Interdisciplinary project-based learning at master level: control of robotic mechatronic systems

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Abstract: This paper presents a project based learning at master level with strong interdisciplinary elements. Within the course of ICT and Mechatronics at Ghent University, the classical laboratory experiments do not present a suitable challenge for the students. In order to motivate them and rise their interest in the field, challenging smaller projects (i.e. control of a mechatronic system) are introduced in the curriculum. During the projects, the students have to use their skills such as programming languages (e.g. C++, Java etc.), communication, basic control techniques, etc. As an outcome, the students acquire the appropriate competences (e.g. ability to understand a mechatronic system, a motion control strategy, etc.) needed to deal with this kind of problems at industrial level.

Keywords: Project based learning, robotics, mechatronics, lego cars, group work.

1. INTRODUCTION

All over the world, especially in Europe due to the Bologna process, several changes at university level have been encountered (-, 2015a; Musselini, 2004). Most of the European universities take the opportunity of the Bologna process to revise their curricula and to restructure the educational program. Within Ghent University, the classical 5-years engineering study program has been converted in a 3-years Bachelor and 2-years Master. Each year, the number of students enrolling for a bachelor or a master program has increased significantly. In 2014, more than 900 students have started their studies at Faculty of Engineering and Achitecure at Ghent University. The end of the bachelor degree (after three years) is marked by an interdisciplinary project work where the students become familiar with the practicalities of the theory they studied hitherto. Almost the entire number of students choose to continue their studies at master level, where they acquire specific expertise in their choice of specialisation. Within the choice of Control Engineering and Automation, several courses are introduced with new emerging learning tools.

It has been shown that for engineering students, in order to provide a better understanding of the theory, the student needs to apply it in real-life experiments (Dormido, 2004). However, the infrastructure necessary to perform laboratory experiments is not always available and therefore other solutions have to be invented, leaving room for creativity of both the tutor as well as the student (Rossiter, 2013).

As presented in (Ionescu et al., 2013; Chevalier et al., 2015, accepted for publication, 2016) one solution implemented at Ghent University to address the problem of practice for large groups of students (i.e. typical bachelor years) is to use remote lab applications. In this way the students can use the infrastructure available in various locations in the department/faculty/university to apply their theoretical knowledge. Other successful solutions have been also proposed such as applied exercises (Pasamontes et al., 2012) and problem based learning (Barrows, 1986; Padula and Visioli, 2013). Moreover, the students are not just applying the theory they also learn how to work in teams (i.e. task management, leadership, etc.), also known as active learning (Acevedo et al., 2008; Prince, 2004).

In the last decades the technology advanced significantly, but also the attitude of the students has changed during last years and all these aspects of the new academic environment have a great impact on teaching activities. Nowadays, the new technologies (e.g. computers,smart phones, tablets) are highly accessible to the students (Lindsay and Good, 2005; Rossiter, 2013). Moreover, Ghent University has subscription to multiple on-line libraries and the students have access to high quality scientific papers which offer the possibility to be always up-to-date with the latest news. Hence, the professors have to be also updated with the latest technology in order to offer the best motivation to the students. Something perhaps worth mentioned here is that this new style of teaching has increased the workload of the teacher at the benefit of the student.

This paper presents the development of project based learning within the course of ICT and Mechatronics given at Ghent University; the full description of the course is available online (-, 2015b). By performing these experiments the students will have to apply their knowledge on motion control, programming languages, communication protocols, in order to achieve the final goal of the project. At the end of the projects, adjacent to the initial skills, they will acquire competences such as design and implement computer-based motion control strategies, etc. Teams and individuals will be evaluated for: project results, depth of execution, presentation skills, motivational aspects of their choices and a peer assessment.

The paper is structured as follows. In Section 2 the academic context and project description is presented, along with a short overview of the course and a detailed description of the projects. In Section 3 the hardware used for the project is presented. Section 4 defines the control problem addressed in each project. In Section 5 the results and overall assessment are detailed followed by conclusions.

2. ACADEMIC CONTEXT

The ICT and Mechatronics course studies the interaction between information-processing systems and the physical world in the context of mechatronic *robotic* systems. The course is conceived as an overview of concepts and methods that play important roles on the information processing of mechatronic applications. The course consists of three main parts. Firstly, the basic structure of microprocessors is shortly described, emphasizing the elements that allow real-time reaction and processing of multiple tasks. Secondly, modelling and steering of complex robotic systems is addressed. More specifically, it reviews the basic methods for representation and steering/planning in a more general scope than the already known traditional linear stabilization. Thirdly, it considers the processing of measured information in a diversity of contexts, and details on how the associated information-handling principles also applies to telecommunication. The course addresses the following topics (selected):

- ICT systems set-up for mechatronics;
- Advanced actuation techniques;
- Sensor properties and types, active sensing;
- Motion control: system identification, discrete-time PID control, autotuning of PID controllers, fuzzy control strategies.

The master course projects are closely related to the course content and aim to aid the students in the process of learning how to deal with control of robotic and mechatronic systems (Astrom, 2006). The number of students enrolled for this course is about 100. To ensure a good management several groups have been created and each group consists of 5-6 students. Since *task management* is also a very important competence that the students should have at the end of their studies, a follow-up process consisting of three steps was implemented. Each group had to hand-in two intermediary reports and one final report. The role of the intermediary reports was to track the progress of the students and simultaneously to have an overview of the workload of each student and of the task distribution for every team member. Wherever necessary, the tutor would intervene. Moreover, the students were encouraged to use forums to ask questions related to the projects among themselves and the tutor would also intervene whenever necessary. In this way, the students are motivated to help each other by giving answers/suggestions/ideas to the faced problems.

The competences aimed at the end of the course are:

- understand how basic components of complex mechatronic systems work, especially on the ICT side
- name relevant techniques and recognize the dangers for multiple-task management
- understand basic communication techniques: setting up communication, choosing information channel and information content
- discriminate between different task organizations: layers, parallel threads, object oriented
- represent simple motion systems with matrix groups and realize their limitations
- divide simple plans by backwards induction.
- design and implement computer-based motion control strategies
- understand the reasoning and assumptions behind correct data interpretation, information extraction and artificial intelligence / machine learning
- propose, analyze, select and implement hard- and software solutions for sensing and actuation in a newly encountered mechatronic system
- efficiently report on project advances, clearly describe technical solutions.

3. DESCRIPTION OF THE PROJECTS

To cover the entire curricula of the course, four different classes of projects were proposed to the students. These projects are briefly defined below:

(A) design of an Antilock Braking System (ABS) on a LEGO racer car (3 groups were assigned for this project)
(B) two-track line follower system which can avoid obstacles present along the line (5 groups were assigned for this project)
(C) path planning task and sensor fusion on a two-track system (4 groups were assigned for this project)
(D) mechatronic implementation of a movable robotic arm including the design and implementation of a control strategy (4 groups were assigned for this project)

Each project class made use of all the knowledge acquired during this course, and from other related courses, while focusing on specific aspects of the course.

The competences that are obtained within this interdisciplinary project, for each class of project are given in Table 1. In order to have the feedback with respect to the experience of the students while developing this type of projects, a set of questions have been addressed to all the students and the average cost are given in Table 1.

3.1 Project type A - Design of ABS

Each group of the students assigned to this project class is provided with a LEGO racer car called Dirt Crusher. The car has a battery pack and two motors in the back,

Table 1. Competences acquired during the project

Competences	project A	project B	project C	project D
Skills to validate hardware and software components and their interaction	5	5	4	4
Applied knowledge about instrumentation	5	4.5	4	4.5
Skills on control design techniques	5	3.5	4	3.5
Applied knowledge about image processing techniques	2.5	4	5	2.5
Applied knowledge about path planning algorithms	1	2	5	3.5
Skills in Matlab programing language	3	3	4.5	3.5
Skills in C++/Java programming language	5	4	5	5
Applied knowledge about sensor fusion techniques	3.5	4	4.5	3.5
Applied knowledge about communication protocols	4	3.5	4.5	3.5
Applied knowledge about direct and inverse kinematics	2.5	3	2.5	5
Skills in task division and group work	5	5	5	5

depicted in Figure 1. The goal of the project is to design and implement the appropriate control strategies, sensors, computer programs, etc to provide the given system with an ABS feature.

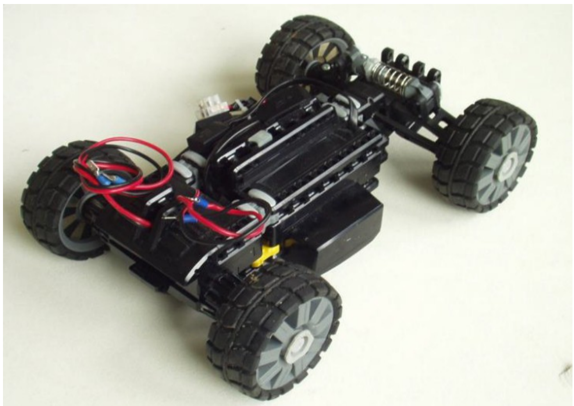

Fig. 1. Lego racer car used for ABS feature.

The final system will have the task to drive the car at maximum speed in a straight line and stop as fast as possible on a slippery/unstable surface without spinning i.e. still facing forward. In order to fulfil the given task, the students had to implement the communication and controls on a Beaglebone Black (Figure 2). This platform has the advantage of being a low-cost, community-supported development platform, which runs on Linux and has the following specifications:

- AM335x 1GHz ARM Cortex-A8
- 512MB DDR3 RAM
- 4GB 8-bit eMMC on-board flash storage
- 3D graphics accelerator
- NEON floating-point accelerator
- 2× PRU 32-bit microcontrollers
- USB client for power & communications
- USB host
- Ethernet
- HDMI
- 2×46 pin headers

The students had an introductory lecture on the principles of ABS. It is up to the students to decide which type of sensors they will use to complete the task. For instance, these could be a combination of optical encoders, mechanical sensors, camera, IR sensors, etc. The choice of the strategy to implement the ABS system is part of the student's creativity. Here, the students should evaluate

Fig. 2. The BeagleBone Black processing unit of the Lego race car

possible strategies such as using front-wheel of rear-wheel traction, PID of fuzzy control, controlling the wheel slip or the wheel angular velocity, etc.

The two intermediate tasks and the final task were defined as following:

- intermediate step 1: design of the overall system and implementation of the sensors and actuators. As a deliverable of this step, the robot should be able to move in a straight line as fast as possible.
- intermediate step 2: the robot should be able to stop as fast as possible on a normal surface after speeding up to its maximal speed and maintain its initial direction.
- final step: the robot should be able to stop as fast as possible on a slippery/unstable surface after speeding up to its maximal speed and without slipping.

3.2 Project type B - line follower

In this class of projects, the students are provided with the Surveyor SRV-1 Blackfin robot shown in Figure 3. The system has a front camera for which the image processing can be executed on the given Blackfin microprocessor. The default hardware consists also of two infrared IR sensors which can be implemented on the system. Notice that the robot was not fully operational at the beginning of the project.

The goal of this project was to design and implement the appropriate control strategies, sensors, computer programs etc, to follow automatically as fast as possible a curved line from point A to point B while avoiding obstacles.

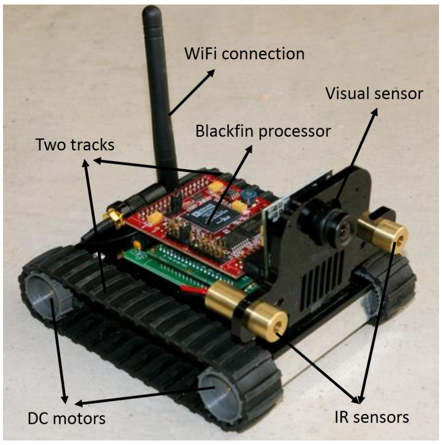

Fig. 3. Surveyor SRV-1 Blackfin

A combination of optical encoders, mechanical sensors, camera, IR sensors, etc should be used to fulfil this task. The main components of the Surveyor SRV-1 Blackfin robot are:

- WiFi connection
- Video camera
- Blackfin BF537 processor
- Two tracks
- IR sensor
- 4 DC-motors

Similarly as for the first project, this project consists of two intermediate steps and a final step:

- intermediate step 1: assembling the robot with the necessary instrumentation and initiate operability of the robot
- intermediate step 2: the robot should be able to follow a predefined line in the absence of obstacles.
- final step: the robot should be able to follow a predefined line, recognize obstacles and avoid them.

3.3 Project type C - path following

Here the students are provided with a robot based on the Surveyor SRV-1 which is shown in Figure 4. A microprocessor and optical wheel encoders have been added to the basic system.

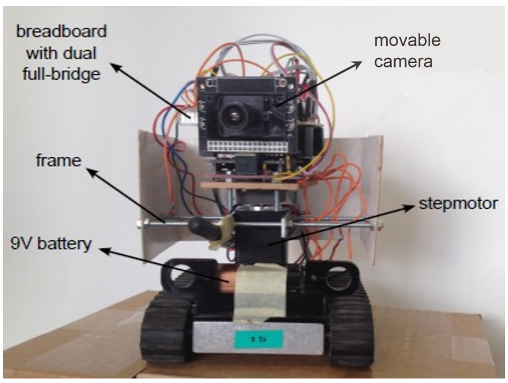

Fig. 4. Surveyor SRV-1 with the stepper motor and movable camera

Different from project class B, here the robot is equipped with a stepper motor which allows a rotation movement in the interval $(-90°, 90°)$ of the visual sensor. For this system, the image processing is performed using the Blackfin microprocessor, while for the lateral and longitudinal movement a PIC18F452 micro-controller was considered. This PIC microchip is illustrated in Figure 5 and has the following specifications:

- 2 PWM 10-bit
- 40 MHz Max. Speed
- PSP and ICD
- 'C' compiler
- friendly development environment
- 8 channels of 10-bit A/D converter

Fig. 5. PIC microcontroller

The goal of this project is to design and implement the appropriate control strategies, sensors, computer programs etc, such that the robot automatically navigates - as fast as possible - through an area with fixed obstacles, between a specified begin- and end-point. In order to detect the obstacles, the students have intermittent access to a fixed top view of the area via an IP camera. Based on image processing techniques the students should be able to recognize the obstacles and by means of path planning algorithms they should be able to design a collision free path. The students had to implement the motion of the robot-car along that optimal path.

Using sensor fusion of the IMU and the position of the robot from the intermittent top view images, the robot is able to know his current position in the area. Again, it is up to the students to decide which type of sensors they will use to complete the task. This can be a combination of optical encoders, mechanical sensors, camera, IR sensors, etc.

This project consists of two intermediate steps and a final step defined as:

- intermediate step 1: equip the system with the necessary sensors and actuators, use image processing algorithms to obtain the positions of the obstacles from a top view of the area
- intermediate step 2: calculate and follow the optimal path between two given points A and B
- final step: the robot should be able to go from point A to point B via the optimal path while avoiding obstacles at the maximum possible speed.

3.4 Project type D - manipulator arm

In this class of project, the students are provided with a robotic arm system which is shown in Figure 6. The system consists of three segments and a gripper:

- Gripper
- Wrist rotation
- Elbow rotation
- Shoulder rotation
- Base rotation
- Arduino board

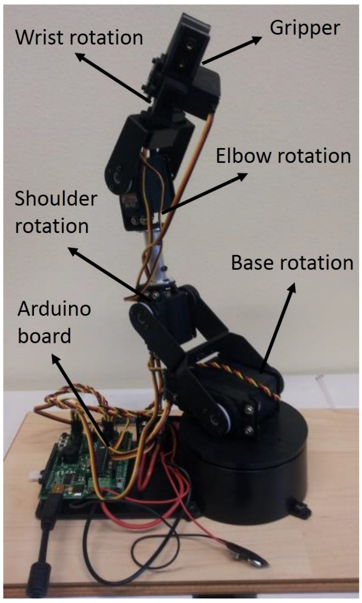

Fig. 6. Robotic arm

The goal of this project is to design and implement the appropriate control strategies, sensors, computer programs etc, to automatically move an object from point A to point B in an environment with obstacles. The position of the obstacles is unknown a priori and has to be detected during the motion. In order to fulfil the given task the students have a Arduino board, shown in Figure 7, available (BotBoarduino of Lynxmotion) with following specifications:

- USB connection
- Onboard speaker
- Sony PS2 controller port
- Reset button
- Logic and servo power inputs
- I/O bus with 20 pins
- 5vdc 1.5 amp regulator
- Up to 18 servos can be plugged in

In order to detect the obstacles, the robot should make use of a camera and/or IR sensors which needs to be implemented on the system itself. It is up to the students to decide which type of sensors they will use to complete the task.

This project consists of two intermediate steps and a final step:

- intermediate step 1: implement the necessary controller to move an object from point A to point B in an obstacle-free environment

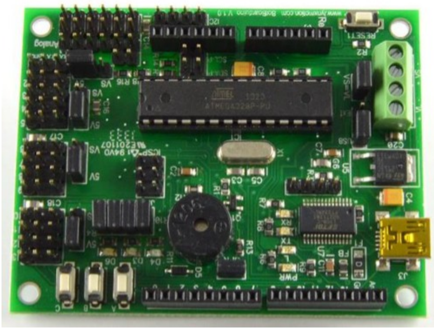

Fig. 7. Arduino board: BotBoarduino v 1.0

- intermediate step 2: make use of sensor fusion techniques in order to recognize the obstacles in the environment
- final step: the robot should be able to move an object from point A to point B while recognizing and avoiding obstacles along the way.

4. PROJECT EVALUATION AND IMPACT

The initial competences envisaged in the beginning of the course were successfully acquired by the student. Besides all theoretical competences gained during the course, the students had the opportunity to develop during the project competences and skills such as: self-criticism, peer-assessments abilities, how to act as a team-leader, to be responsible and hard worker, they learned to work in groups and to distribute tasks among co-operators, they gain experience about what a decision making process is based on.

Student evaluation consisted of intermediary reports where the students had to address the progress of the project, the challenges encountered and the further steps to be performed. At the end of the course, a final report with a detailed description of the project followed by the results obtained (i.e. to which extent they achieved the goal) had to be delivered. Since the students worked in groups one report per group was sufficient. However, in order to be able to provide individual evaluation, the students were asked to provide a peer-assessment of themselves and their fellow colleagues along the project execution.

A full-day demonstration of the prototypes developed by the groups has been organized and the final goal evaluated by the tutors and their fellow colleagues. A set of questions and answers were performed, aimed at clarifying aspects of the tasks which were less fulfilled than expected. Some of the groups who failed were enquired whether or not they know the reason of their failure in achieving the final goal, as part of the self-criticism competence. Alternative solutions were also asked and evaluated for feasibility. An important feature of the projects was the time allocated by the students to the completion of the tasks, and task distribution among the individuals within each group. It turned out that the students were positive about their performance but they felt that the time they allocated was inadequate, i.e. due to sub-estimation of the difficulty level of the problem, a lot of time has been inefficiently consumed in the beginning of the time interval. The most progress has been done in the last week(s) before the deadline with intensive efforts from the students in order to reach the final goal of their projects. This indicates that the student lacks a maturity in estimating its own capabilities and thus allocating the correct time and effort to the sub-tasks. This is an important aspect of real-life application of theoretical concepts and perhaps could be included as an additional competence in the course's competence matrix.

Overall, the selection of the projects has been appreciated by the students as a good and useful example of a inter-disciplinary task. The core of this project is obviously the control of mechatronic systems. However, in realizing this task, the students were confronted with several aspects of engineering and they had to use their knowledge acquired via different courses during their studies. The students showed a lot of interest, inspiration and creativity during the project development. In the very end, they were all proud of the result of their efforts.

For the next academic year we plan to use LEGO robots for the projects. These are robust and it is a stable framework based on which further educational project can be defined. Moreover, this is an up to date infrastructure which allows the student to implement all the cases presented in the theory leading thus to a good fitting between theory and practice. Beside this, the number of the students per group will be reduced from 6 students to 3 (max 4) students in order to have a better evaluation per student. For a good interaction with the students, a communication channel will be available for project setup introduction and a closer follow-up procedure will be implemented, i.e. via interim report and peer-assessment. Moreover, the evaluation criteria will be available for the students since the start up of the project.

5. CONCLUSIONS

This paper illustrated a set of projects anchored to an interdisciplinary course on ICT and Mechatronics. The competences envisaged in this course were successfully achieved by means of teaching hours, practice guided hours, self-study and project based learning. The evaluation of the results indicates that a good balance between course content and project workload is necessary and useful for a successful learning process. The students received well the proposed projects and were well motivated to deliver good results.

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