Development of a Six-Axis Robot Arm to be Used in a Mechatronics Degree Course

G. Masferrer, M. Mundó, M. Serra, P. Marti-Puig, J. Serra

Abstract—**In the 2009/2010 course the University of Vic (UVic) began the first degree in mechatronics in Spain. As a robotic arm perfectly reflects the interrelations between the disciplines within the mechatronics paradigm, a six-axis robot arm was built for educational purposes. It was used in practical classes that integrated different disciplines, in a module called "Integrated Projects". In this paper this handmade six-axis robot arm and its educational applications are presented.**

***Index Terms*—Education, Mechatronics, Six-Axis Robot Arm, Project-Based-Learning.**

I. Introduction

Mechatronics, according to one of its most commonly used definitions, is "the interdisciplinary field of engineering dealing with the design of products whose functions rely on the integration of mechanical and electronic components coordinated by a control architecture" [1]-[4]. The first European university to offer a degree in mechatronics engineering was the University of Lancaster (United Kingdom) in 1984. The degree was a response to industry's need for engineers with a multidisciplinary profile [5]. Later, in the second half of the eighties, these studies were offered in other universities at both undergraduate and postgraduate levels [6], [7], [16], and became particularly relevant in European countries with strong industry such as Germany, United Kingdom or Finland or USA, Mexico, Brazil, Japan or Australia among others around the world. In the 2009/2010 academic year the University of Vic (UVic) began a degree in mechatronics engineering [8], [9] in accordance with the new European Higher Education Area (EHEA) framework, and has thus become a pioneer of these studies in Spain. Like the first European mechatronics degree, this degree is also the result of collaboration between the university, in this case UVic, and local industrialists, who participated in designing the curriculum. The curriculum includes a module called Integrated Projects (IP) in which students have to combine multidisciplinary knowledge (mechanics, electronics, control and computer science) acquired in different subjects studied previously. In order to create a system that integrates all these mechatronics disciplines [11] a six-axis robotic arm has been designed (Alpha6UVic) to be used in practical classes in this module. Comparing this educational project with others existing in the literature, it can be seen, for example, that [10] is a project aimed more at industrial automation than mechatronics, as the mechanical part is fixed. In the same way the mechanics are fixed in other educational projects [17]-[20] that use mobile robots based on kits. In these projects there is a lot of programming which makes them adequate to the study of sensors but limited for learning mechanics. In the case of [21] the project is much more fully developed but focuses more on automotive industry. By contrast the focus of the project described here was to reflect the needs of the industrial sectors in the local context. The aim of these kinds of projects is for students to be able to work on different multidisciplinary projects. The novelty of using the Alpha6UVic is that it is an open mechatronic project, where the technology can be completely modified from start to finish. This allows the teacher to present a case study based on the Alpha6UVic and the students of each course to propose various mechatronic solutions and apply these changes to it. In contrast, if a commercial robot were used, it would not be possible to modify it and neither would the necessary technical information be available to carry out the modifications. As skills and knowledge from different interrelated disciplines are necessary to develop a robot we consider that this project fits the mechatronics paradigm very well. This paper presents the main features of the robot and how it has been used in the practical classes in the IP module. Section II introduces the six-axis robot arm with information ordered in nine parts: mechanics, sensors, actuators, power supply, control boards, I/O board, central unit, communication bus and the shell. Section III is devoted to the educational aspects and describes the utilization of the robot in the IP module. Section IV outlines the evaluation of IP and the use of Alpha6UVic within this module. The conclusions are reported in section V.

II. The six-axis robot arm Alfa6UVic

The main characteristic of the robot is that it has six axes that are moved by electric motors. It is shown with some of its details in Fig. 1. This robot can perform different actions with objects that it can grab. Positioning objects in three-dimensional space is its most general application. Movement is transmitted with belts and pulleys. Each motor is controlled by an electronic control board which receives orders from the central unit through a communication bus and information from sensors. The central unit has a shell that can run user defined actions. This section describes the handmade robot in the following nine parts.

A. Mechanic elements

The robotic arm was built with solid anodized aluminium strut profiles that are 0.8 Kg/m in density and 30x30mm in size, and thus provide high strength and low weight.

The pulleys are made of aluminium. The number of teeth in the pulleys is designed to achieve a direct relationship between motor steps and rotation degrees. The power is transmitted from the motor to the axis with polyurethane timing belts. Each arm has been designed ensuring that its moment of inertia with respect to its axis of rotation is minimized by distributing the weights appropriately and adding additional counterweights where required. Another important practical point is to ensure that the wire distribution (power, communication and pneumatic circuit) does not interfere with the mobility. To do this, the set of wires is placed inside the aluminium strut profiles, and limits on the rotation angles of each axis are established with software. The rotation of axes 1 to 5 is limited to ±120º and the rotation of axis 6 to ±170º.

B. Sensors

Two kinds of sensors are used to position the axes: the encoders and the quadrant detectors. Axes 5 and 6 use magnetic absolute encoders with a resolution of 10 bits. The other axes use relative encoders, which work with a resolution of 3600 steps. These kinds of encoders only provide pulses and not the absolute position of the axes, however, as it is necessary to count pulses, the robot needs to start from a known position and quadrant detectors are required to provide this information. The quadrant detectors used are formed by an opaque semi-disk joined to the axis and a barrier detector. The barrier detector has a logical output according to the disc position so that it obtains the quadrant once it finds the axis. See Fig. 4(a).

C. Actuators

Six electric motors are used to move the axes. A vacuum pump is used to hold objects. Axes 5 and 6 use bipolar motors and the other axes use unipolar motors. Stepper motors allow us to control the position of the rotor through the relationship between steps and degrees by applying a specific sequence to the windings. The Alpha6UVic uses a direct drive for axis 6 and a small reduction of 3.6 in the transmission elements of axis 5. The windings of these motors are controlled with the control board using the sequence in Fig. 2 (a/b). For the transmission of axes 1, 2 and 3 gearboxes with a ratio of 25:1 have been included to ensure that the inertia of the rotor is ten times higher than the load. Transmission shaft 4 does not include a gearbox. The bipolar motors have a consumption of 300mA and a base voltage of 3V, whereas the unipolar motors have a consumption of 800mA and a base voltage of 5V.The object restraint system is formed by a vacuum pump, a vacuum cup (Fig. 4(b)) and an air circuit. The air pressure is 4Atm and the diameter of the tubes is 2.5 mm.

D. Power supply

The robot uses standard voltage and a power supply that regulates the AC voltage from 220V to 24VDC. This power supply provides a maximum current of 7.5A Fig. 4 (c).

E. Control boards

The axis position is controlled by a control board that receives orders from the central unit and information from sensors. The control board's main device is a 8-bit µcontroller (ATMEG6A88) that works at a frequency of 20MHz (See

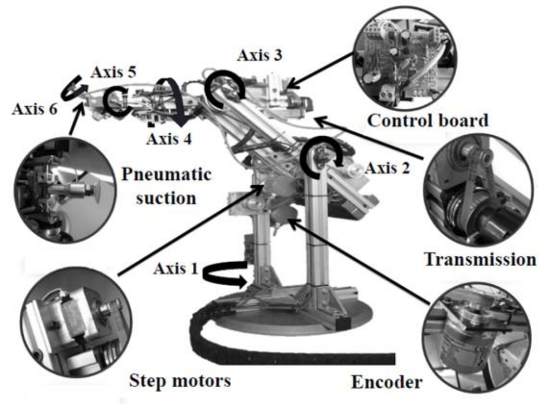


Fig. 1. The Alfa6UVic robot with details of some of its parts.

Fig.4(d)). The robot has two types of control boards (Fig. 3): one for unipolar motors and relative encoders and one for bipolar motors and absolute encoders. Both control boards process orders that arrive through a communication bus using a MAX3089 driver. The first type of control board requires an automatic regulation circuit for keeping the motor torque constant despite the variations in the motor's speed. The circuit used is a buck converter, and a diagram of it can be seen in Fig. 6(b). It basically regulates the supply voltage of the motor windings by measuring the consumed current value. Four MOS transistors (IRFZ44) are used to excite the four windings of each motor, one for each coil. The excitation sequence is generated directly from the microcontroller. The circuit includes four Schottky rectifiers as a protection against reverse currents. The feedback system follows a proportional-integral (PI) discrete control scheme. To implement this control the system obtains the error value $e(n)$ between the value of the current consumed by the engine $i_{out}(n)$ and the desired reference current level I_{ref}. This relation in the Z domain is:

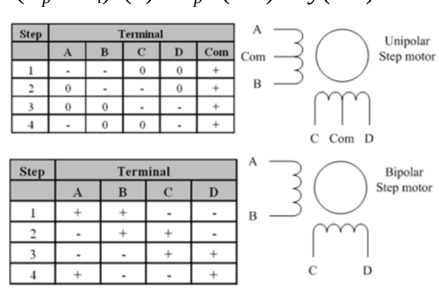
$$E(z)=I_{out}(z)-I_{ref} \tag{1}$$

Where $E(z)$ and $I_{out}(z)$ are the Z transforms of $e(n)$ and $i_{out}(n)$ respectively. This error $E(z)$ is introduced to the microcontroller that applies the PI equation, which in the Z domain is:

$$Y(z) = \left[K_p + K_i\,(1- z^{-1})^{-1}\right] E(z) \tag{2}$$

Where $Y(z)$ is the Z transform of the output $y(n)$, being K_p and K_i the proportional and integral constants respectively. Equivalently the equation that the microcontroller implements in the discrete domain is:

$$y(n) = (K_p + K_i)e(n) - K_p\, e(n\text{-}1) + y(n\text{-}1) \tag{3}$$



Step	Terminal				
	A	B	C	D	Com
1	-	-	0	0	+
2	0	-	-	0	+
3	0	0	-	-	+
4	-	0	0	-	+

Step	Terminal			
	A	B	C	D
1	+	+	-	-
2	-	+	+	-
3	-	-	+	+
4	+	-	-	+

Fig. 2. Winding sequence and scheme (a) the top image shows the bipolar motor (b) the bottom image shows the unipolar motor.

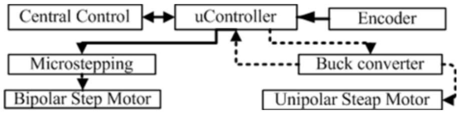


Fig. 3. Block diagram of control boards. Bipolar in continuous line and unipolar in dotted line.

The K_p and K_i constants are determined following empirical PI tuning rules. As the discrete compensator is implemented with the 8-bit microcontroller in order to avoid real multiplications, its values are approximated to the nearest power of two so that multiplications can be performed by bit shifts. Fig. 6(a) compare the relation between torque and speed with and without the PI compensator. A better response is obtained when the control voltage is applied because the torque is more constant when the speed increases (Fig. 6 (a)). The second type of control board uses an A3967 microstepping driver to control the bipolar motor. This control is an H-bridge, represented in Fig. 5 (a), that provides full resolution of 1/8 of a step. The driver provides a maximum voltage of 30V and a maximum current of ±750mA. The resolution is achieved by controlling the magnetic flux applied by the poles to the rotor in order to reach the selected angle.
To obtain the axis position the µcontroller makes a request to the absolute encoder through the SPI (Serial Peripheral Interface) port. The internal program of the µcontroller is almost the same in both types of control board. The variations only affect the hardware interfaces. Basically, all the boards receive orders from the bus indicating the position to which the axis needs to be moved. Then, the boards check the current position and once the position is obtained, they generate the sequence required to activate the motors in order to reach the desired position. Once this is reached they wait for the next order. If this does not happen it means that an error has occurred and this is reported. Fig. 7 shows this sequence in a block diagram.

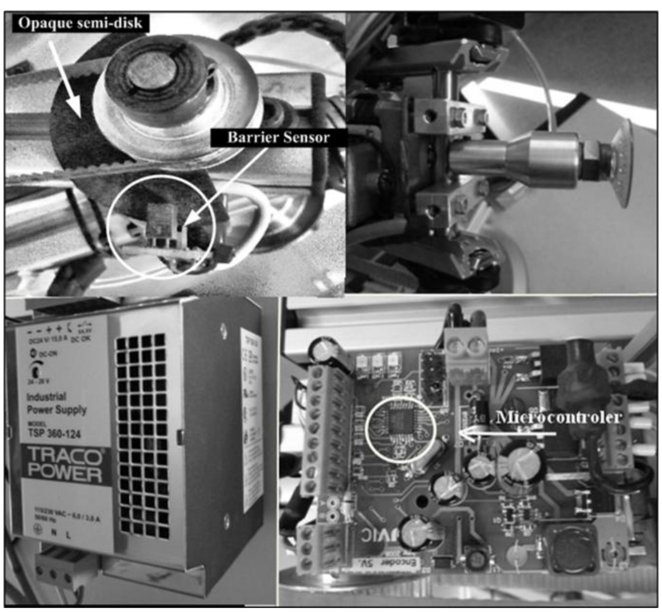


Fig. 4. (a) The top left image shows the quadrant detector. (b) The top right image shows the vacuum cup. (c) The bottom left image shows the power supply. (d) The bottom right image shows the ATMEG6A88.

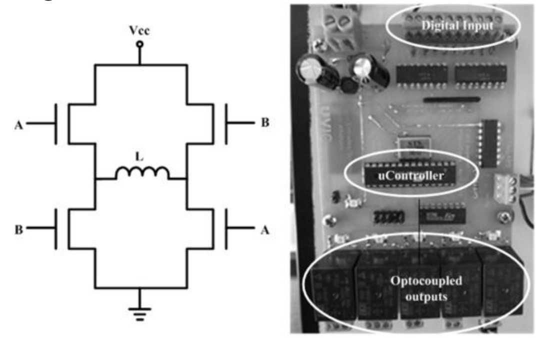


Fig. 5. (a) Left H-Bridge scheme (b) Right Input /Output board

F. I/O board

The robot also has an I/O board with eight digital inputs and five relay type outputs that allow us to interact with different external devices such as sensors or switches. The digital inputs use opto-coupled ACPL-847 devices. The output of these devices is connected to a µcontroller digital port through a 10kΩ pull-up resistor. The relay outputs are activated with a voltage of 24VDC. The ULN2003A driver is used to adapt the signal levels with the µcontroller. The relay output voltage can reach 250V and 10A (see Fig. 5(b)).

G. Central unit

The central unit governs the system by performing the actions defined by the user. This is achieved by sending orders to the control boards. These functions are performed by the shell. The central unit was implemented by an embedded PC with a processor of 1GHz, 1Gbyte of RAM and 320Gb HDD. It also has external interfaces for the keyboard, mouse, display output and USB ports. The operating system is the LINUX Ubuntu 11.04 version prepared to work in graphic mode, which is suitable for editing programs, and also in terminal mode, suitable for executing programs.

H. Communication bus

The control boards, I/O board and central unit communicate through a bus based on the RS485 standard. This type of bus provides a robust industrial environment with custom protocol. The RS485 bus is a multipoint differential transmission bus.

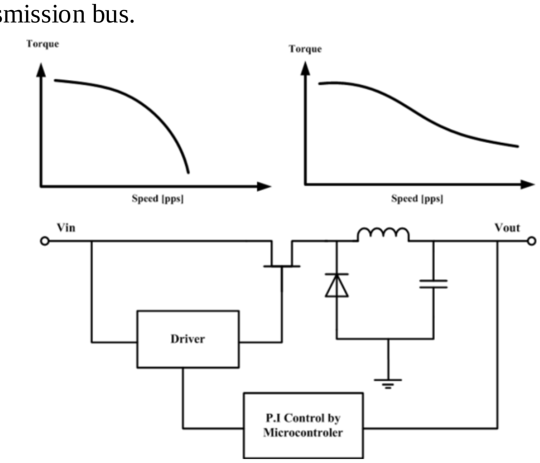


Fig. 6. (a)The two diagrams at the top show the relation torque/speed without PI control (left image) and with PI control (right image). (b) the bottom diagram shows the buck converter for regulating the engine supply voltage windings.

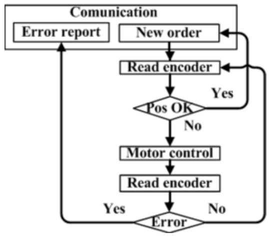


Fig. 7. Block diagram of the control that executes the control boards.

It allows working at high speeds over long distances (35 Mbps up to 10 metres and 100 Kbps to 1200 metres) and through noisy channels. The physical channel is a twisted pair which supports up to 32 stations and half-duplex communication. The bus needs a power supply of 5V and bus voltages are between -7V and +12V. A block diagram of the communication system is shown in Fig. 8. A simple custom protocol designed by UVic and based on a fixed message structure allows the central unit to send instructions to a specific board.

I. The Shell

The central control has a shell that allows the user to describe the sequence of actions in a program. This shell converts the sequence to the frames, which are sent to the control and I/O boards. The shell was developed with C++. The program that controls the robot movement sequence is written in plain text, and each line of code has a single command. The program needs another plain text document that contains the positions defined by the user. For example, some commands are named with words: BREAK, CALL, CONTINUE, DEFSUB, DEFVAR, MOV. The interpreter also allows commands like MOVA, MOV and SPEED to position the robot with or without acceleration. READPOS obtains the current position. READIN can be used to read the value of the I/O board entries, and SETOUT to set the relay outputs. Other commands have been developed to facilitate the programming and make it possible to define variables, print messages on the terminal, perform mathematical operations, wait for commands, perform iterations or execute conditional commands. Fig. 9 shows an example of code.

III. Integrated Projects

A special characteristic of the degree in mechatronics engineering is that it is interdisciplinary. The goal is to integrate knowledge of electronics, control, computer science and mechanics. Therefore, the teaching methodology in the degree, including in the IP module, is based on projects with different technological levels and complexities. The IP module allows students to tackle real problems. This module is separated into two 6 ECTS subjects: Integrated Projects I (IP1) and II (IP2).

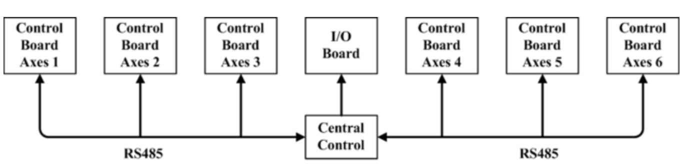


Fig. 8. Block diagram of the communication system.

```
READIN                      //Read inputs
SPEED 10                    //Define axis speed
WHILE testbit(In,0)         //Iteration condition
    MOVA position1          //Aceleration move
    WPOS                    //Wait position
    CALL readposition       //Jump subrutine
    PCI                     //Initial position
    READIN                  //Read inputs
ENDWHILE
```

Fig. 9. Example of shell code.

The methodology used in these subjects is based on Problem-Based Learning (PBL), in which students learn through problem solving and open projects. The PBL methodology [12], [13] aims for students to learn by tackling real problems. In the classroom, teachers will provide data from a real industrial process in which the Alfa6UVic is involved, and this has to be improved upon. Students work in groups and analyse the problem, apply their knowledge to see what they can do and what they need to do in order to solve it. The teacher guides the students to the solution by providing the appropriate tools, asking questions and encouraging discussion among group members. The projects the students undertake are based on several subjects in the course, as shown in Fig. 10. The projects are intended to be realistic and may arise from practical problems in companies or industry. In addition, each project is coordinated by several teachers and/or external experts. Two subjects in the module are closely related because in both subjects the Alpha6UVic robot is involved in an industrial process and there is a problem that must be resolved. During the course the students acquire basic knowledge for project management, data analysis, planning and writing the project report while working on a real problem. In IP2 the knowledge acquired in the first part is applied to a project with greater technical complexity. IP module can therefore be thought of as a small group teaching method that combines the acquisition of knowledge with the development of generic skills and attitudes such as communication skills, teamwork, problem solving, independent responsibility for learning, sharing information and respect for others.

A. Integrated Projects I and II

IP1 subject is structured in two parts: theory and practice. In the theory, students learn to use tools for quality management (6sigma [14] and 5-whys [15]) and project planning, identifying and removing the causes of defects and minimizing variability in the processes. In the practical classes, students apply the lessons learned to the presented case study. The information provided allows students to extract graphic information, such as Pareto diagrams, histograms and scatter graphs as in Fig.12.

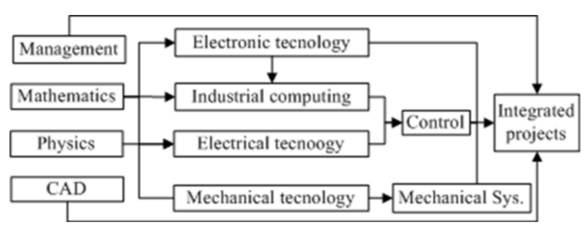


Fig. 10. Study plan of mechatronics degree, represented by blocks of subjects.

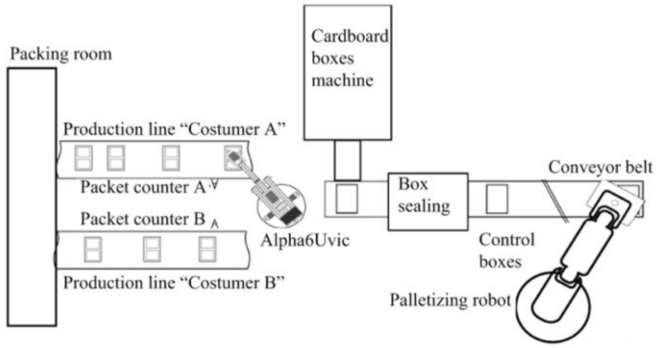


Fig. 11. Packaging product line of the presented case study.

Finally, the students present a project report which summarizes the changes to be made to the Alpha6UVic robot using, if necessary, CAD representations, electrical schemes, or the new code developed, as well as the planning needed to perform these changes.

Integrated projects II (IP2) is carried out after IP1. Two options are provided: the first option being in the case that the results from IP1 can be feasibly implemented during the course time. In this option the report produced in IP1 is used and the students first verify the changes and then implement them physically. The second option is when the results are not implementable during the course. In this case teachers provide an alternative technical report from which students can work with to make a technological improvement of the Alpha6UVic. Students are intended to participate in the development of the Alpha6UVic robot with the aim of designing a second version with more advanced features. Finally, students present a project report which summarizes the work carried out and give a presentation to demonstrate their results.

B. Case Study

In this section a case study from IP1 is briefly presented as an example. The case is the following:

Description. It is a line of packaging products of a food company. This company only produces for client A. The line has been changed due to the entry of a new client B. Now there are two production lines, one for client A and one for client B. At the end of the production lines Alpha6UVic robot picks up the product and puts it into a box containing. Finally, a second robot is responsible for palletizing the boxes containing the product (Fig.11). After some time it is detected that in order to maintain the same production in client B's line more hours are required than for client A. Also, in line B, a

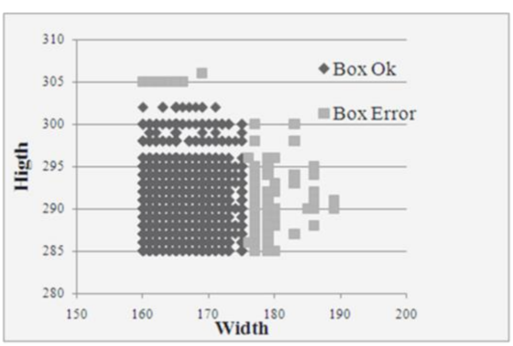


Fig. 12. Scatter plot which compares width and height showing that the error in the process of palletizing is due to the size of the boxes

problem is observed when palletizing; the boxes are not closed properly. However, there are no problems when working for client A.

Information provided to the student. Besides all the technical documentation concerning the Alpha6UVic, production data for boxes and pallets of clients A and B is provided. This data is used to detect potential problems.

Students' work. The goal of the students is to use the given information to improve the production process using the tools studied in the theoretical part of the course.

Solution. What students are expected to find, using numerical data and real tests on the process of boxing, is that the error in the process of palletizing is due to the positioning error of Alpha6UVic (±8mm). This error, added to the new dimensions of the client B container (±5mm) causes some of the containers to remain poorly placed and boxes not to close properly.

To solve the positioning error of Alpha6UVic the working group decided to change the gears of each of the axes. To reach this solution a deep knowledge of the Alpha6UVic's technology is required, since the replacement of gears involves further modifications in the rest of the robot. In this case, the proposed change affects the balance of the different axes as well as the need to modify the code of the control boards. Once the problem is identified the students must plan and organize the project detailing the tasks to be done, who will perform them and how the team will be organized. Moreover, they have to hand in a report detailing all these changes.

IV. Assessment results

The students have to acquire different generic and specific competences: They (1) can analyse and summarize, (2) can organise and plan, (3) can work in a group, (4) can communicate in oral and written form in the native language, (5) can use information, (6) can make decisions, (7) can apply knowledge to practice, (8) can research information, (9) can use leadership, initiative and the spirit of the entrepreneur, (10) can efficiently combine electronic, electrical, computing, mechanical and management knowledge to design products and innovate and to solve multidisciplinary problems in the field of Mechatronic Engineering and (11) can carry out technological projects in Mechatronic Engineering. The generic competences are defined by the UVic according to indications in the Tuning Educational Structures in Europe project [23]. As for specific competences the criteria from the *Consell general de Col.legis d'enginyers Tècnics Industrials* (COGITI) [22] has been adhered to.

The different activities and project reports as well as the solution reached and the procedure used are taken into account in order to evaluate the skills acquired in the IP module. The assessment of the acquisition of competences throughout the course is based on continual assessment of academic groupwork and individual work by a course tutor who provides small oral and written tests. Active participation in class and in groups is part of the assessment of the different generic and specific competences. Students have to present their work to a committee formed by the teaching staff from the module.

Learning outcomes	Assessment method	Average mark
Knows and applies methods for communicating and working in a group.	continual assessment	6,5
Knows and applies the technical resources for developing technical projects	report and oral presentation	7
Consolidates and interrelates technological concepts of different disciplines.	continual assessment	8,2
Appies theory and practice to the development of the project.	report and oral presentation	7,7
Writes technical information in the native language	report	5,3
Critically analyses the results obtained.	report and oral presentation	6,3
Effectively presents results obtained in the project orally.	presentation	8,1

Fig. 13. Learning outcomes obtained in the IP module. Marks out of ten.

The committee assess: (1) Originality, integration of acquired specific and generic competences from the degree course and applications of the project; (2) Content documentation, structure and the formal written presentation of the report (3) Presentation of the project to the university committee.

This has been the first year that the module was given and the results have been very positive with 100% students passing with an average of 7.3 out of 10. These results could be due to the reduced number of students on the course which has allowed teachers to provide more individualized attention. It would be difficult to obtain a 100% pass rate with a larger number of students. To provide some orientative marks the averages of the learning outcomes are given. In Fig.13 the learning outcomes reached at the end of the course are provided. These relate directly to the competences described in the previous table. Moreover, a survey was conducted at the end of this course to find out the students' opinion about the quality of the course materials, the different skills learned during the course, their experience of acquiring knowledge directly from professionals in the industrial field, the value of using a robot and the influence of the PBL workgroup methodology for learning the desired skills. The ratings from this survey were very satisfactory.

V. Conclusions

This paper reports the pioneering effort by the UVic to provide the first mechatronics degree in Spain. Therefore, UVic is responsible for developing a study plan that satisfies the needs of the industry. The Alpha6UVic was designed with the aim of providing the students with a complete mechatronic example to use in different subjects within the mechatronics degree, including IP1 and IP2. What makes Alpha6UVic unique is its flexibility and accessibility which makes it modifiable at every step of its development. Using the robot in the subjects provided the students with practical experience as they could practice with a real robot and improve it with their own modifications. This gives students the opportunity to consolidate the transversal skills acquired during the degree. Finally, it should be mentioned that Alpha6UVic is the first version of the robot developed at the UVic and the improvements made have been very satisfactory. For this reason, we aim to continue developing it with future student-led work in IP.

References

[1] D.G. Alciatore and M.B Histand, *Introduction to Mechatronics and Measurement Systems* 3rded. New York: McGraw-Hill 2005.
[2] A. S. Brown, "Who owns mechatronics?", *Mechanical Engineering. American Society of Mechanical Engineers.* pp. 24–29, Jun. 2008.
[3] J. A. Rietdijk, "Ten propositions on mechatronics", *Mechatronics in Products and Manuf. Conf., Lancenter Univ.*, UK, Sept. 11-13, 1989.
[4] T. King, "The merits of multi-disciplinary engineering, Mechatronics" *Millwrights to mechatronics*, Vol. 5, Iss. 2-3, March 1995, pp. 95-115.
[5] M. Acar and R. M. Parkin, "Engineering Education for Mechatronics", *IEEE Trans. of Ind. Electr.*, Vol. 43, num. 1, Feb 1996.
[6] M. Grimheden, M. Hanson, "Mechatronics-the evolution of academic discipline in engineering education*", J. Mechatronics,* Elsevier 2004.
[7] V. Salminen, "Ten years of mechatronic research and industrial applications in Finland," *Mechatronics, IEEE/ASME Trans. on* , vol.1, no.2, pp.103-105, June 1996.
[8] S. A. Yost, "Introducing mechatronics in a first-year intro to engineering design course", *in Proc. 2000 ASEE Annu. Conf. And Expo., St Louis, MO, United States*, 2000, pp. 3823-3826.
[9] T. R. Hsu, "Development of an undergraduate curriculum in mechatronics systems engineering", *J. Eng. Educ.*, vol, 88 no. 2, pp. 173-179, Apr. 1999.
[10] S. Stankovski, L.Tarjan, D.Skrijat, G.Ostojic and I.Senk, "Using a Didactic Manipulator in Mechatronics and Industrial Engineering Courses*", IEEE Trans. on educ.*, Vol 53, no. 4 November 2010.
[11] L. Feisel, A. Rosa, "The role of the laboratory in undergraduate engineering education", *J. Eng. Educ.*, v.94 n.1, pp. 121-130, Jan. 2005.
[12] A. Mantri, S. Dutt, J. P. Gupta, and M. Chitkara, "Design and evaluation of a PBL-based Course in Analog Electronics", *IEEE Trans. on educ.*, Vol. 51, num. 4, Nov 2008.
[13] M. M. T. Valdez, C. I. F. Agreira, C. M. M. Ferreira, F. P. M. Barbosa, "PBL implementation in a Lighting Design course", *Universities Power Eng. Conf. (UPEC), 2009 Proceedings of the 44th International* ,vol., no., pp.1-5, 1-4 Sept. 2009.
[14] S. Chowdhury. "The Power of Six-Sigma", *Ind. Machinery Press*, 2003.
[15] U. Murugaiah, S. J. Benjamin, M. S. Marathamuthu, S. Muthaiyah, (2010) "*Scrap loss reduction using the 5-whys analysis*", *Inter. Jour. of Quality & Reliability Management*, Vol. 27 Iss: 5, pp.527– 540.
[16] M.K. Habib, "Mechatronics Engineering The Evolution, the Needs and the Challenges," *IEEE Industrial Electronics, IECON 2006 - 32nd Annual Conf. on* , vol., no., pp.4510-4515, 6-10 Nov. 2006.
[17] S. Das, S.A Yost, M. Krishnan, "A 10-Year Mechatronics Curriculum Development Initiative: Relevance, Content, and Results—Part I," *Educ., IEEE Trans. on* , vol.53, no.2, pp.194-201, May 2010.
[18] M. Krishnan. S. Das. S.A. Yost, "A 10-Year Mechatronics Curriculum Development Initiative: Relevance, Content, and Results—Part II," *Educ., IEEE Trans. on* , vol.53, no.2, pp.202-208, May 2010.
[19] J. Y. Hung, "An integrated junior-year laboratory based on an autonomous mobile robot platform," *Frontiers in Educ. Conf., 1998. FIE '98. 28th Annual* , vol.3, no., pp.1154-1159 vol.3, 4-7 Nov 1998.
[20] M. Krishnan, M.J. Paulik, S. A. Yost, T. Stoltz, "Shared projects with a multi-sub-disciplinary flavor - providing integration and context in a new ECE spiral curriculum," *Frontiers in Educ. Conf., 2008. FIE 2008. 38th Annual* , vol., no., pp.F1H-1-F1H-6, 22-25 Oct. 2008.
[21] M.J. Paulik, M. Krishnan, "A competition-motivated capstone design course: the result of a fifteen-year evolution," *Educ., IEEE Trans. on* , vol.44, no.1, pp.67-75, Feb. 2001.
[22] Internet web page COGITI. [online] Avaliable: www.cogiti.es
[23] Tuning project (2010, Oct, 3), "Tuning education structures in europe", Available: http://www.unideusto.org/tuning/.

Gerard Masferrer graduated in Electronics and Telecommunications (2010) and Master's degree in Digital Technologies (2011) from the Department of Digital and Information Technologies (DIT), Technical school, UVic. He is a Teaching Assistant with the DIT department. His research interests are in robotics, mechatronics and software engineering.

Marc Mundó graduated in Electronics and Telecommunications from the Department of Digital and Information Technologies (DIT) (2008) of UVic and Master's degree in Electronic Engineering from the Department of Electronics, Technical University of Catalonia (2011). He is a teaching assistant with the DIT department. His research interests are in robotics, mechatronics and software engineering.