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Control Education within A Multidisciplinary Summer Course on Applied Mobile Robotics

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Abstract: This paper presents our teaching experience in control educational issues through a summer course "Applied Mobile Robotics". The main aim is to integrate different knowledge related to control and computer science through an adequate robotic framework that acts as an educational multidisciplinary tool in the course. As a practical approach, the majority of educational activities of the course are carried out at our university labs. The students are greatly motivated by working on such a robotic platform, which permits them to consolidate the acquired knowledge and to extend their complementary curricula.

1. INTRODUCTION

Future direction in control education is pointing towards the ability of understanding the technical details of a wide variety of disciplines (Antsakis et al. 1999). Control system society and computer science share a mutual interest on robotics. However, despite of the enormous progress in robotics over the last half century, this field is still in its infancy. For instance, the robot behaviour is much simpler compared with the human behaviour, in which its ability to move, to understand complex sensorial inputs, or to perform higher level reasoning, is limited. The clues for achieving a renewed path of progress are the integration of several knowledgeable fields, such as computing, communications, and control sciences, in order to perform a higher level reasoning and use decision tools with strong theory base (Murray et al. 2003). Moreover, developed experimental environments have helped to breathe life into various control theories found in text books and have thereby greatly changed the educational experience of students of automatic control (Hristu-Varsakelis and Brockett 2002). Thus, students react positively to realism, since the models used for such experiments are in general accurately described by some relatively simple differential equations. Within this framework, the challenge of mobile robots is clearly exhibited. Within the educational community, the Robotics Education Lab becomes a resource to support courses of academic curriculum in a broad range of subjects. Some important institutions such like the Carnegie Mellon University have developed various teaching activities by introducing the mobile robots as a necessary academic tool from a broad sense in order to extend the acquired knowledge of the students. Moreover, other related activities are developed, such as the mobile robot competitions or some special summer programs like RoboCamp, which permit the students to do themselves the design, programming and construction of the autonomous robots.

This paper presents the educational control aspects of the developed summer course "Applied Mobile Robotics". The main aim of the course is to integrate different knowledge as electronics, programming, architecture, perception sensors, communications, control, computer vision and trajectory planning by using an educational open mobile robot platform PRIM (Pacheco et al., 2006). The academic skills are attained by the students in a broad sense; hence experiments are used to reinforce previously introduced knowledge by integrating relationships between different academic subjects. The paper is organized as follows: In section 1, the main ideas and research objectives are presented. Section 2 shows the community of students suitable for this teaching activity within the context of our university framework. The used robotic platform and the summer course program are presented from a wide scope concerning about the multidisciplinary teaching. Section 3 presents the detailed program related to the control issues to be developed. Especially, attention is paid to describe the different experiments designed in order to fulfil the process of knowledge learning. The integration of control issues with other research topics such as perception and path planning is also briefly commented. The Section 4 presents the main conclusions attaining future research directions as a feasible way to improve the student's feedback. Finally, the opinions of students are also outlined.

2. EDUCATIONAL ROBOTIC FRAMEWORK

The course "Applied Mobile Robotics" started in the summer of 2005 at the Polytechnic School of University of Girona. It was proposed by a group of faculty members belonging to the teaching areas of Control and Computer Engineering and sharing a common background that involves the research on mobile robots. Hence, its purpose consists in integrating different teaching aspects from a practical point of view by using an available robotic platform. The number of students is limited to 12, accordingly with the lab reality and the need of a mutual relationship and contact between the students and teachers. This section presents the profile of related student's community to which the course is addressed. The headlines and schedule as well as the mobile robot platform used in the course are also introduced.

2.1 Profile of students and Evaluation

The summer course is addressed to a wide range of student profiles. Both undergraduate and graduate students can take this course to consolidate their complementary study curriculum. However, it is of special interests to the students of Electrical and Computer Engineering around their final academic year. The students passing successfully the course will be awarded to 3 credits that correspond to 45 hours of teaching activities. It is recommended that the student who wants to pursue the course had acquired previously basic skills in some fundamental issues as electronics, programming, control and perception systems. Table 1 describes the courses and schedules of the control knowledge curricula provided by our university to the undergraduates who major in Computer Engineering (CE) and Electrical Engineering (EE).

subject	career	year	semester	credits
Modelling and simulation of dynamic systems	EE	2	4	6 (E)
Automatic control	EE	2	4	9 (F)
Computer control	EE	3	5	6 (E)
Automatic control & systems engineering	CE	2	4	9 (F)

Table 1. Students' academic background in control training.

As it is shown in Table 1, the CE and EE students have acquired a similar background concerning about the basic classical control theory in continuous-time (Ogata, 1993; Kuo, 1996). However, it is not a homogeneous aspect and some discrepancies arise from the difference in academic profiles. For example, additional knowledge is given to the EE students through some advanced materials in control theory (Ogata, 1996; Aström and Wittenmark, 1988), while CE students show obviously better experience in their programming skills. The above discrepancy in educational background is solved by providing to students a self-guided lab practice manual that includes the theoretical fundamentals of the summer course.

In this context the student's evaluation is developed by considering the educational background within the different proposed practices. Hence, basic and advanced practices are evaluated by considering the previous level of the students. The correctness of the solutions and their independence and decisions are also contemplated within a continuous evaluation laboratory process. Hence, as i.e., the CE students successfully pass the control teaching block when they deal properly with classical PI design issues. Moreover, other complementary knowledge attained as discrete time systems is used to improve student assessments.

2.2 Mobile robotic platform

The mechanical structure of the robot PRIM, shown in Fig.1, is made of aluminium, with two independent wheels of 16cm diameters actuated by two dc motors.

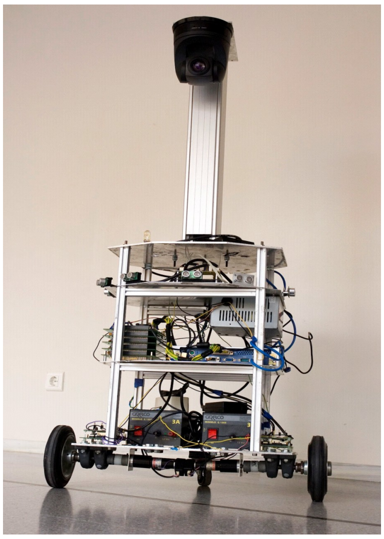


Fig. 1. Mobile robot educational platform PRIM

The distance between two wheels is 56.4cm. A third spherical omni-directional wheel is used to guarantee the stability of system. The maximum continuous torque of each motor is 131mNm. The gear reduction proportion for each motor is 86:1 and thus the total force actuating on the robot is near 141N. Shaft encoders with 500 counts/rev are placed at the motor axes, which provide 43000 counts for each turn of the wheel. A set of PLD (programmable logic device) boards is connected to the digital outputs of the shaft encoders. The printed circuits boards (PCB) are used to measure the speed of each motor at every 25ms. Another objective of these boards is to generate a signal of 23khz PWM for each motor. The communication between the central digital computer and the boards is made through the parallel port. The speed is commanded by a byte and thus it can generate from 0 to 127 advancing speed commands. The maximal speed is near 0.5m/s. A set of microcontroller boards (MCS-51) is used to read the information available from different connected sensors. The distance between objects is provided by an array of 8 sonar sensors, which are based on ultrasound sensors within a range of measurement from 3cm to 6m. The data provided by these boards are gathered through the serial port in the central computer based on a VIA C3 EGBA 733/800 MHz CPU running under LINUX Debian OS. The rate of communication with these boards is 9600 b/s. An absolute counter provides the counts in order to measure the robot position by the odometer system.

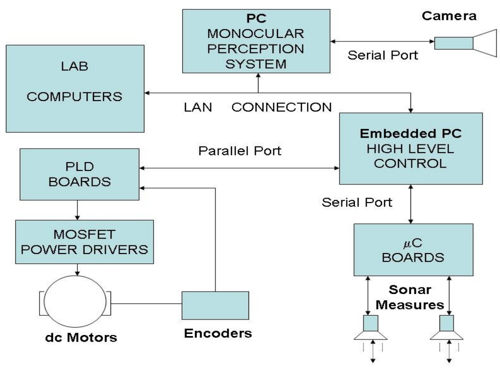


Fig. 2. Sensorial and electronic system blocs.

Fig. 2 shows the electronic and sensorial system blocks. The data gathering and control by digital computer are set to 100ms. The proposed educational open hardware has its advantages in many aspects. First, the use of a structure similar to that employed by students at the laboratories can enable their easy understanding and prototyping of a new hardware of low level. Furthermore, the reinforcement of the teaching activities can be achieved through the knowledge integration of different subjects. The system flexibility is increased with the possibility of connecting it with other computer systems through a local LAN. Hence, in this research a network server has been implemented, which allows the different lab groups to make their remote connection with the mobile robot during different practices. The use of a PC as a high level device is presented from two different points of view, consisting in PC high level programming by using VBASIC language and the TCP/IP protocol net knowledge that allow running on-robot LINUX created functions by the use of the laboratory LAN. Thus, lab personal computers become a flexible and easy tool that allows communicating with the on-robot hardware real-time devices by the use of WIFI connections. Hence, the students can remotely command the robot speed or set up the PID parameters, and read the robot position, orientation, velocities, or measures of the sonar sensor, during the different proposed practices. Another possibility by connecting an additional computer consists in increasing the sensing capability of the robot, which can be used for instance as a machine vision system.

2.3 Framework of the summer course

The summer course was developed during two weeks in July, with 4.5 hours everyday. It consists of the theoretical (T) and laboratory (L) sessions, related to the following different topics:

- DPED: Design and Programming of Electronic Devices;
- MCS: Modelling and Control Systems;
- TPC: Trajectory Planning and Control;
- CVS: Computer Vision System.

The schedule of the course is shown in Table 2.

First week

Time	M	T	W	T	F
8:30-11:00	Welcome+ DPED (T)	DPED (L)	DPED (L)	MCS (L)	MCS (L)
Coffee break					
11:30-13:30	DPED (L)	DPED (L)	MCS (T)	MCS (L)	MCS (L)

Second week

Time	M	T	W	T	F
8:30-11:00	MCS (T+L)	TPC (T)	TPC (L)	CVS (T)	CVS (L)
Coffee break					
11:30-13:30	MCS (L)	TPC (L)	TPC (L)	CVS (L)	Final demo

Table 2. Framework of summer course.

The DPED bloc presents the robot architecture and the PLD and mp use. Thus, the first lab PLD practices are addressed to design digital PWM, absolute pulse counter, or robot velocity bloc by using a function generator instead of incremental encoders. The port parallel protocol is also suggested as an additional work. In the second day, it is introduced the mp environment by practicing with the serial port, AD converter or PWM generation. Finally, by using high level language from the PC labs, students can learn about how to use the created functions to realize the remote inter-actuation with the robot sensors and actuators. The MCS bloc presents the concerned basic control theory related to experimental modelling, classic PID controllers design and optimal observers. Students try to obtain the model experimentally, make the controller design on the computer by using the MATLAB program and validate finally the results on the robot. The TPC bloc studies the strategies of trajectory planning as well as trajectory tracking by using techniques of speed control or model predictive control (Maciejowski, 2002; Camacho and Bordons, 2002). The most important practice consists in implementing a high level program code that performs a reactive navigation using the sonar sensor measures. Finally, the last bloc introduces the computer vision as an advanced perception system that can improve the robot environment knowledge. The summer course ends by performing some robot demos to show the main issues dealt with in the course. It should be pointed out that due to the limited time of the course it is very difficult to give students profound knowledge training. However, the students are capable of learning from the course about how to face up and solve real problems, especially through a portable methodology that integrates multiple topics of higher level's reasoning.

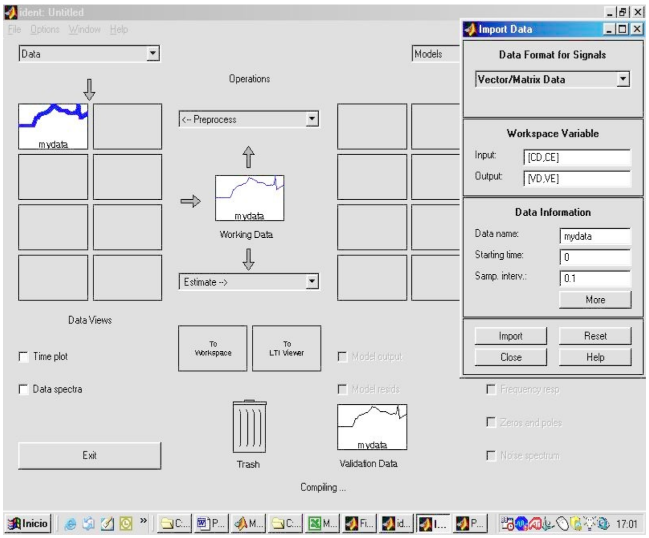


Fig. 3. System identification toolbox of MATLAB.

3. DESCRIPTION OF LAB PRACTICES

The first lab control practice begins with the experimental parametric model identification (Lju, 1989; Van Overschee and Moor, 1996). Hence, the model is obtained by sending different PRBS (Pseudo Random Binary Signals) to the robot for the low, medium and high speeds. The students select the adequate speed model and load the experimental data to MATLAB environment. Each data group has 5 different arrays containing the time, right consign, right velocity, left consign and left velocity, respectively. Then, they obtain the time response of the inputs and outputs. The system identification is carried out by using the MATLAB toolbox "ident" (as shown in Fig.3), selecting a second-order ARX model and importing the necessary workspace data that should be identified. Tendency suppression and data filtering are suggested. The obtained complete MIMO discrete-time model will be used by students for validating the control effectiveness.

The second practice consists in finding a simplified robot model. The continuous-time model is introduced into the SIMULINK environment, as shown in Fig. 4. Several studies concerning about the importance of coupling terms are carried out by students through the analysis of stationary gains, while the order reduction is done by searching for dominant poles. The students learn from the obtained results that the MIMO model can be approximated by two SISO models.

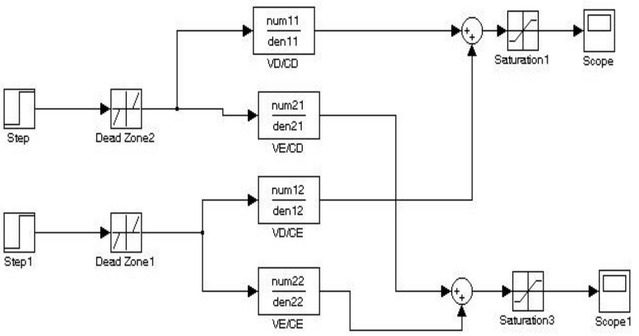


Fig. 4. MIMO robot model in SIMULINK environment.

The third practice consists in obtaining a controller based on the simplified SISO models. The students will try to make the controller design by using the pole placement techniques and the MATLAB design facilities.

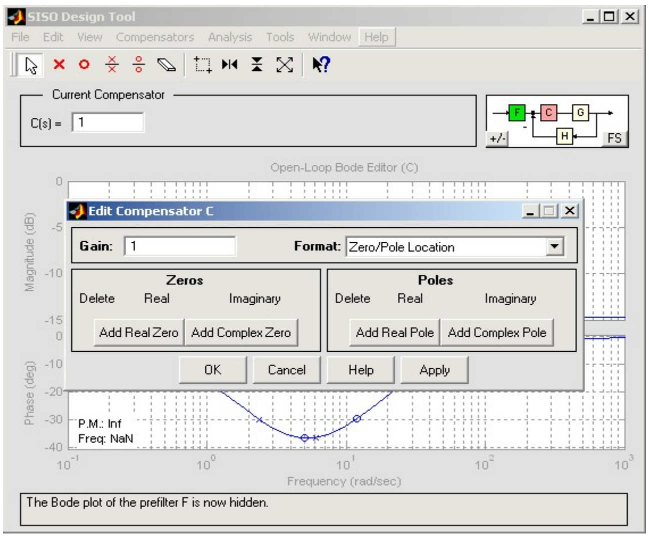


Fig. 5. "sisotool" design window.

For instance, students can use the MATLAB "sisotool" (as shown in Fig. 5) to design the controller by importing first the transfer functions corresponding to both robot wheels. Then, they depict the open loop frequency response without compensator. Afterwards, students learn to add a PI controller to the system in order to achieve the desired response.

The control performance is verified by using the complete MIMO model of the robot in the presence of several perturbations. The students will analyze the uncontrolled and controlled system response. The advanced students are also encouraged to consider the case in which the measurement noise is involved. Kalman filter is designed based on the model knowledge and is implemented in SIMULINK environment, as shown in Fig. 6.

The on-robot speed control is a subject of the last MCS practice. The students transform firstly the controller from continuous to discrete time. Then, they use the robot remote network server to send the controller parameters to the robot in order to test the speed control performance.

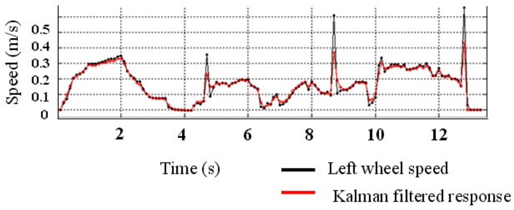
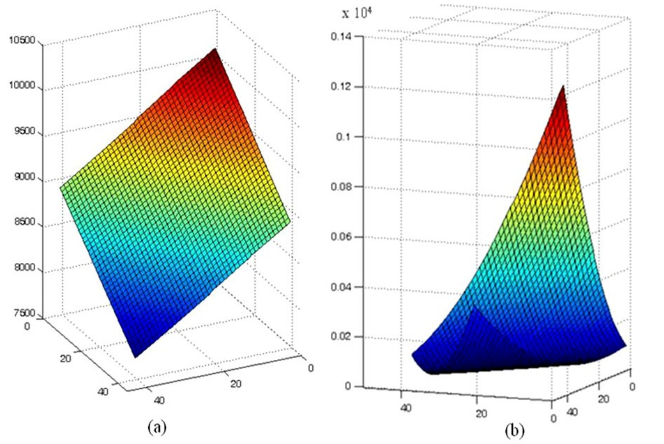


Fig. 6. Estimated left wheel output after Kalman filtering.

TPC theory introduces the trajectory planning techniques through the concepts as C-space and robot wide-path (Schilling, 1990). The path planning approach consists in following a sequence of straight lines and considering the vertex of obstacles and the desired final configuration (Pacheco and Luo, 2007a). Thus, the trajectory tracking can be performed through either straight lines following or turning actions (Reeds and Shepp, 1990). The trajectory control tracking is attained by introducing discontinuous control laws and MPC methods. The discontinuous control approaches are presented to students as an in-lab robot demo, while the MPC strategies are simulated at the laboratory by using the methods and software developed by our teaching members participated in the course (Pacheco and Luo, 2007b). In the MPC design, students will try to find the optimal input sequence taking as design parameter the input constraints, prediction horizon, and cost function weights. The MPC simulation software provides to students a set of files and facilities to draw the results, and consequently the students can represent the files containing the cost function values, for different available set of inputs, corresponding to different moments of the simulation.

Fig. 7a shows the computation of optimal cost using the complete input search and gradient descent approaches. When the cost function has a unique minimum, both approaches provide some similar performances during the acceleration or des-acceleration actions of the robot. From Fig. 7b, it can be seen that the complete input search and gradient descent methods may provide discrepancies when local minimum exists. Fig. 8 shows the simulated results for the trajectory tracking of a 2m straight line with two prediction horizons: 1s, n=10 (in red) and 0.5s, n=5 (in blue).



(a) (b)

Fig. 7.

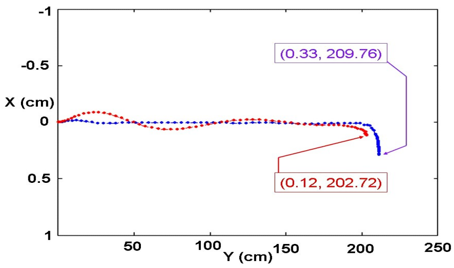
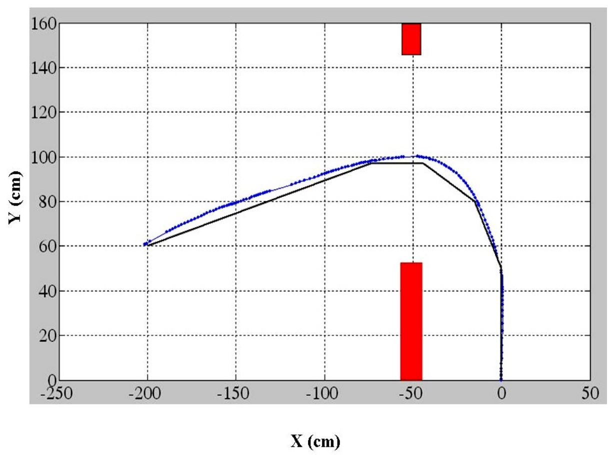
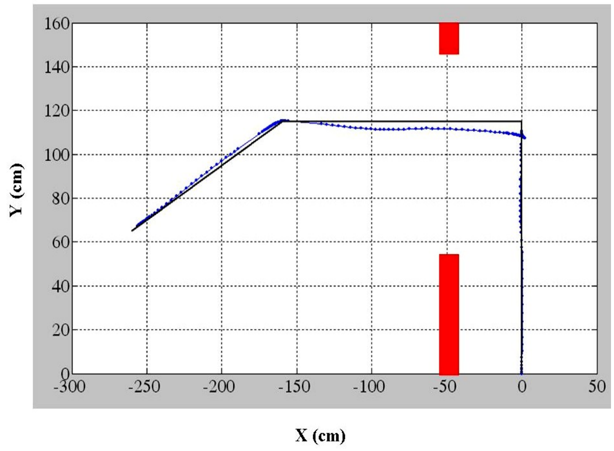


Fig. 8.

The final TPC practice consists in implementing a high level program code for achieving the reactive obstacle avoidance, in which the students should avoid obstacle collisions by sending the speeds commands to both wheels of the robot by means of sonar sensor measures. The CVS teaching bloc introduces to students some applied aspects as colour constancy and image energy filters (Horn, 1998; Pacheco et al., 2007). The course ends with final demonstrations concerning about the trajectory tracking and advanced perception features. Hence, the reactive behaviour in obstacle avoidance and meaningful coloured object tracking by using machine vision systems are shown. The accuracy of trajectory tracking using MPC technique is also discussed.



(a)



(b)

Fig. 9. (a) The robot moves always is advancing sense. (b) The robot turns around itself.

Fig. 9 shows the experimental results obtained when the robot of 35cm wide-path passes across a lab door of 80cm width.

4. CONCLUSIONS

The teaching experience gained from the summer course has shown the usefulness of the mobile robot as an important experimental platform for control education. The course framework has allowed a different level of knowledge learning according to the students' academic background. Various control techniques have been provided to students as a main issue in order to improve the robot behaviour. They can acquire a higher level of skills by integrating different subjects related to electronics, control system, computer science, communication, etc. Students with advanced control skills have been given the opportunity to familiar with some advanced control techniques as Kalman filter or MPC techniques. It should be mentioned that the developed lab practices related to the theoretic counterparts have greatly increased the motivation of the students and have achieved the multidisciplinary knowledge consolidation of the proposed objective of control education. According to the students' feedback to the course, the average opinion of 27 students about the summer course is 4 over 5. They remark the interests and attractive educational and practical aspects as the relevant characteristics of the course. One of the suggestions is to augment the course hours in order to perform better the theoretic analysis, lab practices and algorithm implementation. Nowadays, the teaching staffs from different research areas are promoting the evolution and consolidation of the course as an optional subject proposed during the normal teaching calendar and increasing the total number of hours. Authors are also opened to transmit their experience to the international educational community.

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