New environment for learning by doing in mechatronics education

Yves Piguet, Francesco Mondada and Roland Siegwart

Institut de Systèmes Robotiques
Swiss Federal Institute of Technology Lausanne (EPFL)
1015 Lausanne, Switzerland
E-mail: *firstname.lastname*@epfl.ch

Abstract. *A global scenario for a course of mechatronics is presented. The course is divided in several steps mixing individual distant learning and experimentation at home with remote support from the teachers, and work in teams to encourage collaboration. What is new with respect to previous ways of teaching mechatronics is that it focuses not on technical skills, but on the process of building on skills acquired in other, specialized courses and developing a multidisciplinary product with constrained resources and time. Many elements of the course have been proposed in the framework of a mobile robot competition to students of the Swiss Federal Institutes of Technology in Lausanne and Zürich and other engineering schools. Preliminary results are given.*

1. INTRODUCTION

With the fast progress in microelectronics and computer science, products and systems undertook a drastic change. Most of today's products can no longer be assigned to a single discipline, but are highly multidisciplinary. For example, in a modern car the electronics and control play a dominant role (up to 50%), whereas a car from the seventies and even early eighties was nearly purely mechanical (90%). This trend to multidisciplinary (mechatronics) products, even if it has not yet reached its peak, has and will have an important impact on the design process and on engineering in general.

Engineering design has clearly become a multidisciplinary undertaking, happening in multicultural and very diversified teams. In order to prepare our students and the practicing engineers from industry for these new, fastly changing challenges in design, new learning technologies and models have to be developed.

Appearing in the late eighties, mechatronics plays meanwhile an important role at most technical universities. Since the early nineties various conferences, workshops and journals in mechatronics have been established (see e.g. [5-7]) and specialized books appeared on the market [2,3]. Most workshops and conferences also introduced special sessions on mechatronics education where educational curriculums are presented and discussed.

It is well accepted among the experts in mechatronics that experimentation and hands-on education is very crucial for successful and sustainable mechatronics programs. Most existing mechatronics programs cover all the aspects from mechatronics design to sensors, actuators and control theory. Dependent on the department that created the program, the focus is set differently. This limits the audience of the corresponding program. Additionally, the experimentation parts are usually limited to laboratory experiments and are often not well coordinated within the context of the lectures. In the programs where mechatronics design competitions are also offered, basic support is usually very limited, resulting in systems that barely work and do not take advantage of the knowledge gained in the mechatronics course. The main reason for this is that the courses are badly coordinated and no adequate hard- and software exists.

To our knowledge, there are no mechatronics courses available for distant learning. This is probably due to the fact that mechatronics requires an important effort to set up distant learning concepts including real experimentation. However, there are plenty of books [1, 4, 11] and of little robot kits on the market that allow for mechatronics and robotics experiments [10, 11]. Unfortunately, these experimentation kits are very limited and most of them have no use for higher education. On the other side, there are different companies producing and selling mobile robots for research; but these systems are usually too complex and too expensive for using in mechatronics design courses.

The uniqueness of the proposed education concept and learning material is that the whole course is assembled to a consistent framework, from the learning material available through the Internet to the tools used during simulation and to the robot competition. This allows getting maximal benefits from each of the course elements.

2. NEW PEDAGOGICAL CONCEPT

The goal of this new pedagogical concept is to create a problem-based learning framework for mechatronics that can be followed by physically distant people in an asynchronous way. The course is divided in several steps mixing individual distant learning and experimentation at home with remote support from the teachers, and work in teams to encourage collaboration.

Students from different engineering schools and universities as well as engineers from industry or private persons can take the 1st, 3rd and 4th step of the course on an individual basis. The 2nd and 5th steps are common events where all the participants of the course meet for some days at a common location.

2.1 Step1: Learning on an individual basis on the Web

In a first step the students learn on an individual basis via the Web-based learning modules. Through engineering cases and basic introduction material, they acquire the key skills and knowledge for innovative mechatronics design: Innovation, system design, basic introduction to mechatronics elements, sensors, actuators, micro-controller, intelligent (smart) control. This first phase also equalize the basic knowledge of the participants with different backgrounds. Students are also asked to add new learning material to their field of competence.

2.2 Step 2: Fast prototyping for simple systems

During a two-days workshop at a common location (Swiss Federal Institute of Technology at Lausanne (EPFL) and/or Zurich (ETHZ)), the interdisciplinary teams work on engineering cases and build a simple system (fast prototyping). Basic material like motors, simple sensors or LEGO parts are placed at their disposal. This event allows the participants with different backgrounds (disciplines) and origins (universities, engineering schools and industry) to get to know each other and to form the teams.

2.3 Step 3: Experimentation with actuators and sensors

In this step, the students perform experiments with real hardware. To do so, they get an experimental kit with sensors, actuators and interface software (delivered at home or usable in freely-accessible labs). Using easy-to-use interface software, they can experiment with the most common sensors and actuators. A typical experiment might be to observe the influence of the control parameter and load mass on the behavior of a controlled DC motor. The experimental kit will be connected through the serial port to the PC and be accessible by standard Internet browsers (Netscape, Internet Explorer) or a software package delivered with the kit.

2.4 Step 4: Design of a mobile-robot controller using a virtual reality simulator

Control experiments on a virtual-reality robot simulator are available through the Internet. They will allow developing and testing preliminary code to control the robot. The simulator will include all the basic sensors offered with the real robot kit and a model of the real environment for the competition. The developed code will be fully compatible with the code running on the real robot. However, custom-made mechanical structures and sensors built by the teams for the competition will not be available in the simulator. During this preparation phase, the participants will already work within their team. Coordination will be made through a specially arranged environment on the Internet.

2.5 Step 5: Robot competition

The knowledge acquired during the previous steps is applied to a real robot. This step is carried out at EPFL or ETHZ. The students work in teams and have to build a fully functional robot to win the competition. Basic modules are provided; they include all sorts of mechanical parts and all the sensor and actuator modules which have been investigated in Step 3. The Kameleon micro-controller board from K-Team is used to control the robot. The control code developed in step 4 can be directly reused on the real robot controller. Through simple control examples, the students are introduced to the system and motivated to apply the control theory they have learnt. This phase lasts around three to four days and ends with a competition. A separation in two blocks with an intermediate evaluation based on simulations is also possible. Examples of typical robot competitions are garbage-sorting robots, golf-playing robots, tower-building robots or fire-fighting robots.

4. SUPPORT TOOLS

The scenario described above requires reference material, hardware, and software whose purpose is to let students learn how to realize a working product by doing it in a constrained time frame.

4.1 Basic Learning Modules (PDF documents)

In addition to the standard PDF documentation of the technical components, a database has been developed to describe both the basic physical principles and their applications for sensors and actuators (see Figures 1-4). The database is currently provided as a PDF file for each domain: electronics (see Figure 1) and physics principles (see Figure 2) and their use in actuators (see Figure 3) and sensors (see Figure 4). It will later be available on the Web with links and a way for students to add information, either for themselves or for all the participants.

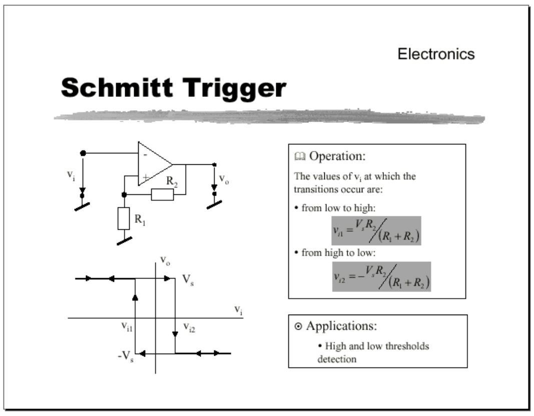

Figure 1: Example of file illustrating an electronic circuit.

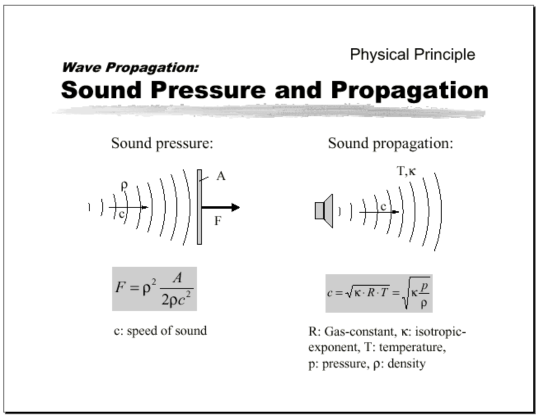

Figure 2: Example of file illustrating a physical principle.

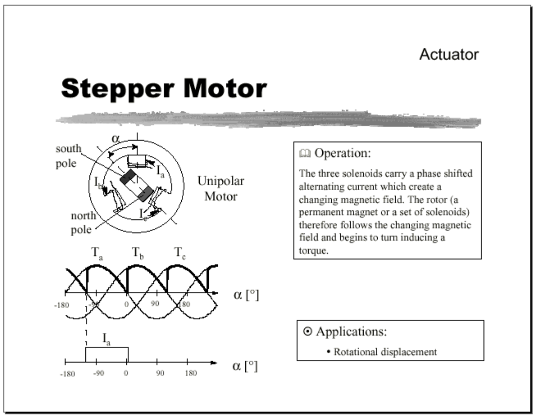

Figure 3: Example of file illustrating a type of actuator.

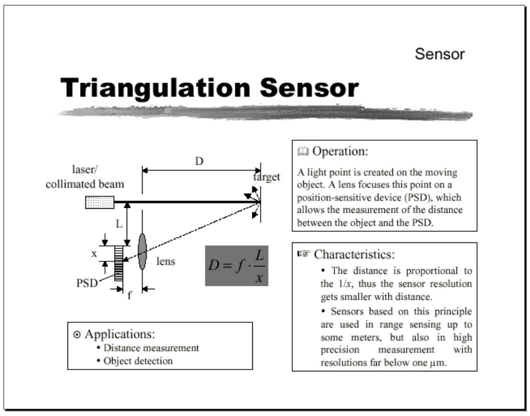

Figure 4: Example of file illustrating a type of sensor.

4.2 Sensor and Actuator Modules for Experimentation

Sensor and actuator modules have been developed and improved, permitting the students to learn through experimentation. Each module is made of an interface board based on a PIC micro-controller which manages the actuator or sensor, performs low-level signal processing, and interfaces with the PC or Macintosh through an I^2C bus and RS232 serial link. In a first stage, the modules are experimented separately to let the students understand how they work, what their performance and limitations are, and how they could be used to help them to solve their problems. In a second stage, the modules are used directly on the mobile robot and interfaced with the master micro-controller board.

The following modules have been developed:

- linear camera, which gives a grayscale image of 64x1 pixels (see Figure 5).
- 8-bits infrared optical triangulation distance sensor (up to 4 Sharp sensors per module), measurements of up to 60 cm (see Figure 6).
- 8-bits ultrasonic distance sensor (sonar), measurement range of 1m, 2m or 4m.
- servomotors (up to 4 units per module).
- Inclination sensor.
- DC motor controller.

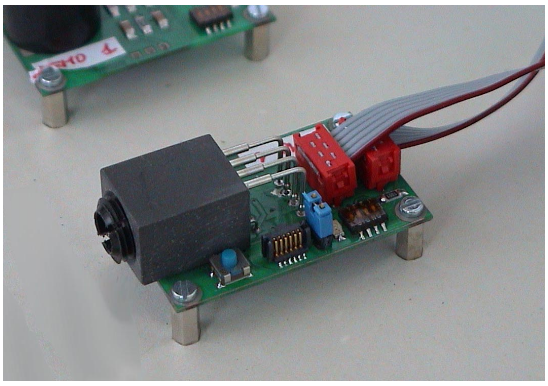

Figure 5: Linear camera module.

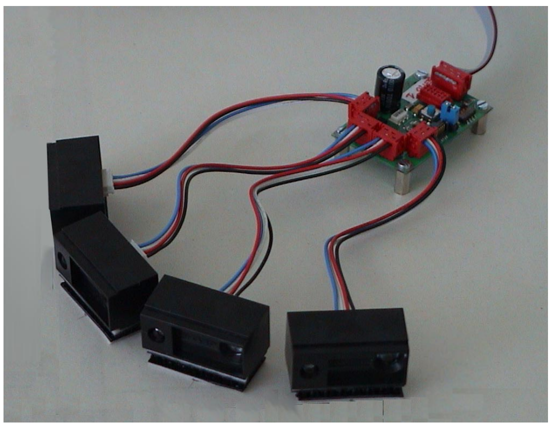

Figure 6: Optical Sharp distance sensor module.

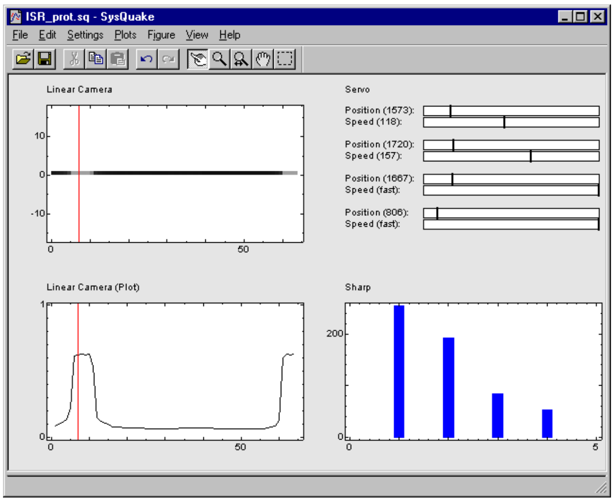

Figure 7: Example of sysquake control for the optical distance sensor (bottom right), the linear camera (left) and the servo control (top right).

To make immediate experimentation possible, an application has been realized for SysQuake, software for simulation and scientific visualisation which permits the fast development of interactive graphics [12,13] (see Figure 7). It enables the configuration of modules and the acquisition of measurement data with an easy-to-use graphical interface. The module user interface is provided as source code. Students can learn how to interface the modules not only with the module documentation, but also by studying the source code. They can also experiment modifications and learn for example how to merge information from several sensors to acquire a better knowledge of the environment; or how to make an actuator react to the stimulus of a sensor. SysQuake's rich language, compatible with Matlab which students already use in control courses, provides a fast prototyping environment. Configuration, control, and data acquisition is implemented in low-level functions which can be reused easily.

4.3 Virtual-Reality Simulator

A virtual-reality simulator has been developed with Webots, software for the simulation of mobile robots and their visualization in virtual reality [14,15] (see Figure 8). The behavior of the robots and of their proximity sensors, their interaction with concurrent robots, the objects they must collect and the environment are simulated and displayed in real time. Students can develop the navigation algorithms and the strategy to pick objects, to avoid other robots, and to bring objects to the target area. The simulator is very flexible; it lets the student choose what kind of sensor to use and at which position. The controller is implemented as a C extension module of Webots; it can then be reused on the real robot.

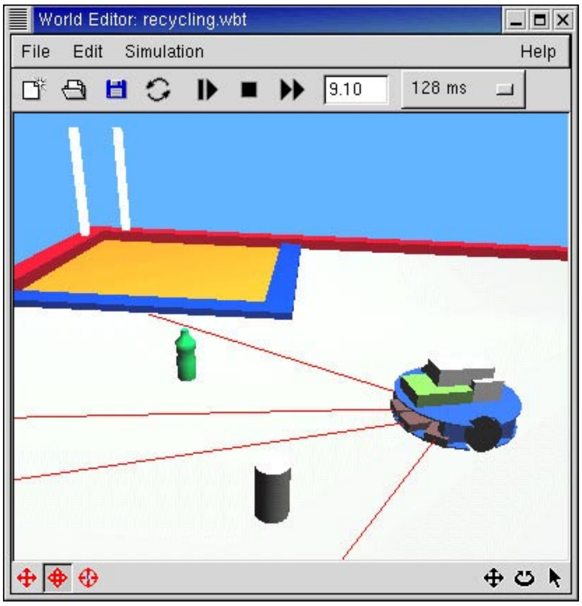

Figure 8: The WEBOTS simulator is able to simulate the SmartEase robot.

4.4 Robot Kit "SmartEase"

A mobile robot kit has been developed for this project (see Figure 9). It is made of a cylindrical body with two wheels driven by two separate DC motors. The body supports typically a Kameleon micro-controller board [16], sensor and actuator modules, as well as any other electromechanical part the students may want to add. In its simplest form, the kit does not include the Kameleon board; students are free to choose another computing unit, such as a small laptop computer or a handheld device.

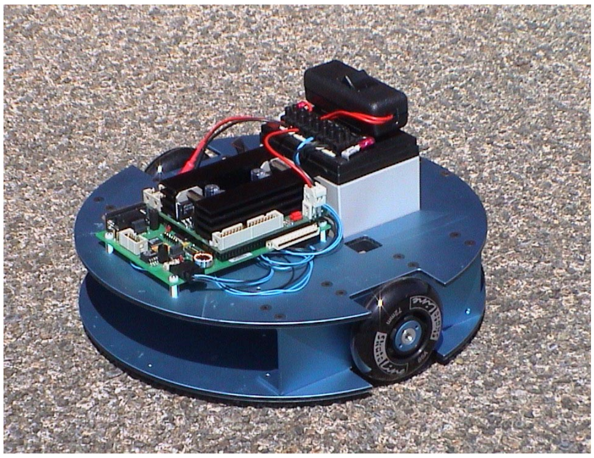

Figure 9: SmartEase mobile robot platform.

4.5 Off-the-shelf Products

In addition to the material which has been specifically developed for the NTC project, the following products are provided to the students (not all products are distributed to all teams):

- Kameleon micro-controller board with its electrical drive controller extension and its gcc-based development environment. The board can be used as the autonomous master computer of the mobile robot which controls the electrical drives and the sensor and actuator modules [16].
- SysQuake LE, software for scientific computation and interactive graphics used for experimentation with the modules.
- Lego MindStorms, a set of micro-controller, sensors, actuators and building Lego bricks.
- Laptop computers[1], which we provide with all software and documentation pre-installed.

5. EXPERIENCE

During the last semester, a first experience has been made in the context of the robot competitions already organized for ten years at EPFL, the similar ETHZ robotic contest [17], a standard course on system design and a partial implementation of the pedagogical concept using the tools presented in the previous section. The goal of the competition was to find, sort and bring into collectors ten aluminium cans and ten PET bottles.

5.1 Motivation

In the final robot competition, we had 54 students grouped in 14 teams and coming from four schools. Most of them (37 students from EPFL, 11 from other schools) got the support and access to the equipment mentioned above. Most students have made this work in their free time; some of them have used the possibility to associate it to the course and get credits at the end. We questioned the students about the motivation they had to participate. From 33 answers (mostly EPFL students) we got the results illustrated in Figure 10.

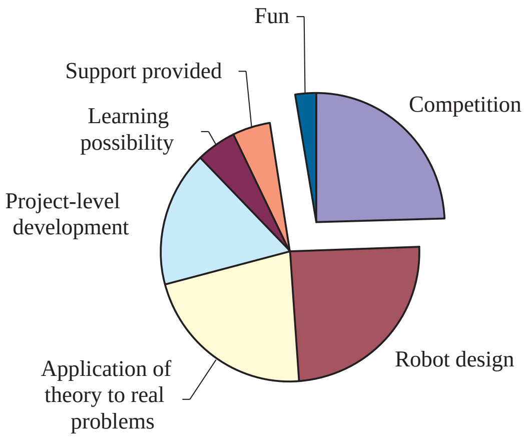

Figure 10: Preliminary analysis of the students feedback about their motivation to participate.

It is interesting to observe that the main aspects of learning by doing in mechatronic system engineering are present. The mechatronic itself is present in the project-level and interdisciplinary work (both under project-level development) and implicitly in robot design. The need of practice in education is also clearly expressed. Several students mention explicitly a strong need of seeing the application of the huge quantity of theory they have acquired.

This technical motivation plays a large role (about 75%) shared with a more personal motivation in participating to a robot competition or simply having fun. This non-technical motivation is important (more than 25%) and plays an important role in the pedagocical concepts to increase the student involvment.

5.2 Acquisition of competences

The equipment provided and the task defined for the contest have influenced most of the teams to invest in mechanical design. Figures 11, 12, 13 and 14 show four examples of robots designed for the contest. Most robots developed by EPFL students (for instance "Kran", "Zébulon" and "Twister") use the same main control board (a Kameleon single board computer provided on the SmartEase platform) but only few (for instance "Kran") use the unmodified mechanical structure of the SmartEase platform. Most students, hoping to get better performances, have decided to create a new mechanical structure, investing most of the time in this part of the design.

Very few teams have invested time in electronic development, the Kameleon board and the I^2C modules being sufficient to build a performant robot.

More time has been spent in developing software to make the best use of the sensors and implement the best strategy.

The distribution of efforts between mechanics and software has generated a very strong interaction between mechanics and software developers. Younger students had also more theory to learn: some had no idea about control, regulators and the related theory.

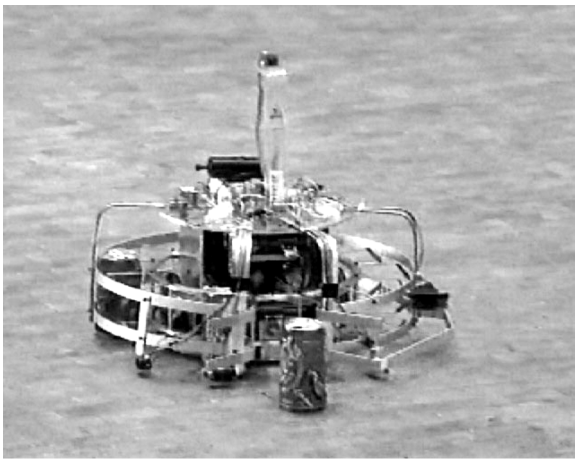

Figure 11: The robot of the "Zébulon" team.

[1] Sponsored by ABB, whose we gratefully acknowledge the contribution.

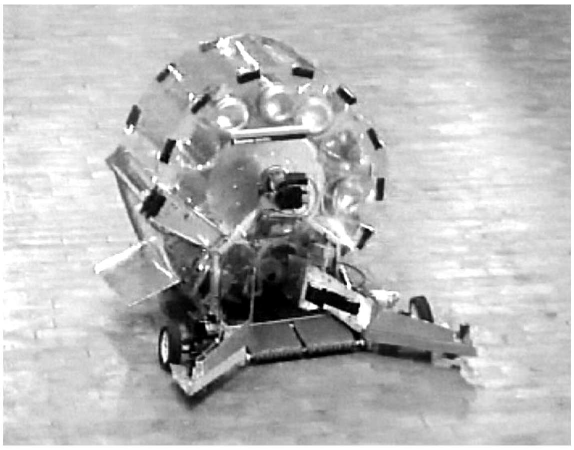

Figure 12: The robot of the "Russisches Roulette" team.

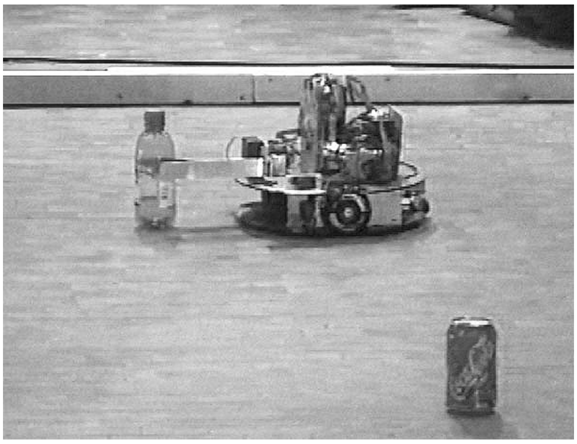

Figure 13: The robot of the "Kran" team.

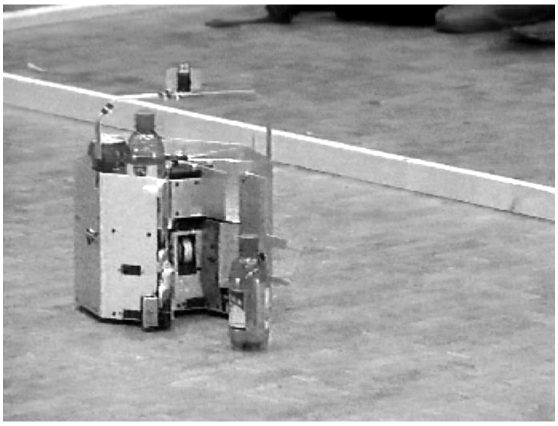

Figure 14: The robot of the "Twister" team.

5.3 Comparaison with a standard course

We asked to the students a feedback about what they learnd in this framework, making a comparaison with a classical course. The result is illustrated in Figure 15 and shows clearly that students consider the practical experience as the main additional feature of this approach. A large number of students believe also that this framework gives them a better technical experience ("now we know that a transistor can overheat and how to deal with this aspect"), which is strongly related to the practical experience.

Figure 15: Preliminary analysis of the students feedback about the additional aspects learnt during the contest in comparaison with a more classical course.

6. CONCLUSIONS

We presented a pedagogical concept and its partial implementation during the last semester in the context of the annual robotic contest.

A discussion with students having tested our learning environment shows that there is a clear need for practical application of theoretical concepts in mechatronics. This technical motivation is a very important aspect of our concept and is merged with a personal motivation given by the final contest.

Students seem also to agree that there is a clear improvement in comparison with a classical course, especially because of the practical expertise acquired.

AKNOWLEDGEMENT

We gratefully acknowledge Michel Lauria for the organization of the competition, all persons that helped during the event, the students for their participation, Ralph Piguet and Grégoire Terrien for the development of the robotics parts, Laetitia Major for the development of the learning material and Nadine Stainier for the analysis of the students feedback.

REFERENCES

[1] L. Jones, Anita M. Flynn, Mobile Robots, Inspiration to Implementation, Joseph A K Peters Publisher, 1993

[2] D.A. Baradley, D. Dawson, N.C. Burd and A.J. Loader, Mechatronics, Electronics in Products and Processes, Chapman & Hall, 1991

[3] Michael B. Histand and David G. Alciatore, Introduction to Mechatronics and Measurment Systems, McGraw-Hill, 1998

[4] http://www.robotbooks.com/index.html

[5] http://www.synthesis.org/Mechatronics-Workshop

[6] http://www.me.gatech.edu/AIM99/

[7] http://www.me.gatech.edu/mechatronics2000/

[8] R. Siegwart, R. Büchi, Ph. Bühler, Mechatronics Education at ETH Zürich based on 'Hands-on Experience', Proceedings of MECHATRONICS'98, Skövde, Sweden, September 9-11, 1998.

[9] SmartROB, ETH Zürich, 1992 – 1998, movie summarizing the robot competition from 1992 till 1998 at ETH Zürich.

[10] http://www.RobotStore.com

[11] http://www.robotbooks.com/

[12] Intuitive Design of Complex Real-Time Control Systems, Martin Dimmler and Yves Piguet, 11th Internation Workshop on Rapid Prototyping (RSP 2000), Paris, 2000.

[13] http://www.calerga.com/

[14] Webots: Symbiosis Between Virtual and Real Mobile Robots, Olivier Micherl, Proceedings of the First International Conference on Virtual Worlds (VW'98), J.-C. Heuding (Ed.), LNCS/AI 1434, Springer Verlag, 1998.

[15] http://www.cyberbotics.com/

[16] http://www.k-team.com/

[17] Siegwart R., *Hands-on Mechatronics Education - Learning by Doing*, Special issues on *Education* of the IEEE Robotics and Automation Magazine, June 2001