capability, orienting to synthesis of automated or mechatronic system. Wide room is given to learning-by-doing activities that represent a significant part of the last year work.

The present paper will describe the experience of a co-tutored project-based activity that for the first time has been developed in Bologna. After a description of the educational goals, the paper discusses the phases of the activity and the main methodological aspects, then briefly presents the adopted tools for the design and simulation of the developed mechatronic system and finally discusses the achieved results.

2. EDUCATIONAL GOALS AND ARTICULATION OF THE ACTIVITY

The main educational goals can be summarized as follows:

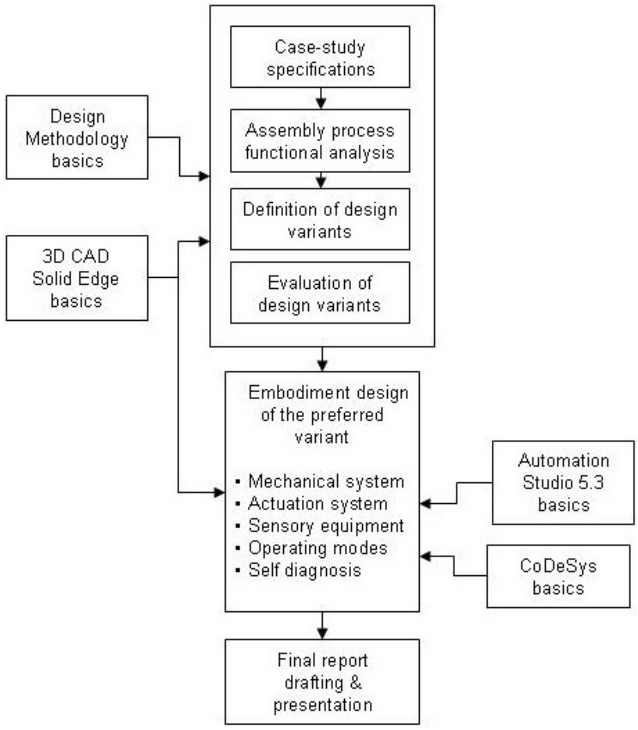


Fig. 2. Articulation of the overall activity.

- To stimulate the creativity of the students involving then in the solution of a design problem of real interest for industry, never faced before, needing a synergistic multidisciplinary approach; emphasis is put on conceptual design and on design variants comparison, in order to demonstrate the potential of a mechatronic approach with respect to different approaches;
- To provide them methodological indications on how to move along the process of development of a complex mechatronic system;
- To achieve specific skills in the use of design and simulation tools, jointly used in the development of the different aspects of the project;
- To train their capability to analyze and describe a problem, to generate and evaluate solutions under a concurrent set of design constraints, to present and defend the results of their work, not neglecting a critical review of the achieved results.

The activity has been developed both as class work (in total 6+6 hours per week for about 11 weeks) and as home-work (an estimated average amount of 20 hours per week). The students were 12 in total and were divided in two cooperating subgroups. Each subgroup developed detailed design of a part of the automated system, but the initial activity of the conceptual design of the system was developed jointly.

In Fig. 2, the articulation of the overall activity is presented. The following comments can be added.

- In parallel with the analysis and discussion of the possible solutions to the specific automation problem, a consistent part of the class work was dedicated to the acquisition of skills with important design tools, a 3D Cad (Solid Edge) for physical description of the

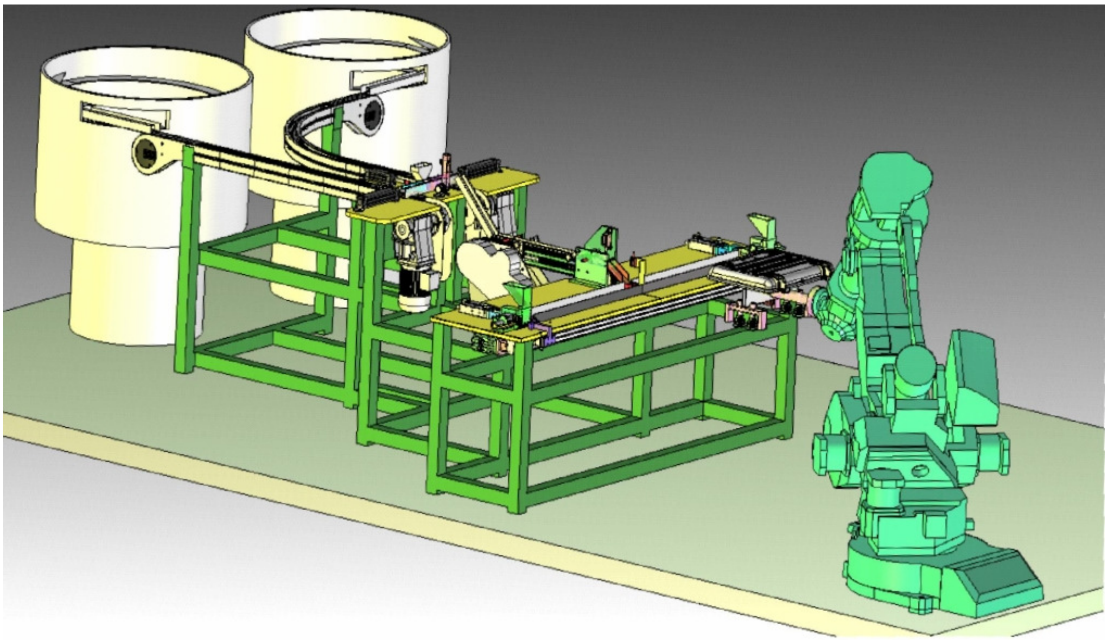


Fig. 3. Final result of the students' activity.

designed system, and a PLC simulation tool for the development of the working sequence of the system (CoDeSys);

- The development of the system was really based on a mechatronic approach, that means that all the aspects concerning actuation, sensory equipment and control were considered jointly with the design of the mechanical part of the system and a sort of simultaneous engineering was applied;
- The students were required of a public presentation of their work and attention was paid to the efficacy of communication.

3. THE CASE-STUDY

The project has proposed a solution to the need of automatic assembling of retaining hooks on the top cover of a technical case. These cases are produced in different sizes and models by GT Line, a company operating in Bologna and are made with molded polypropylene. At present the assembly process is completely manual and represents a consistent part of the final cost. The automated system proposed and developed by the students pre-assembles the hooks (three parts) and inserts a variable number of such hooks into a cover (every hook must be positioned with respect to the cover edge, then a stainless steel pin must be laterally inserted).

The final result of design is shown in Fig. 3. In order to obtain the required flexibility, the task of manipulating the covers has been given to a robot, for which a special purpose gripping device based on suction-cups has been designed. The robot is interfaced with a stationary equipment, with two terminal stations were two hooks can be positioned. This duplication is necessary due to the fact that the pins securing the hooks placed near the corners of the cover need to be inserted from opposite directions. Upstream respect to the two positioning stations is placed a system that, starting from parts fed in bins, orients and mates them generating assembled hooks. Assembly and inserting postures are different, so that several manipulation procedures must be applied; feeders present also buffering functions, in order to add operating flexibility to the system.

Actuation, sensory equipment and control apparatus have been chosen depending on the functional requirements; particular attention was paid to include self-diagnosis capability, obtained by additional sensors and by purposely defined control procedures. To this respect the simultaneous design of the physical part of the system and the development of control and diagnosis procedures has been very influential on final design. The developed system does not adopts very sophisticated technology, but is a complete mix of commonly used solutions (pneumatics, vacuum technique, controlled axes, etc.).

4. THE ROLE OF CO-TUTORING

Tutoring has been intended as a resource available to students in order to be assisted in the design process. One tutor was coming from the area of mechanical design, the other from the area of electronics and automatic control, so that an experienced skill in most of the aspects of mechatronic design could be provided. The two tutors most of the time were operating separately, except in the initial phase where the general features of the system had to be defined, and in the final phase were the overall result had to be harmonized and jointly discussed during final presentation.

The role of tutors was different in the various phases of activity. At the beginning this role was active and passed mainly through the proposal of methodological guidelines for the development of the project and through an organized presentation of the tools to be used in analysis and simulation. As soon as the students were entering in the design variant proposal phase, the function of the tutor gradually passed to that of a reference person present in the work-group, ready to help in the solution of any problem, but purposely with no will to influence the choices of the designers, that were left free to move along the directions they were preferring. The main effort of the tutors was to stimulate the creativity of the students suggesting a correct way to examine the problems and to formulate solutions, without conditioning their decisional process.

5. SPECIFIC CONTRIBUTIONS FROM THE MECHANICAL ENGINEERING AREA

The main effort was directed to provide the basics of methodological design, that is to suggest a way to organize the decisional process according to a define-evaluate-compare-choose sequence, avoiding the main temptation of beginners to follow a decisional process based on local intuitions. To this purpose, the basic steps for the development conceptual design according to VDI 2225 recommendations (Pahl and Beitz [1999]) were illustrated and substantially followed in the development of the project, even if not always fully formalized for lack of time. Emphasis was put on functional analysis, in order to describe in a very detailed manner the basic specification of the system to be designed. In order to better define the design specifications and to understand the technical problems and the economical constraints involved in the process automation, the students spent some hours inside the company, analyzing in detail the manual assembly process and the present organization of the workplaces. Even if not always formally represented, the identification of concurrent design alternatives through a morphological matrix was adopted and qualitative discussion about the preferred solution was developed as class work-group. Available time was not enough for a systematic application of quantitative criteria, as the weighted objectives tree procedure.

A relevant role was given to the use of a mechanical 3D CAD tool: this skill was missing in the students background, that was exhibiting fair knowledge of basic and applied mechanics, but no previous training to represent technical objects in 3D space. The capability to represent the result of the inventive work was considered an essential pre-condition before starting the development of the project. A learning-by-doing procedure was imposed by the lack of time: after a few hour lectures about the basic elements of 3D representation, the students started designing their own technical system, progressively facing growing difficulty problems. It was very useful, in this phase, to understand how CAD means virtual prototyping, allowing the representation to continuously and easily follow the progressive modifications of design.

May be due to the fact that the students were fully motivated and that they were contextually developing their ideas and representing them, the learning process was extraordinarily fast and after a few weeks they were exhibiting full command of the CAD tool.

6. SPECIFIC CONTRIBUTION FROM THE CONTROL AND INFORMATION SCIENCE AREA

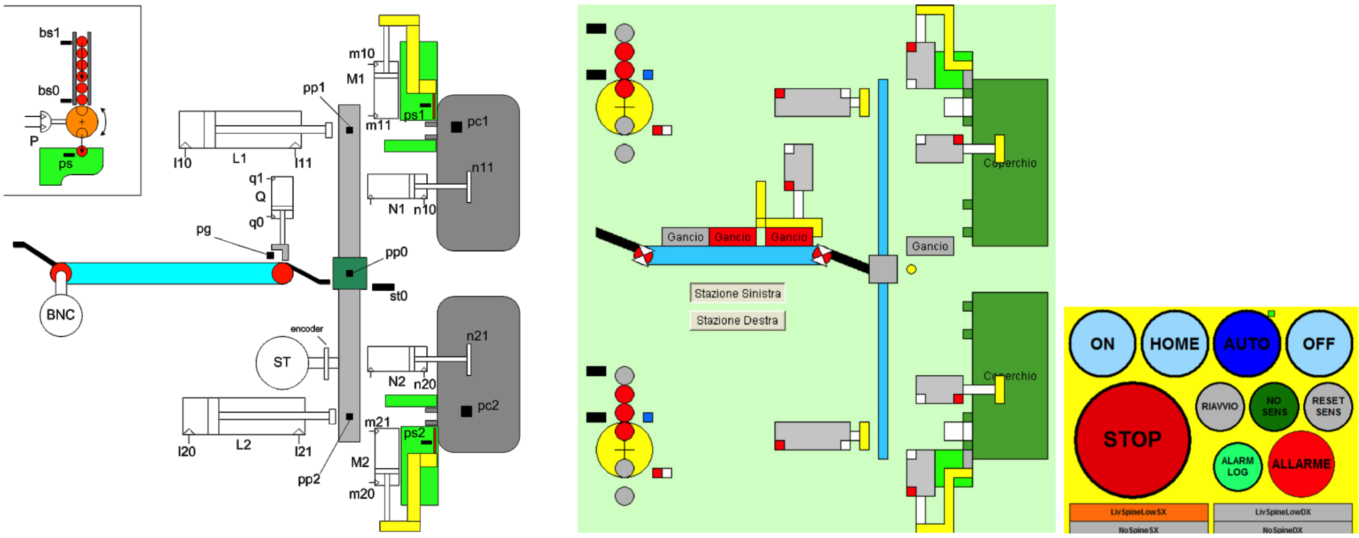
The steering idea of this module is to teach how to develop software for industrial automation having modularity, re-usability and encapsulation as a main target. These concepts are very popular in computer science and have been practically realized in the so-called object oriented methodologies. However, industrial automation met these ideas quite lately as demonstrated by some standards (e.g. IEC61131-3 and IEC61499) which have been considered in commercial products only recently. The academic literature is very rich in providing structures and object types together with suitable modeling frameworks for industrial automation Bonfè and Fantuzzi [2004], Bonfè et al. [2006], Ferrarini et al. [1993], but these concepts have not been completely assimilated by small and medium-size industries yet.

Aim of this module is to present a simple framework for the development of software for industrial automation making use of standard tools available on market. From a methodological point of view, the most important concept introduced is the one of "generalized actuators", which originates from a current research activity in our department, Faldella et al. [2007]. This object allows the definition of a design procedure which realizes automation functions by exploiting a clear and structural separation between Actions and Sequences. The main advantages of the proposed modeling framework and design procedure are the following:

- Effectively support hardware virtualization, component re-usability and interoperability;
- Allow hierarchical management of the the plant, separating control policies from actuation mechanisms;
- Detect anomalous situations (fault detection and quality control) following a distributed and hierarchical approach;
- Allow hierarchical reconfiguration of the systems after anomalous situation.

Roughly speaking, the generalized actuator is a highly-customizable piece of software devoted to the control of a single actuator. Each actuator in an automatic machine should be managed by the same function block once properly configured. This function block is characterized by an interface towards the actuators and by a second one towards the higher level software which implements the control sequence, fault detection procedure and quality control. Beside sending the start/stop command to the physical device, it is interfaced with actuator sensors which provide binary information on the status of the device (i.e. if the device reached the ON or OFF status). Thanks to the use of a couple of internal down-timers starting from the maximum activation and deactivation time respectively, the software module is provided with an internal procedure which is able to identify faulty situations on the sensor(s) and on the actuator. This information can be send to the higher level part of the software where proper solutions are implemented.

The students learn how to write such generic code and to organize a modular software architecture which implements the full automation software by properly sending commands to the generalized actuator and reading the error/diagnosis message from the module itself. This latter part is instrumental for identifying faulty situations. Finally, they learn how to use commercial software for automation to implement everything. In this course, CoDeSys (3S Software [2007]) has been chosen but, in prin-



(a) Draft scheme of the plant.

(b) CoDeSys model of the plant and simplified HMI.

Fig. 4. Example of the CoDeSys implementation of the plant.

ciple, any modern development environment IEC61131-3 compliant can be used. On the other hand, this choice is instrumental for letting the students gain experience on industrial electric drives produced by ELAU [1], whose programming environment (EPAS-4) is based on CoDeSys and, in the near future, on ABB PLCs [2] that can be programmed directly within CoDeSys. These facilities are available for students in our laboratory.

The solution of the case-study is based on a two step procedure. At first, the nominal operative procedure is tested with the help of the simulation package Automation Studio 5.3 [3]. The students can easily implement the pneumatic circuit of the machine and integrate electrical drives and sensors. However, due to the limitations in terms of the IEC-61131 programming capabilities, it is not possible to implement the control procedure according to the general framework illustrated before that makes use of the generalized actuator concept. Consequently, once the nominal working procedure has been defined and tested in Automation Studio, the students go back to CoDeSys in which the complete control procedure, which includes also the management of faulty and emergency situations, is developed and tested on a simplified model of the machine. An example is reported in Fig. 4. More in details, the schematic description of the plant of Fig. 4(a) presents all the actuators ans sensors and it is mapped into a discrete state model, implemented in CoDeSys (see Fig. 4(b)). The students, then, have to develop the complete control logic for this "virtual" plant. This means that, beside the nominal working sequence, exceptions and faulty conditions, together with a simple Human-Machine Interface (HMI), see again Fig. 4(b), have to be properly managed.

7. COMMENTS

The success of this didactic experiment depended on several factors:

- A consistent, fairly balanced background achieved by the students in the basic disciplines that contribute to the mechatronic domain; such an activity can be hardly proposed to students at the early stages of their technical education;
- A proper choice of the project to be developed, that presented a good level of difficulty, equally distributed between mecha- and -tronic areas, but not, at the same time, too complex;
- The parallel simultaneous development of all the design aspects related to mechatronic design, overcoming the limits of traditional approach (where the mechanical engineer conceives and designs a system, then passes the project to a control engineer that must make it move); efficient planning of this joined activity was a source of problems, but we think it was preferable with respect to a serial concatenation;
- The enthusiastic approach by the students, strongly stimulated by the trust that the company showed respect their creativity and technical capacity; a quasi full-time activity, with great attention to the communication inside the work-group and to the joint participation of students and tutors to the generation of ideas and solutions.

Among the limits, the incompleteness of the project, that was limited to strictly technical aspects and could not fully develop, due to lack of time, the evaluation of economical and technological aspects. One of the most challenging perspectives could be to integrate the contribution of a third tutor, purposely operating on this crucial aspects.

8. CONCLUSIONS

Two academic courses, each of them based on contents belonging to a specific disciplinary area, have been joined around a project developing activity, with the intent to contribute to a true mechatronic education, that is to train engineering students to approach design of technical systems with a balanced use of all the available knowledge.

[1] http://www.elau.it/
[2] http://www.abb.com/product/us/9AAC100143.aspx
[3] http://www.automationstudio.com/

The proper choice of a case study allowed a learning path were the use of methodological tools was joined with a pragmatic approach to the solution of particular design problems. The main added value can be identified on the constant interaction of complementary disciplines that allowed the participants to have a unified synergistic approach to the design activity. The results have been over the expectations and have been very appreciated first by active subjects, the students, then by the academic community that positively evaluated this didactic experimentation, finally by the company, that will probably implement the designed automated system after the necessary work of design refinement.

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