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Low-Cost Mobile Robotics Platform for Active Teaching

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***Abstract* – This paper describes a series of projects developed for a Real-Time Control course addressed to CS and EE students. The objective of this work is to show the realization of robotics experiments using low cost hardware. During the course the students are immersed in a realistic design environment, where they can strengthen the theoretical principles while improving their abilities to think, analyse, and solve problems using "learning by doing" approach.**

I. INTRODUCTION

A laboratory activity is a fundamental part of the learning process since students can put into practice both technical and theoretical knowledge [1], while increasing motivation and cooperation attitude which prepares them better for future jobs. In this context, more and more often laboratory activities are included in academic courses addressed to engineering students so as to improve their abilities to think, analyse, and solve problems [2]-[5]. It is necessary to motivate the students and give them the opportunity to acquire new knowledge supporting them to achieve relevant and meaningful goals [6]. To this aim, competition-based education can generate great benefits for the students stimulating their creativity [7], [8] and the possibility to develop a work that can be presented at a large audience gives them great satisfaction [1].

Robotics is a typical interdisciplinary discipline used in engineering courses to introduce students to different aspects of science and technology. For examples, the authors in [9] present laboratory exercises to give students hands-on experience in robotic manipulator, computer vision, artificial intelligence and mechatronics areas. An application of controlling an educational robotic arm with a computer vision system in a simulated industrial environment has been presented in [10] whereas multimedia information are also used to control mobile robots in [11]. Internet-based controls of robot arms have been implemented in a control engineering courses in [12], [13].

The aim of this paper is to present the experience of two years of the course "Process Control" addressed to students of the fifth year of the degree course in Electronic Engineering and Computer Science Engineering, University of Sannio. Unlike the classic concept of a university course based on lectures where the role of the student is passive, in this course we used an approach "Project-based" or based on the "learning-by-doing" methodology, where the student takes actively part to the process of transfer and acquisition of knowledge. The project-based Learning Approach has the goal of stimulate students to conceive, design and implement a real experiment. With this method we encourage to develop a critical "Problem Solving" attitude, to improve their management skills and to discuss communication issues arising from work in teams.

The concept of integration between disciplines is fundamental indeed: in addition to automatic control. All projects require the use of concepts of electronics, physics, mechanics and computer science. The course takes place in the second half of the year and is divided into three two-hour lessons a week, over a ten-week total. The first lessons, organized as seminars, are used to both refresh and deepen various control techniques, and to present the hardware available in the laboratory, highlighting their key features. Afterwards groups are formed, preferably with a maximum of two people each, which propose a project and analyze its feasibility. Projects must achieve two fundamental objectives: use at least one control technique and physically implement one of the goals proposed by the students along the way.

The individual projects are very different from each other. For the final evaluation such aspects were used as difficulty of the project, originality of solution, team integration and final presentation for extensive tests on mobile robots.

The main difficulties are caused by space problems because the labs are (relatively) small, by the time students have at their disposal, and by economic problems, because they use material with limited hardware and low cost. For each project, the team consists of two students except in one.

The course took place in the academic years 2012-2013 and 2013-2014, the following describes the projects developed and implemented by the students and the results achieved.

Fig. 1. The Ruzzle-arm project.

II. PROJECTS

A. *Ruzzle-Arm*

This project, consisting of a robotic arm which plays the Ruzzle game on mobile device in a fully automatic way, was developed by two Computer Science students. The screenshot of a device is processed and the corresponding letter are extracted; once the letters are available, they are used for compose the trajectory on the mobile device.
The most important learning topics are:

- An Image acquisition and OCR (optical character recognition) for capturing single letter. The grid with the letters in the Ruzzle game has to be first captured through screenshots to the Android tablet, and then manipulated in order to extract letters and bonuses and recognize specific screens
- A *branch and bound* algorithm to optimize the tree search procedure on acyclic graph. This solving algorithm have been used to compose every admissible word with the feature that sequences of letters that are not prefix of longer words are not analysed in order to speed up the search;
- A trajectory planning algorithm to make the robotic arm compose the word on the tablet, using *inverse kinematics*. Given a recognized word to be entered in the Ruzzle app and given the coordinates of each letter in the game grid, a trajectory planning algorithm is executed to command the robotic arm and compose the word on the tablet.

The arm is mounted on a mobile platform and is build with reused hardware. The students have achieved excellent results and this work has been published[14].

B. *e-puck formation*

This experiment was presented by three students and describes a formation of equilateral triangle configuration of three e-puck mobile robots based on centralized control.

Learning topics:

- Unicycle and kinematics model for describes e-puck robotics. The e-puck robot consists of a circular structure with two independent wheels on the diametral axis. This structure can be mathematically described by *unicycle model*. The velocities of wheels were the variables of the kinematics equation used for describing the robot movement in cartesian plane.
- Webcam and Image acquisition technique as a feedback for the control system. The coordinates of the colored circles represent the position of the three robots, while the coordinates of the black circles are used with the previous to determine the orientations.
- Several control techniques are available to handle this kind of non linear system. They are used *feedback linearization* control that simplify the stabilization problem.
- Trajectory planning was used for controlling the robots in such a way to form an equilateral triangle avoiding the collisions. The reference coordinates for the three robots were computed through geometrical roles.

The Fig. 2 shows the initial and the final configuration of the robots, the colored circles identify the single robots, while the coordinates of the black circles are used to determine the orientations. The position of the webcam is at the center of the plane and approximately one meter from the ground.

Students initially found some difficulty with the e-puck platform. The only cost of the project was the workbench because the e-puck have been bought previously.

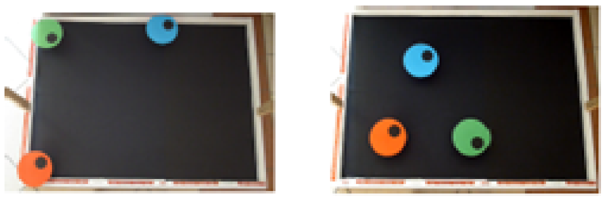

Fig. 2. Initial and final configuration of the 3 e-pucks

C. *AGV's Cooperation*

In this project the students designed and implemented an Automatic Guided Vehicle Cooperation (AGV) to mimic an industrial production/distribution center with two "LEGO MINDSTORM NXT" robots. There are M-production establishments and N-stores that are served by two AGVs vehicles that collaborate with each other in order to optimize the transportation problem.
The most important problems solved in this project are:

- Control of the mobile robot on the path using line following, where thy are used *Ziegler-Nichols* method for estimate the parameters of PI controller

- Transportation problem can be solved with *Simplex Method*, that operates on linear programs in standard form
- The pattern was composed by three source nodes, six intermediate nodes to represent the crossroads and three destination nodes. All nodes are connected through edges with different non-negative costs. They are used *Dijkstra's algorithm* for solve the shortest path problem on the pattern.
- Create a cooperative protocol between robots to avoid collision on the path and to work together to manage the sorting of products. This protocol was implemented using *Bluetooth* communication.

The only cost was the color sensor and the final results were good.

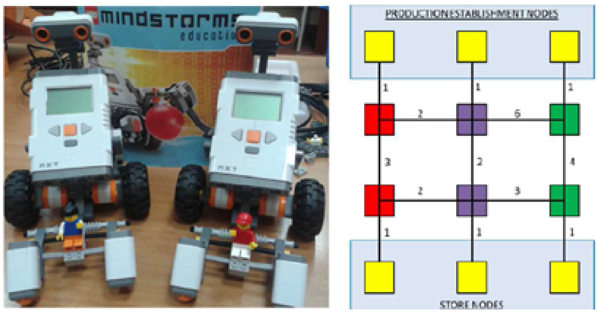

Fig. 3. Guided Vehicle Cooperation

D. *Automatic Park System*

The goal of this project is the development of an automatic park system (APS) using a low-cost skid-steering mobile robot built and a low cost embedded system (Arduino). The two most important tasks are to realize the design of a feasible reference path and the tracking of this reference in closed loop.

Learning topics:

- Use a parametric identification of dynamical vehicle system using ARX, ARMA, ARMAX model
- Design a Kinematics Two-Wheeled Model for mobile robots, supposing that the *Ackermann steering* is hold true
- To implement the parking system students do have to study the Ultrasonic sensors and the DC-motors encoders.
- Simulate and implement the algorithm for the parking planning to determine the geometry of the reference path.

The total costs are approximately 70 dollars and the final results were good.

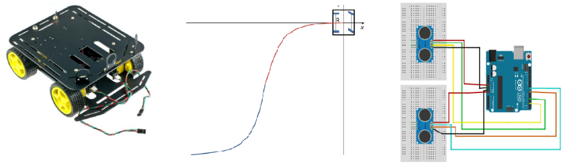

Fig. 4. Automatic Park System

E. *Sonar-Based Wall Following*

The aim of this experiment is to build a mobile robot maintaining a costant distance to a wall on the side using ultrasonic sensor. The detection of a wall by the sensors activates the controller which simply attempts to align the robot with the wall at a specified reference distance. Once aligned, the robot follows the wall and attempts to maintain alignment by compensating for lateral slippage. Also, in this case, the platform of mobile rodot is Arduino-based

Learning topics:

- Use average speed check system based on ultrasonic sensors for identification of vehicle.
- Study of *Skid-Steering Mobile Robot*. For a skid-steering robot there is no steering mechanism and motion direction is changed by turning the left and the right side wheels at different velocities thanks to a non zero lateral slippage. Design a model of Skid-Steering mobile robots,suppose that the Ackermann steering is hold true
- Build model, simulation and implementation of wall-following problem. The robot needs to maintain a constant desired distance from a wall. For measurements the distance they are used two ultrasonic sensor placed in lateral position
- Use the above models as the beginning of a new project based on platoning between two vehicles, where a robot follows another with the fixed distance.

In this project have been used very similar hardware to the project "Automatic Park System", also in this case the final results are good.

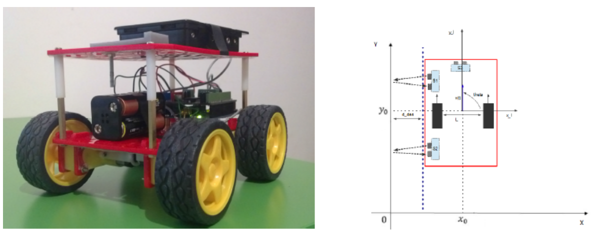

Fig. 5. Sonar-Based Wall Following

F. *Optimal Pathfinding*

The objective of this work is implementing Optimal path-finding based on search of the minimal cost path between two points using an E-Puck robot. The robot has to reach the final destination, starting from a known point, avoiding possible obstacles. The position of the obstacles is "a priori" unknown. In order to solve this problem, a webcam is integrated in the system to permit image acquisition of the whole working area

- Image acquisition and processing for recognizing the working area with robot and the position of the obstacles
- Implementation of graph shortest path as Breadth-First Search, Dijkstra and A*.
- Build model, simulation and implementation of wall-following problem
- Model and control of e-puck robot

In this case the total cost was null because they are reused the hardware of the e-puck formation project described above.

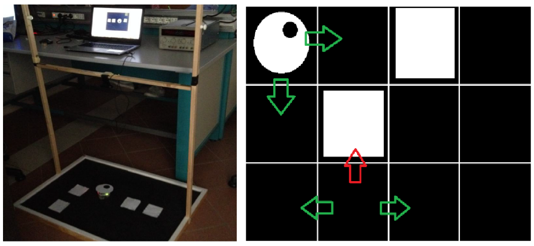

Fig. 6. Optimal Pathfinding

III. CONCLUSION

In this paper, we described several projects using Low-Cost Mobile Robotics Platform for a Real-Time Control course addressed to CS and EE students. The objective of the projects is the development of a completely autonomous mobile robots using "learning by doing" approach. The hands-on experience has been appreciated by the students and has contributed to consolidate their knowledge in different topics and fields.

REFERENCES

[1] X. Paneda, D. Melendi, S. Cabrero, R. Blanco, R. Garcia, and A. Rodriguez, "Three techniques for competitive lab activities based on project-oriented learning in information and communication technologies," Tecnologias del Aprendizaje, IEEE Revista Iberoamericana de, vol. 8, no. 1, pp. 39-46, 2013.

[2] S. Jung, "Experiences in developing an experimental robotics course program for undergraduate educa-

[2] S. Jung, "Experiences in developing an experimental robotics course program for undergraduate education,"Education, IEEE Transactions on, vol. 56, no. 1, pp. 129-136, 2013.

[3] A. Price, R. Rimington, M. Chew, and S. Demidenko, "Project-based learning in robotics and electronics in undergraduate engineering program setting," in Electronic Design, Test and Application, 2010. DELTA' 10. Fifth IEEE International Symposium on, 2010, pp. 188-193.

[4] Y. Ugurlu and T. Nagano, "Project-based learning using labview and embedded hardware," in System Integration (SII), 2011 IEEE/SICE International Symposium on, 2011, pp. 561-566.

[5] L. G. Huettel, A. S. Brown, K. Coonley, M. Gustafson, J. Kim, G. Ybarra, and L. Collins, "Fundamentals of ece: A rigorous, integrated introduction to electrical and computer engineering," Education, IEEE Transactions on, vol. 50, no. 3, pp. 174-181, 2007.

[6] R. Schark, T. Berman, and K. Macpherson, Learning by doing. London, UK: Routledge, 1999.

[7] R. Murphy, "Competing for a robotics education," Robotics Automa- tion Magazine, IEEE, vol. 8, no. 2, pp. 44-55, 2001.

[8] J. Tauer and J. Harackiewicz, "The effects of cooperation and competition on intrinsic motivation and performance," J. Pers. Soc. Psychol., vol. 86, no. 2, p. 849-861, 2004.

[9] E. Krotkov, "Robotics laboratory exercises," Education, IEEE Trans- actions on, vol. 39, no. 1, pp. 94-97, 1996.

[10] T. Cabre, M. Cairol, D. Calafell, M. Ribes, and J. Roca, "Projectbased learning example: Controlling an educational robotic arm with computer vision," Tecnologias del Aprendizaje, IEEE Revista Iberoamericana de, vol. 8, no. 3, pp. 135-142, 2013.

[11] T. Kikuchi and T. Kenjo, "Developing multimedia training materials for use with small robot controls at chubu polytechnic center in japan," Education, IEEE Transactions on, vol. 39, no. 3, pp. 349-356, 1996.

[12] M. Wu, J. hua She, G.-X. Zeng, and Y. Ohyama, "Internet-based teaching and experiment system for control engineering course," Industrial Electronics, IEEE Transactions on, vol. 55, no. 6, pp. 2386-2396, 2008.

[13] M. Murtra, G. Jansa, H. Martinez, J. Domingo, J. Gamiz, and A. Grau, "A proposal of remote laboratory for distance training in robotic applications," in Emerging Technologies and Factory Automation, 2007. ETFA. IEEE Conference on, 2007, pp. 1180-1187.

[14] D. Meola, G. Siano,L. Glielmo, "Ruzzle arm: A low cost educational application in Real-Time Control course", European Control Conference (ECC), 2014, pp. 844-849.