A Contest-Oriented Project for Learning Intelligent Mobile Robots

Hsin-Hsiung Huang, Member, IEEE, Juing-Huei Su, Senior Member, IEEE, and Chyi-Shyong Lee

Abstract—A contest-oriented project for undergraduate students to learn implementation skills and theories related to intelligent mobile robots is presented in this paper. The project, related to Micromouse, Robotrace[1], and line-maze contests was developed by the embedded control system research group in the Department of Electronic Engineering, Lunghwa University of Science and Technology, Taiwan. It targets both those students who have to earn credits for a one-year special topics course, and those who are just interested in making robots, and is designed to motivate them to learn digital motion control, path planning, attitude correction, curvature detection and maze solving algorithms. The students begin by getting acquainted with the development environment of microcontrollers, the characteristics of different sensors, and servomotor control techniques. Having learned these basic skills, they acquire further specific advanced skills and proceed to design their own mobile robots to compete in contests. The special topics course students' robots must pass examination by five teachers. Blogs and a wiki website for recording students' progress and experiences enhance the project's learning outcomes. Although not every student wins a prize in the contests, student feedback still shows that the contest-oriented project did motivate them to acquire the skills necessary to build and operate intelligent mobile robots.

The authors are with the Department of Electronic Engineering, Lunghwa University of Science and Technology, Taoyuan County, 33306, Taiwan R.O.C.

[1] "Robotrace is the title of Taiwanese and Japanese robot races.

Index Terms—Contest-oriented project, embedded control, intelligent robots, Micromouse, Robotrace

I. INTRODUCTION

Robots are playing an increasingly important role [1], with their use in daily life being underlined when iRobot announced the vacuum cleaning robot, Roomba, and floor washing robot, Scooba [2]. Understanding the construction and control of robots has therefore become a necessity for many electronic engineers. This poses a difficulty in that the robot design draws on many areas of knowledge, such as mechanics and electronics, automatic control theory, and software programming of microcontrollers [3]-[4]. Nevertheless, students are willing to do tedious research work to solve practical problems when these are related to an interesting, competitive contest [5]-[7]. Winning one or two awards in a competition not only gives students a sense of accomplishment but also gives their schools pride and visibility. This is an important factor for technology-oriented university students in Taiwan, who tend to have low learning achievements in traditional theory-oriented lecture courses. The original Robotrace, and Micromouse contests, in which autonomous robots compete in terms of speed and intelligence, were started about 30 years ago; because the robots' performance is still improving, these contests are still very popular with engineering students in the U.K., U.S.A., Singapore, Japan, Fig. 1a, [8], and Taiwan, Fig. 1b, [9].

(a) (b)

Fig. 1. The Micromouse and Robotrace contests in (a) Japan, and (b) Taiwan in 2011

The aim of the work described in this paper is to apply project-based learning [10] to increase students' motivation towards intelligent mobile robots. The objective is clear and simple: to win contests. Therefore, over a period of four years a contest-oriented project was organized by the authors for senior undergraduate students of the Department of Electronic Engineering of Lunghwa University of Science and Technology (LST) who are either in a one-year special topics course or just interested in making mobile robots. The course assessment is based on the students' level of effort and the performance of their robots. The first goal is to win the local line following robot contest [11] with specified non-rechargeable batteries. Having acquired the skills of sensor output calibration [12], line prediction with interpolation techniques [12]-[13], and power control of light emitting diodes (LEDs), one LST student team won the contest, breaking the speed record. Although many students are interested in line following robot contests, the most popular one [11], held by the Fortune Institute of Technology in Taiwan, was suspended after 2008 due to lack of financial support from the Ministry of Education. The Taiwan Micromouse contest [9] was subsequently chosen as a more challenging objective for the students in the project. It was in 2009, when LST held the Taiwan Micromouse and Intelligent Robot Contest, that the Robotrace contest [14] was introduced to Taiwanese students. To make the line following robot contest more challenging, the Robotrace contest gives prompts about curvature changes in the line track, and the start/stop points. The robots can therefore identify the sections of curves, length of straight lines, and even the curvature of each section. In order to be more competitive in the Micromouse or Robotrace contests, students should learn not only maze-solving flood algorithms [15], servo control of linear and angular velocities of differential wheeled robots, calibration of infrared optical sensors [16] and attitude corrections with optical sensor readings [17], but also the mechanical design of robots. Diagonal running capability and the use of gyros for a faster curve turn of the Micromouse, and the evolution from differential two-wheeled robots to four-wheel robots are among the creative innovations devised by some of the contestants to make their robots more competitive.

The authors' experience of running the contest-oriented projects and having students win some prizes enabled them to develop a three-step learning procedure, Fig. 2, for students building Robotracers, Micromouse, or line maze robots. The first step is to make students familiar with the tools that the embedded control system research group provides for designing mobile robots. These include: 1) an integrated development environment (IDE) for dsPIC micro-controllers [18], 2) rapid prototyping of mechanical parts, 3) infrared LEDs and optical sensors for maze wall or line detection, 4) gyros for measuring the angular velocity of mobile robots, 5) mathematical models for mobile robots, and 6) servo control algorithms for DC motors with quadrature encoder interfaces (QEIs).

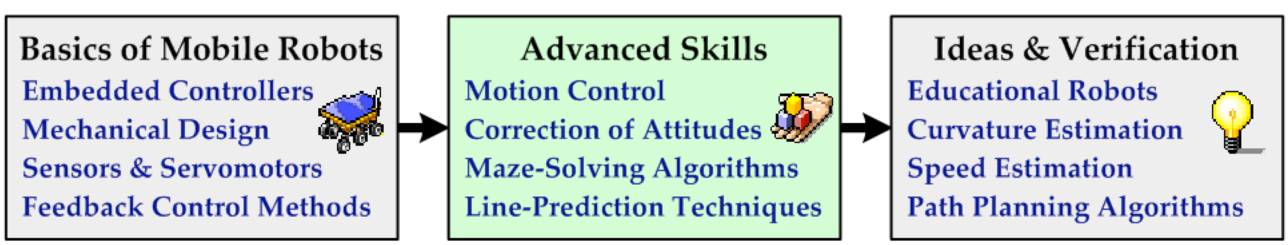


Fig. 2. The learning steps for the one-year contest-oriented project

The second step is for students to acquire the necessary knowledge to control the motion of differential driven mobile robots, and some advanced skills for Robotracers, Micromouse, or line-maze robots. Those students who prefer to design learning platforms or other intelligent mobile robot applications, can choose to design their robots for these specific applications at the final step, and participate in a creativity design contest held annually in Taiwan. The different contests require different advanced skills for their robots. For Robotrace contestants, the interpolation technique with analog output readings of optical sensors [13] is a must if the robot is to run faster than 1m/sec. The flooding algorithm [15] and diagonal running capability [16] are similarly necessary for Micromouse contestants, and the line-maze solver is critical for line-maze contestants. Since the contests are all judged on the run-time of the robots, the students can apply more creative techniques in designing their robot and find out if the ideas are effective at the final step. The robots can then evolve with advances in the related theories, microcontroller performance, and sensor technologies, which gives the contestants a lot of fun and many challenges.

Most of the students in this contest-oriented project design their own robots by themselves, although they sometimes have to discuss their problems with fellow students and with advisors in seminars. They may also ask for help in making mechanical parts with rapid prototyping machines, engraving prototype circuit boards, and implementing related theories in firmware codes. These activities form the project's teamwork environment. The project not only helps cultivate senior undergraduate students' skills in intelligent mobile robot design and control, but also delivers workshops to interested students and teachers in vocational senior high schools, as described below.

II. THE BASIC SKILLS FOR MOBILE ROBOTS

This section describes the necessary basic skills for the project's students, in using microcontrollers and sensors with interrupt-driven firmware, and in controlling dc servomotors.

A. The Integrated Design Environment for dsPIC Microcontrollers

Since the students in the project are expected to have prior knowledge of microcontrollers and programming skills, this part of the project is mainly used to familiarize students with the functions of the dsPIC microcontrollers, and with the implementation of the interrupt-driven task scheduling firmware. The local branch of Microchip Inc. supports this part of the project, providing students with C-compilers and dsPIC microcontrollers at no cost.

Students' skills in this area are tested by having them perform the following tasks on a development board, Fig. 3, developed by the authors:

1. Implement digital input control for buttons, output control for frequency based buzzers, motor position readings via QEIs, and data communication between a microcontroller and a personal computer via UART interface;
2. Implement an interrupt-driven timer firmware with user control, and display characters on a liquid crystal display (LCD), according to user input via buttons;
3. Control DC motor speed via pulse-width-modulation (PWM) technique;
4. Read analog-to-digital conversion (ADC) values from optical sensors, or gyros.

Students are given sample firmware codes for these topics so they can write their own codes faster once they have been introduced to the concepts and the practical implementation skills.

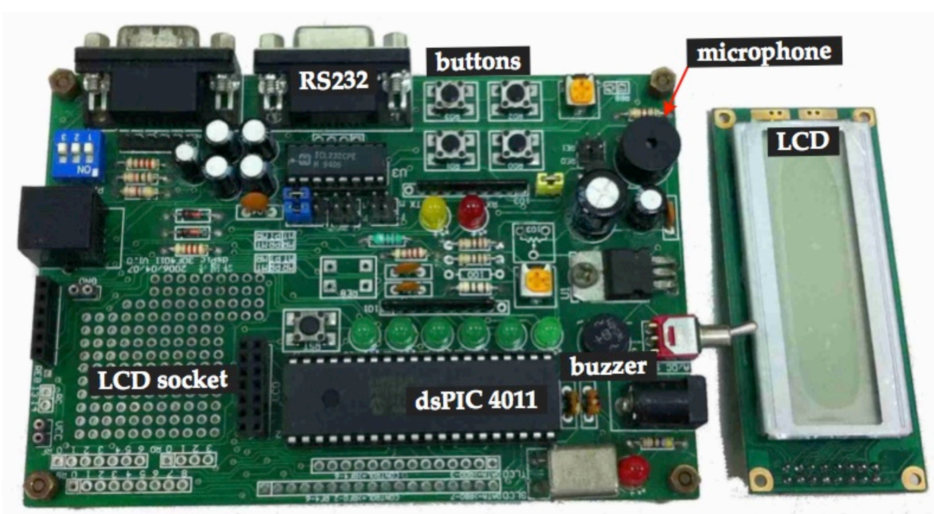


Fig. 3. The development board for learning dsPIC microcontrollers

B. Rapid Prototyping of Mechanical Parts

Recent technological advances in 3D printing have made rapid prototyping of mechanical parts possible and affordable [19], making it quite easy for students who are not mechanical engineering majors to design and assemble their mobile robot conceptually in computer-aided design software. Some of the mechanical parts of the model can then be converted and sent to 3D printers for rapid prototyping. This has been made possible by financial support from LST. Currently, students can design their mechanical parts in the Department of Electronic Engineering, and then send the model to the Department of Industrial Management for rapid prototyping, as illustrated on a Micromouse design in Fig. 4.

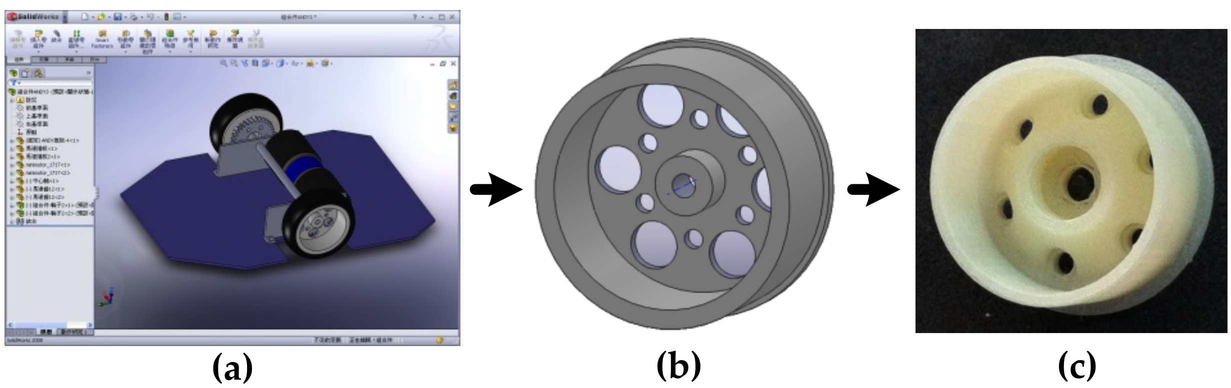


Fig. 4. The use of computer-aided design software to (a) design and assemble a Micromouse, (b) convert the wheel model for rapid prototyping machine, and (c) fabricate the wheel in industrial thermoplastic material

To make a mobile robot more compact, its printed circuit board (PCB) can be used as its chassis. A 0.8mm thick PCB chassis is strong enough to sustain the shock of hitting maze walls at a speed of 3m/sec. The Department's fast and high performance PCB prototyping machine is also made available for these students; it can automatically cut the PCB form for the robot chassis, once the students have designed the circuit to go on the board, Fig. 5.

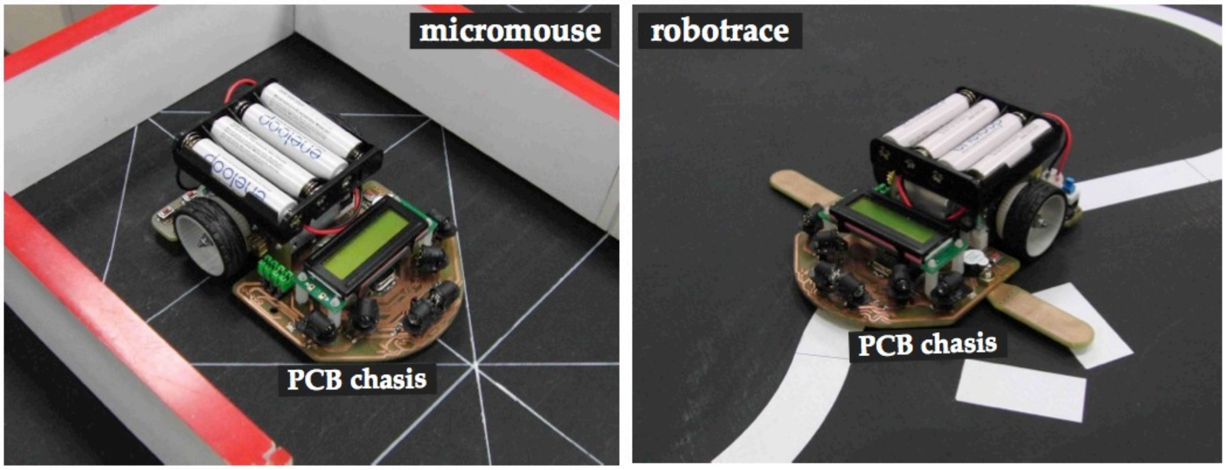


Fig. 5. The principle of using PCB board as the chassis of mobile robots

C. Sensors for Maze Wall or Line Detection

Reflective optical sensors are often used to detect obstacles surrounding robots. They can also be used in Micromouse, Robotrace, and line-maze contests to 1) find the distance between the robot and the maze walls, 2) calculate the alignment errors of the robot in a maze, and 3) predict the line track positions via interpolation techniques. Therefore, the use of reflective optical sensors is introduced in this part of the project. Students should also be aware that optical sensors might not have the same characteristics, even if they have the same part number. Therefore, the analog outputs of each reflective optical sensor should be calibrated [12], such that these output values can later be used to detect a maze wall exists, or the correct line position. The influence of transients and strong environmental light on the sensor outputs [13], Fig. 6 is another important factor that students should learn.

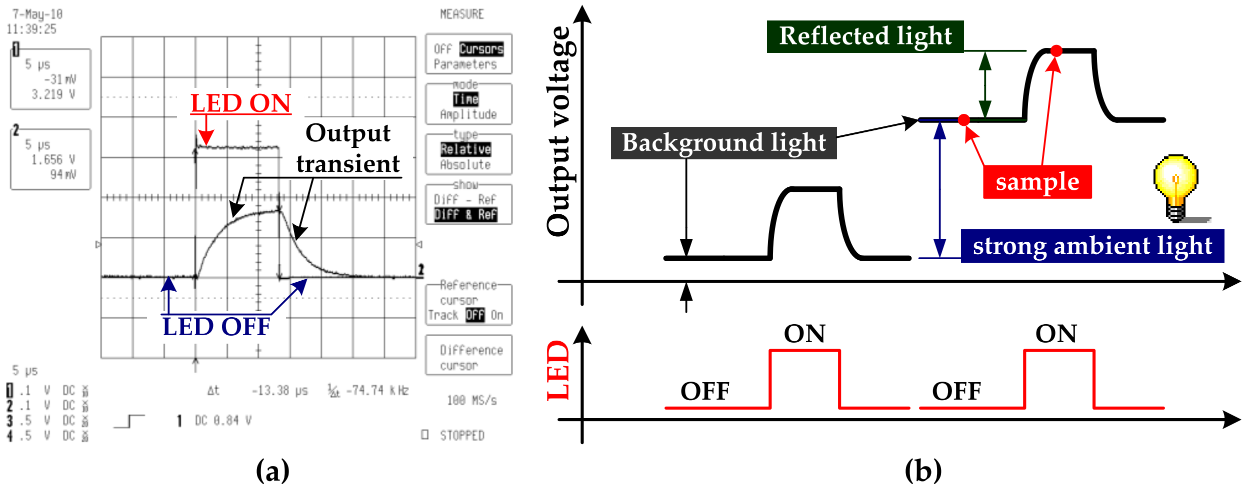


Fig. 6. (a) The output voltage transients, and (b) influence of strong ambient light on output voltage

D. Behavior Model Simulation

Computer-aided simulations help students to understand the behaviors of differential-driven mobile robots before practical implementation; the project's students use MATLAB/SIMULINK for this. It can help not only to simulate the servo control of DC motors, speed and position control of mobile robots, but also to study maze-solving algorithms. For example, the SIMULINK behavior model based on the mathematical model of DC motors, Fig. 7, can be used to learn how digital proportional-integral-derivative (PID) controllers are applied to control the angular position of DC motors through the simulation results shown in Fig. 8. The hands-on process of constructing these behavioral models can also help impress upon students, in a short period of time, the technologies to be used in their mobile robots and to be implemented as firmware codes.

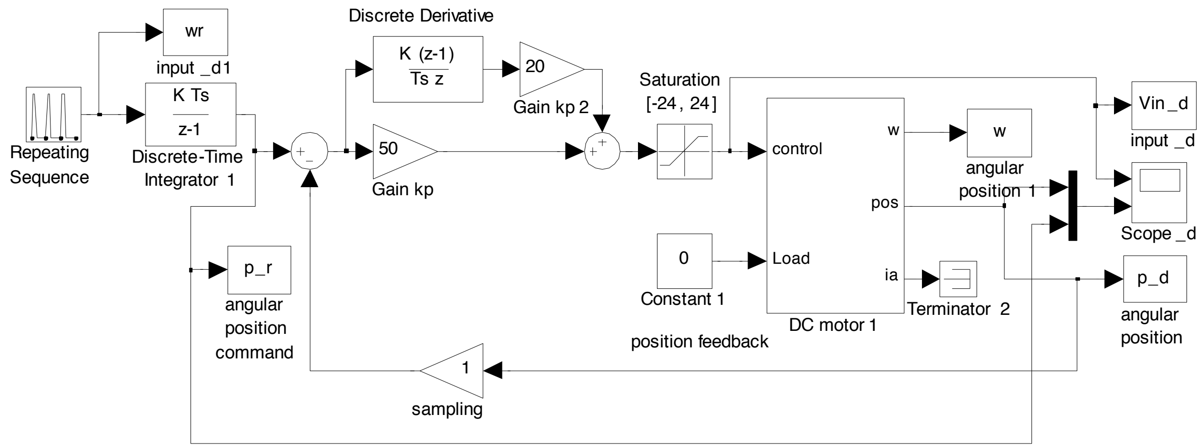


Fig. 7. The SIMULINK behavior model for simulating the angular position control of a DC motor

E. Position and Speed Control of DC Servomotors

The last basic skill for students to acquire is how to control the position and speed of DC servomotors with QEIs. The digital PID controller, and the rules of thumb learned from the behavior model simulations for adjusting its gain, will be implemented as interrupt-driven firmware codes and verified by using an H-bridge driver and PWM techniques [12]. Students should learn how to collect those control variables during the feedback control process in the data memory of embedded dsPIC micro-controllers, and then to feed these back to personal computers for analysis of the performance of the digital PID controllers. In addition to the feedback control structures introduced in this part, the ideas of fixed point arithmetic, and unit conversions for variables in mathematical models and firmware codes are also very important for students to learn in implementations.

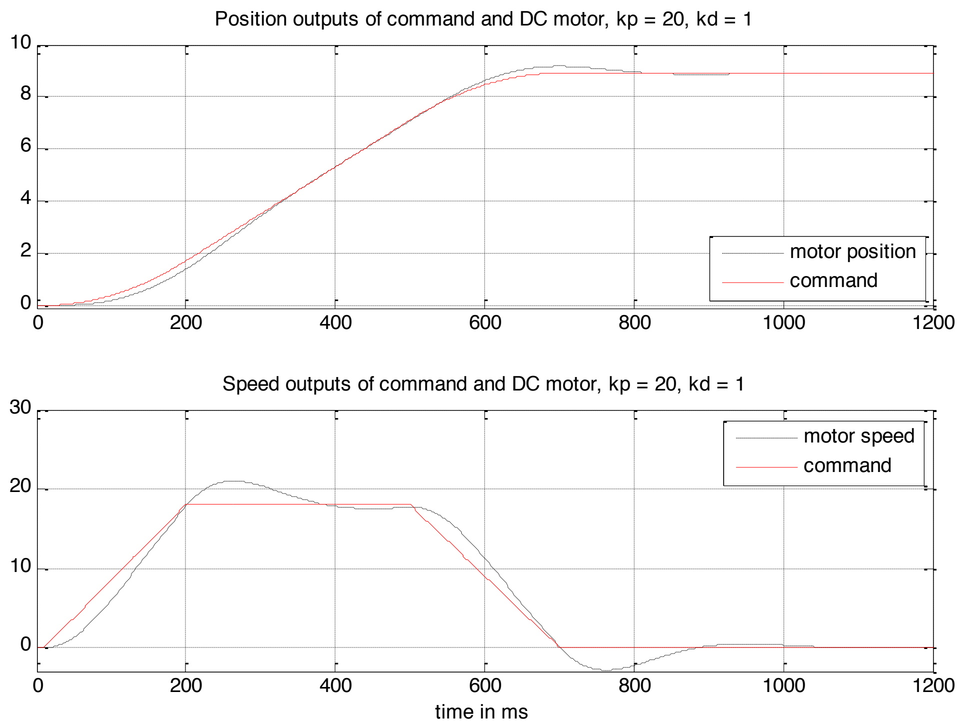


Fig. 8. The simulation results for the angular position control of a DC motor

III. ADVANCED SKILLS FOR INTELLIGENT MOBILE ROBOTS

Having learned the basics of mobile robot design, students can choose which robot contest to join, and try to acquire more advanced skills in implementing their intelligent mobile robots. Table I summarizes the advanced skills necessary for Micromouse, line-maze and Robotrace contestants. As well as being given lecture notes for the theoretical background, and sample MATLAB m-files and SIMULINK behavior models for simulations, students are introduced to experienced seniors to speed up the learning process.

Table I. Advanced skills for Micromouse, line-maze, and Robotrace contestants

Skill \ Contest	Micromouse	Line-maze	Robotrace
Motion control of differential-driven mobile robots (Linear and angular velocity)	✓	✓	✓
Interrupt-driven digital control firmware	✓	✓	✓
Attitude correction via optical sensors or gyros	✓	✓	✓
Maze-solving algorithms	✓	✓	
Smooth turn calibrations for search and fast run	✓	✓	
Line detection via interpolation techniques		✓	✓
Curvature detection techniques			✓

A. Motion Control of Differential-Driven Mobile Robots

The motion of differential-driven mobile robots can be broken into two types: straight run and curve turn [17]. Students should learn to control the linear and angular velocities of mobile robots by controlling the speeds of two DC motors with the structure shown in Fig. 9, based on the basic skill of controlling DC servo motors with QEIs. There is also an alternative to the method shown in Fig. 9, which is to control the linear and angular positions instead of the velocities. Students can compare these methods to check which one is better for motion control implementations of their mobile robots.

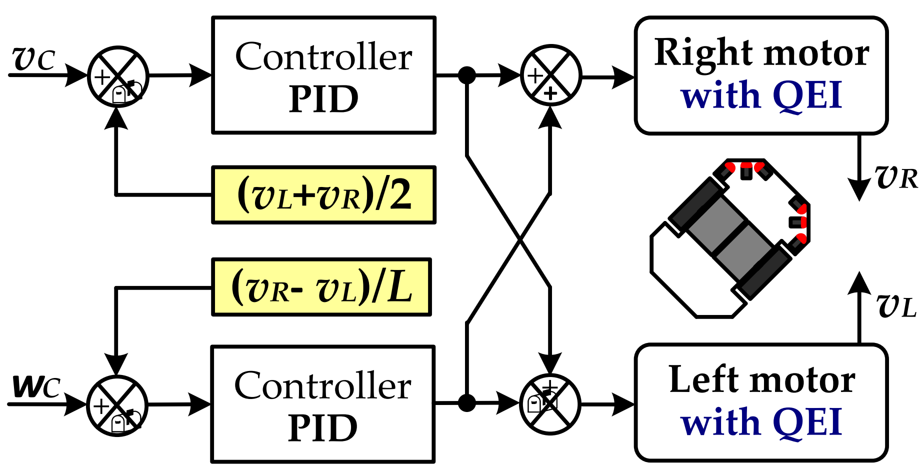


Fig. 9. The block diagram for controlling the linear and angular velocities of differential-driven mobile robots

B. Smooth Turn Calibrations for Search and Fast Run

Smooth turn capability with different speed settings is very important in the Micromouse contest, because the faster the Micromouse can take curve turns the more chance that it will win the contest. Unfortunately, for most Micromouse robots curve turns are blind [17]. The contestants therefore have to store the command profiles and the lead-in and lead-out distances in the firmware for different speed settings and curve turns. This would be a tedious job without computer-aided software to simulate the mobile robot behavior and find the correct data in practical implementations. The graphical user interface (GUI) shown in Fig. 10, and the SIMULINK behavior model in Fig. 11 are constructed and given to students to simulate the curve turn trajectory of a Micromouse running with calculated speed profiles.

These simulation programs not only give reference command profiles for various speed and curve turn degree settings, but also reveal the starting and ending positions for the curve turn trajectories. The students, if time permits, can also make their own tailored simulation programs based on the aforementioned behavior models and GUIs. The testing of parabolic speed profiles for curve turns to reduce the weight transfer effect [20] is an example of such a tailored program done by a senior student. The results of the simulations could be verified and improved later, once the students finish writing the corresponding motion control firmware codes. The verification process is very important in this project because it can help students acquire systematic ways of solving engineering problems, going from theories and simulations to practical implementations.

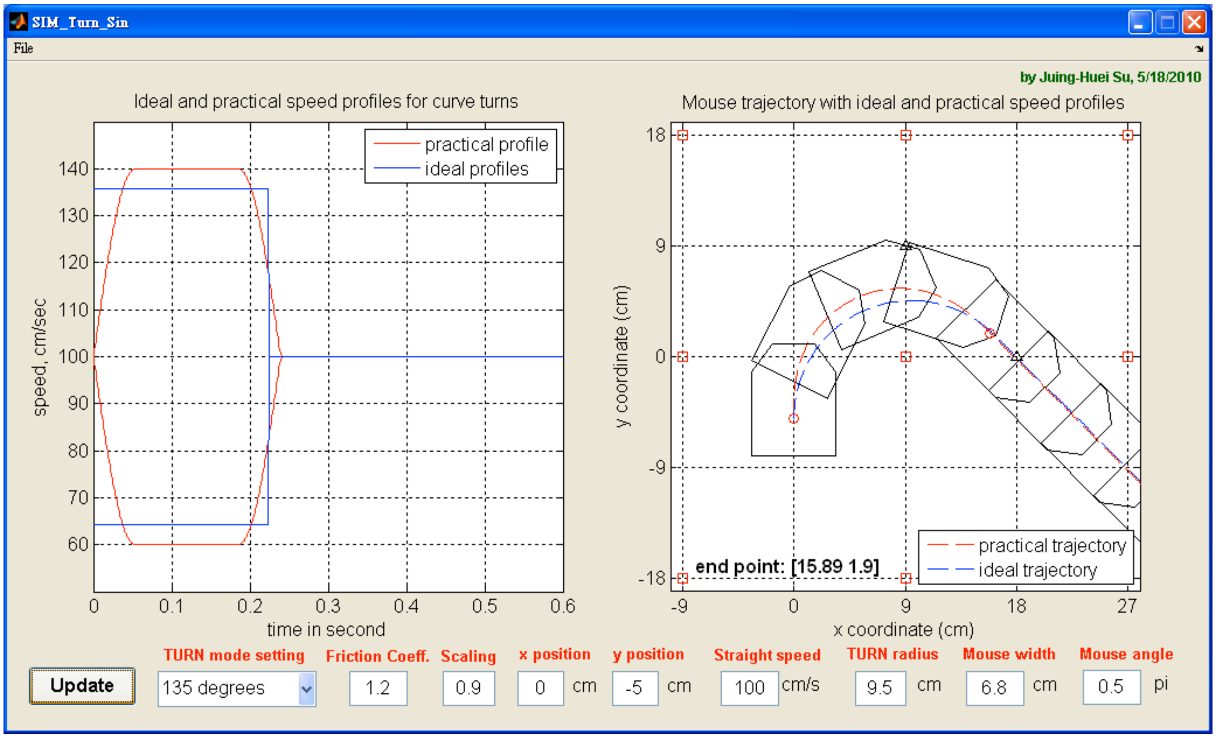


Fig. 10. The GUI used to fine-tune the curve turn trajectory of a Micromouse

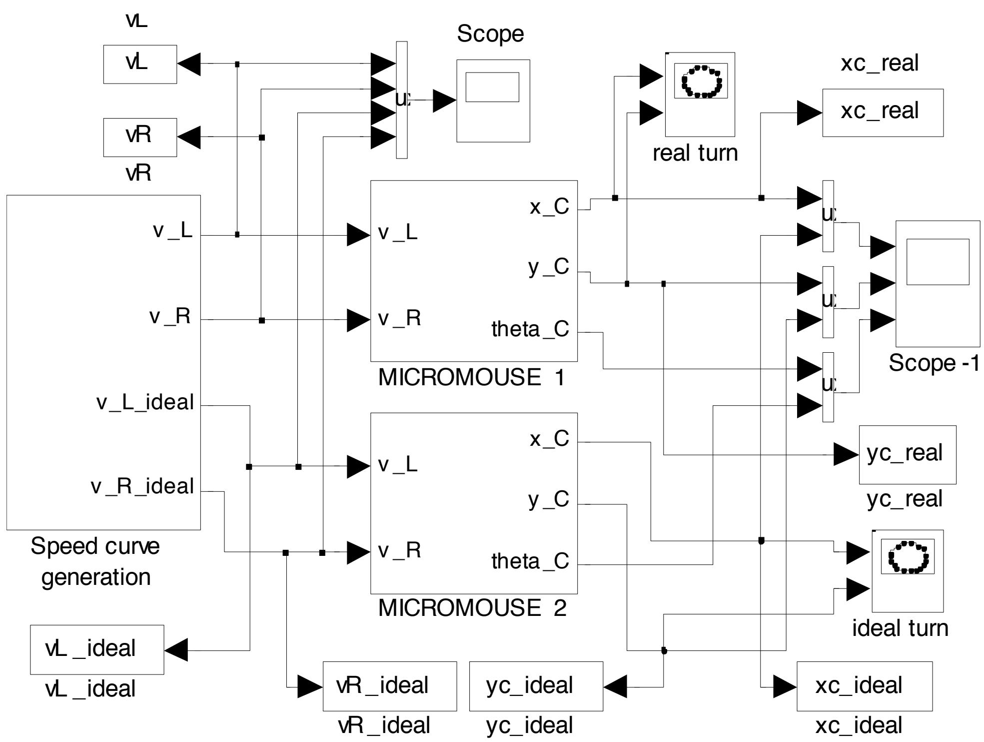
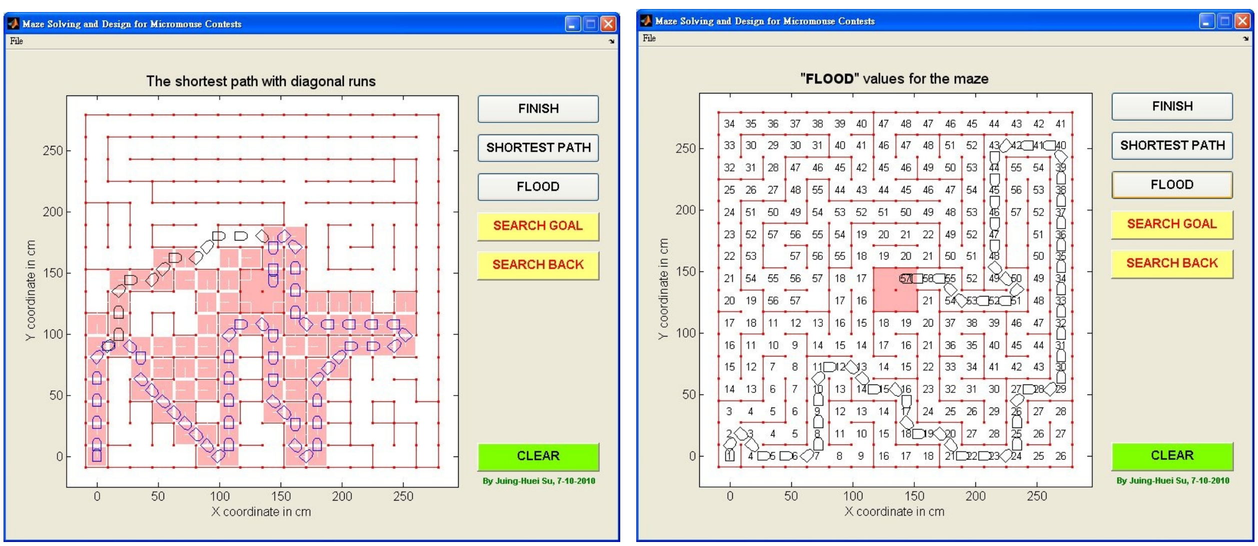


Fig. 11. The SIMULINK behavior model for simulating curve turn trajectory of different speed settings of a Micromouse

C. *Maze-Solving Algorithms*

The flooding algorithm in [15] is the most common method used for a Micromouse to search for the goal and find the shortest path in a maze. There are also some variants of flooding algorithms, which take into considerations the differences between straight runs, curve turns, and diagonal runs with different speed settings. The GUI shown in Fig. 12 and its corresponding MATLAB m-files are used to demonstrate to students how the maze can be solved via the basic flooding algorithm, whether or not the shortest path has really been found, and how diagonal paths are constructed in a given shortest path. The GUI is based on the simplest version of the flooding algorithm in [15], and students can develop their own variants of flooding algorithms or other maze-solving methods by putting their codes into the simulation m-files for verification in the GUIs.



(a) (b)

Fig. 12. The graphical user interface in MATLAB/SIMULINK used to demonstrate (a) how the goal cell is searched for, and (b) how the shortest path is found by using flood algorithms

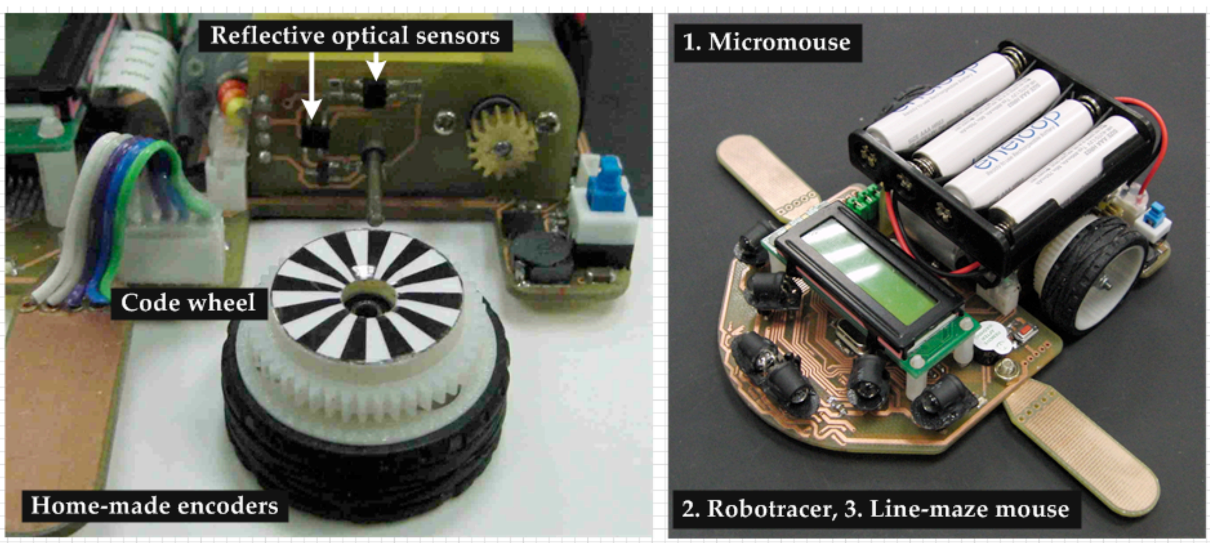
D. *Line Detection Via Interpolation Techniques*

To detect the line in racing tracks, most people use two or more reflective optical sensors [21], with the outputs of these sensors being fed to comparators with predefined threshold trigger values to get the corresponding digital information. Although this approach is effective in detecting the line, the analog information in the reflection rate of the floor and the line which indicates whether or not the sensor is right on the line is lost [12], [13]. Therefore, the idea of line detection via interpolation is presented in [12], [13], such that the line position can be estimated much more accurately than with previous approaches. Linear, quadratic, and center of mass interpolation methods [22], [23] are some of the approaches worth trying by students. They should also learn the influences of the distance between optical sensors and the height of sensors above the ground on the estimation results. The new approach recently proposed by BengKiat Ng [17] in the Robotracer Ning3, which uses inclined optical sensors at the front of the robot for fast line detection, is valuable for students to learn.

IV. ASSESSMENT, CONTESTS, AND FEEDBACK

The students finish their project in one of two ways. If they are in the one-year special topics course, they must compile all the ideas obtained from lecture notes, sample codes, and simulation programs that they encountered in this intelligent mobile robot project, and then write the corresponding interrupt-driven digital control firmware codes by themselves or with team members. To help students who had difficulty in acquiring the necessary knowledge and implementation skills, experienced seniors in the embedded control system research room are introduced to them, and even assigned to teach them. This allows the project advisors to spend more time in discussion with those experienced senior students, to develop and verify more advanced and creative approaches for improving the robots and their performance. To get their credits at the end of the course the special topics students have to pass an oral exam held by five teachers (not including their advisors), which tests the performance of their robots, and how well they had learned the implementation skills and the related theories.

Most of the project students participated in local and even international contests to see how well their robot designs performed; this is the second way to finish the project. Students work hard during this last part of the project to define problems and find solutions. Fig. 13 shows how one three-student team devised a homemade encoder and an educational robot with three functions for economically disadvantaged students. The problem of noisy speed calculation with traditional difference methods by using low-resolution encoder readings was also solved and published as a research paper [24] by these students and the advisors. It is interesting to know that these three students not only worked together for this project, but also designed their own robots for international contests.



(a) (b)

Fig. 13. (a) A low cost home-made encoder (b) a robot kit with three functions

Diagonal path planning in the Micromouse contest is another typical problem that is solved during the last part of the project. Traditionally, the flood algorithm [11] would only give the shortest path with consecutive 90-degree turns instead of a straight diagonal path. A post-processing program has to be used to transform those consecutive 90-degree turns into diagonal routes. This problem is solved by finding the flood values on cell borders, shown in Fig. 14. The algorithm can be further improved by imposing penalties on making turns and bonuses on long straight paths when filling flood values on the borders.

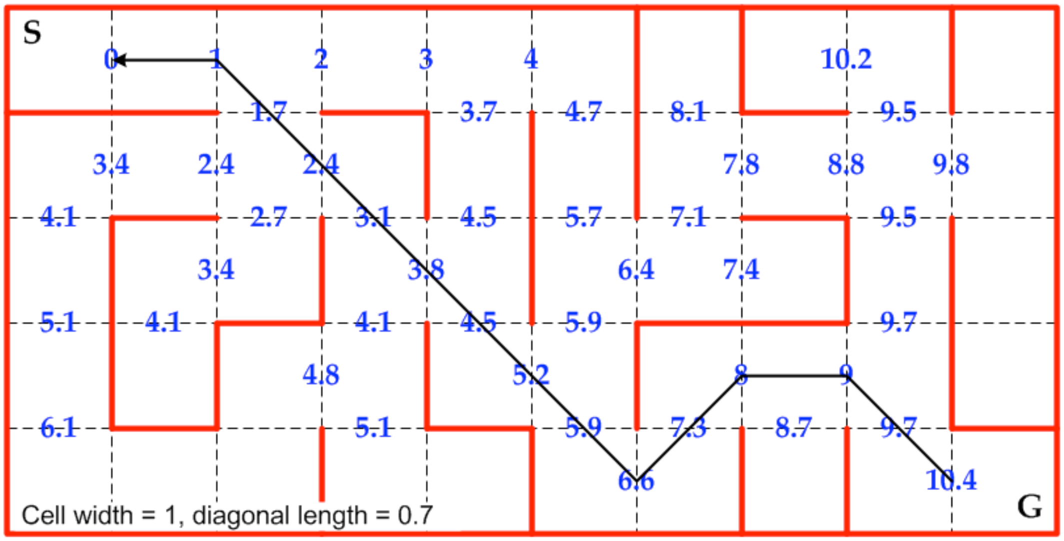
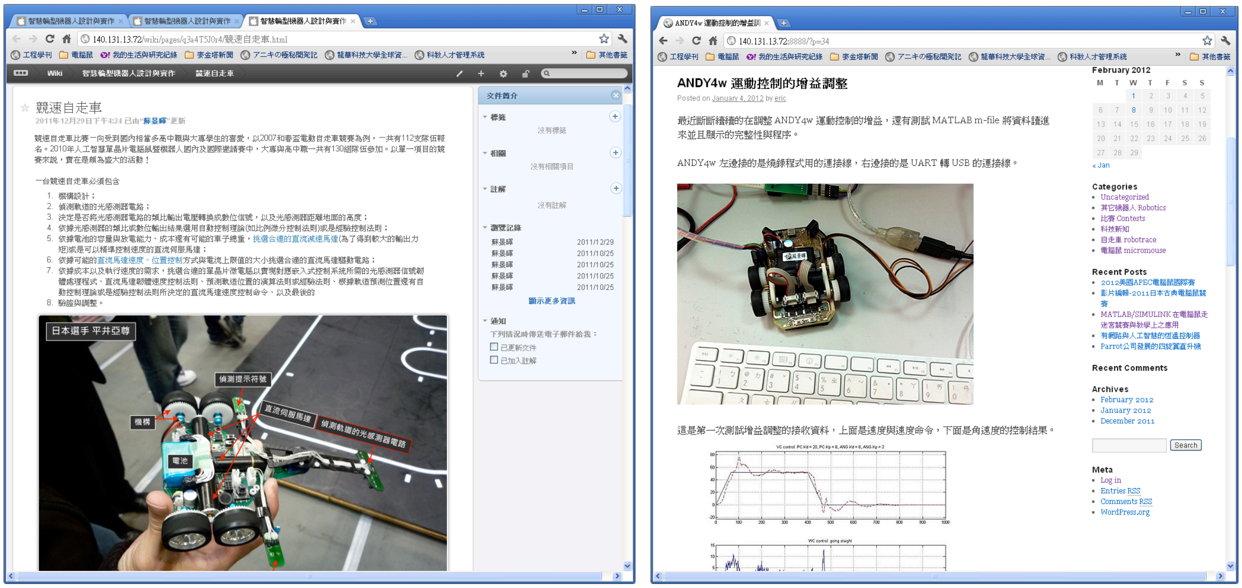


Fig. 14. An illustrative example for planning a direct diagonal shortest path for the Micromouse contest with flood fill on the borders between cells

The performance for Micromouse and Robotrace robots has improved significantly in the four years since the project was implemented, because experience has been carefully accumulated in lecture notes, a dedicated wiki website (140.131.13.72) and blog articles (140.131.13.72:8888), shown in Fig. 15, and passed on to the new students every year. Although in the first year the Micromouse could not move to the goal cell in the maze, one of the experienced students who keep improving his Micromouse, Fig. 16a, honing its mechanics, motion control, attitude correction, and maze-solving algorithms, managed to win, Fig. 16b, the 26th annual APEC International Micromouse Contest [25] in Florida in 2012.



(a) (b)

Fig. 15. The project experience logged in (a) a dedicated wiki website and (b) blog articles for this project

It was also found that the contest-oriented project did motivate students to integrate the knowledge and skills necessary to build their intelligent mobile robots, and to incorporate their creative ideas. For example, one group of students tried to design a four-wheel Robotracer, Fig. 17a, whose mechanical structure is quite popular in the Micromouse Contest; they obtained better results with increased friction. Another group of students also came up with an original idea to estimate the curvature of the line track in contests with gyroscope outputs, Fig. 17b; they won the first and second places in the 2011 Japan International Robotrace Contest with an average speed of about 2m/s.

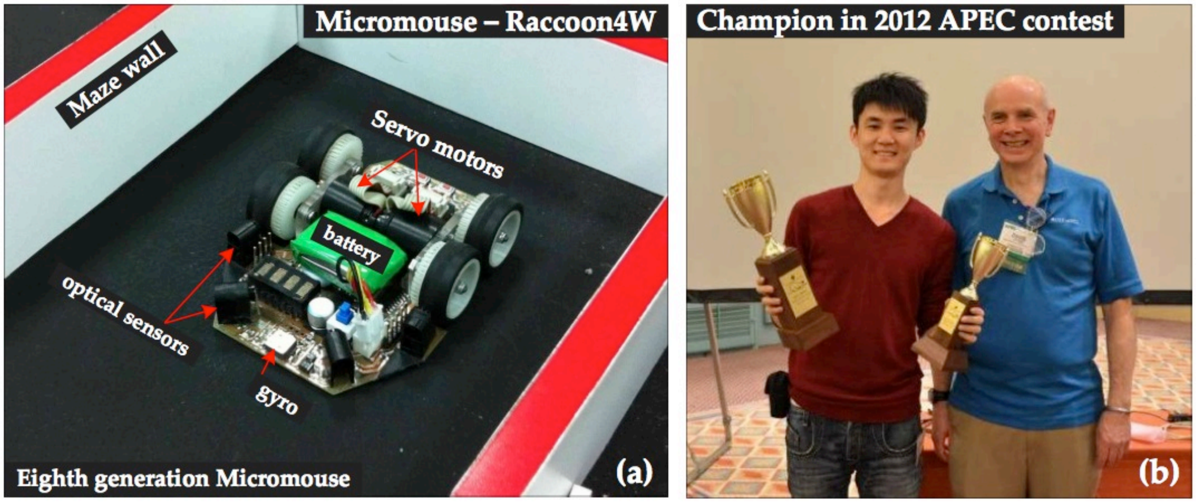


Fig. 16. (a) The Micromouse Raccoon4W in 2012, (b) Champion in 2012 APEC International Micromouse Contest

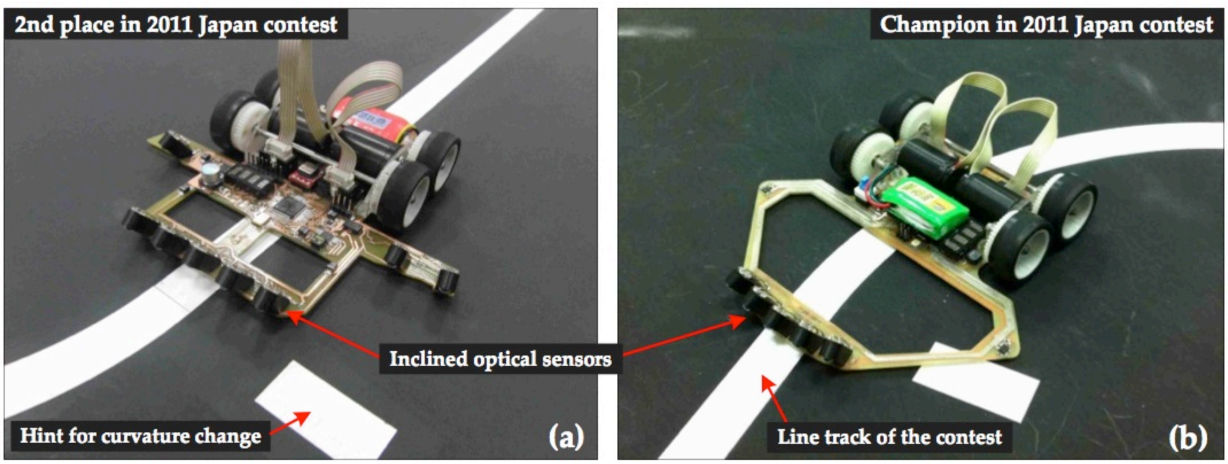


Fig. 17. Students applied their idea to make (a) a four-wheel Robotracer with better friction, (b) a four-wheel Robotracer with gyro-assisted curvature calculation capability

A survey on this contest-oriented project had 28 student responses. It can be seen from Table II that the student feedback was quite positive on aspects of motivation, learning basic and advanced skills. The majority of the students (more than 90%) agreed that they were motivated to learn those skills and theories, and were willing to persist in finishing their robots despite encountering frustrations in the process. The feedback also shows that students were happy to have joined the project and written their own firmware codes, even though they did not win any contest prizes.

However, some skills still elude students; for example, using MATLAB/SIMULINK to simulate motion control and maze-solving algorithms, and applying the technique to calculate the line track curvatures are difficult for them. More hands-on exercises and group discussions led by advisors would be helpful, but it would more of their time to be given to the project. The number of students interested in robots is still quite low when compared with the number of students in the Department, about seven students out of a total of 150. Most of the Department's students just want easy projects, and are indifferent to the competence they could acquire through the one-year special topics course. Therefore, the next step for the authors is to try to expose the project to more freshmen in the orientation, to recruit more students to the contest-oriented project.

Table II. The average survey scores for the contest-oriented project

	Questions	**Average/ Standard deviation (1-5)**
Motivation	I spend more time on the project because of the robot contests	**4.71/0.80**
	I was willing to join the contest-oriented project because the robot contests are so much fun.	**4.71/0.59**
	I really enjoyed the process of the contest-oriented project	**4.61/0.62**
	Although there were many frustrations in the project, I still persisted in finishing my robot and taking part in the contest	**4.68/0.60**
Basic skills	I learned to use embedded controllers and write better firmware codes in this project	**4.50/0.63**
	I learned to use SolidWorks to help me design the mechanical parts of my robot	**4.07/0.96**
	I learned to use the Pulse Width Modulation technique to control motor speed and position in this project	**4.43/0.98**
	I learned to use optical sensors to detect maze walls, or line positions, and I know how to deal with the background light problem.	**4.29/0.80**
Advanced skills	I learned to control the linear and angular speeds of differential driven wheeled robot with digital PID feedback controllers in this project	**4.21/1.01**
	I know how to simulate the motion control and maze solving algorithms in MATLAB/SIMULINK	**3.54/0.98**

	Questions	Average/ Standard deviation (1-5)
	I know how to predict the line track position with analog output values of optical sensors	**4.07/0.96**
	I know how to predict line track curvatures	**3.86/1.09**
	I learned to use MATLAB/SIMULINK to help plan the command speed profiles for linear and angular velocities	**3.68/1.04**
	I know how to correct the alignment error of the Micromouse with analog output values of optical sensors and gyros	**3.89/0.98**
	I know how to correct the alignment error of robot racers with analog output values of optical sensors and interpolation techniques	**4.18/1.00**
	I know the concept of flood algorithms for solving mazes	**3.89/1.05**
Final comments	I used my own idea to write the firmware codes	**4.71/0.45**
	I was glad to learn many implementation skills for intelligent robots in this project, even if I did not get any contest prizes	**4.82/0.38**

V. CONCLUSIONS

This paper presented a contest-oriented project for a one-year special topics course for senior undergraduate students at LST. The feedback from 28 students over four years is quite positive, and they won some local and international prizes from contests, see Table III, with their own intelligent mobile robots. More than ten of these students are now pursuing their Master’s degrees in the area of intelligent robots.

Table III. Contest results in 2008-2012

Contest	Prize
2008-2009 Taiwan Micromouse contest	**1st prize**
2009-2011 Taiwan Robotrace contest	**1st prize**
2009 Taiwan creative robot design contest	**1st prize**
2010, 2011 Taiwan Micromouse contest	**3rd prize**
2011 Taiwan home security robot contest	**1st prize**
2012 APEC Micromouse contest, USA	**3rd prize**
2011 All Japan Robotrace contest	**1st prize**

Contest	Prize
2011 All Japan Micromouse contest	**5th place**
2012 APEC Micromouse contest, USA	**1st prize**

The learning experiences and the intelligent mobile robots developed have also been used in robotic workshops held for vocational high school teachers and students from 2009-12. As teaching assistants at these workshops, the senior students who joined the project with good levels of achievement learned even more by trying to transfer their knowledge and skills to these vocational high school teachers and students. The lecture notes and the step motor Micromouse, in Fig. 18a, were prepared by those senior students after joining the project, who also organized a small contest, Fig. 18b, at the end of the workshop for the participants.

(a) (b)

Fig. 18. (a) Free workshop materials for vocational high school teachers and students, (b) the contest at the end of the workshop

ACKNOWLEDGMENT

The authors would like to thank the National Science Council for its financial support under grant NSC 100-2511-S-262-001, and Microchip Inc. for their support of free C-compilers and microcontrollers.

REFERENCES

[1] Bill Gates, “A robot in every home,” *Scientific American Magazine*, Jan. 2007.

[2] iRobot cooperation, Vacuum cleaning robot - iRobot Roomba, www.irobot.com, Accessed October 9, 2011.

[3] K. Nagai, “Learning while doing: practical robotics education,” *IEEE Robotics & Automation Magazine*, pp. 39-43, June 2001.

[4] K.-S. Hwang, W.-H. Hsiao, G.-T. Shing, and K.-J. Chen "Rapid prototyping platform for robotics applications", *IEEE Trans. on Edu.*, vol. 54, no. 2, pp. 236-246, May 2011.

[5] N. Chen, H. Chung, and Y. K. Kwon, “Integration of Micromouse project with undergraduate curriculum: a large-scale student participation approach,” *IEEE Transactions on Education,* vol. 38, no. 2, pp. 136-144, May, 1995.

[6] R. B. Murphy, “Competing for a robotics education,” *IEEE Robotics & Automation Magazine*, vol. 8, pp. 44-55, June 2001.

[7] D. J. Pack, .R. Avanzato, D. J. Ahlgren, and I. M. Verner, “Fire-Fighting Mobile Robotics and Interdisciplinary design-comparative perspectives,” *IEEE Transactions on Education,* vol. 47, no. 3, pp. 369-376, August, 2004.

[8] New technology foundation – The 32nd all Japan Micromouse contest, http://www.ntf.or.jp/mouse/micromouse2011/index_EN.html, Accessed Dec. 24, 2011.

[9] The 2012 Taiwan Micromouse and intelligent robot contest, http://robot.lhu.edu.tw Accessed August 15, 2012.

[10] F. Martinez, L. C. Herrero, and S. de Pablo, “Project-based Learning and Rubrics in the Teaching of Power Supplies and Photovoltaic Electricity,” IEEE *Transactions on Education*, vol. 54, no. 1, pp. 87-96, 2011.

[11] Fortune Institute of Technology, The line-following robot racing contest 2007, http://www.ee.fotech.edu.tw/contest/information.htm, Accessed January 8, 2012.

[12] C.-S. Lee, J.-H. Su, K.-E. Lin, Jia-Hao Chang and Gu-Hong Lin, “A Project-Based Laboratory for Learning Embedded System Design with Industry Support,” *IEEE Transactions on Education*, vol. 53, no. 2, pp. 173-181, 2010.

[13] Chan, “Desktop line-following robot,” http://elm-chan.org/works/ltc/report.html, Accessed on January 23, 2012.

[14] New Technology Foundation, The 32th all Japan Micromouse contest, Accessed January 10, 2012, http://www.ntf.or.jp/mouse/micromouse2011/index.html.

[15] Society of Robots, “Micromouse – Maze Solver – Theory,” Accessed December 28, 2008, http://www.societyofrobots.com/member_tutorials/node/94.

[16] J.-H. Su, C.-S. Lee, and H.-H. Huang, “A Micromouse kit for teaching autonomous mobile robots,” *International Journal of Electrical Engineering Education*, vol. 48, no. 2, pp. 188-201, 2011.

[17] Beng-Kiat Ng, Mouse technology, http://www.np.edu.sg/alpha/nbk/, Accessed January 8, 2012.

[18] Microchip Technology, Inc., 16-bit dsPIC DSCs, accessed on February 10, 2012, http://www.microchip.com/pagehandler/en-us/family/16bit/.

[19] Stratasys Inc., 3D printers, http://www.stratasys.com/Products/3D-Printers.aspx, Accessed December 28, 2011.

[20] TurnFast.com, “Weight Transfer,” accessed on February 8, 2012, http://www.turnfast.com/tech_handling/handling_weightxfr.

[21] J. Vroman, “JavaBot1…. A line following robot,” accessed on January 19, 2012, http://www.james.vroman.com/javbot1a.htm.

[22] J.-H. Su, C.-S. Lee, H.-H. Huang, S.-H. Chuang and C.-Y. Lin, "An intelligent line-following-robot project for introductory robot courses," *World Trans. on Eng. and Technology Education*, vol. 8, no. 4, pp. 1-7, 2010.

[23] Wikipedia, Center of mass – alternative derivation, accessed on January 30, 2012, http://en.wikipedia.org/wiki/Center_of_mass.

[24] J.-H. Su, C.-S. Lee, H.-H. Huang, S.-W. Chao, S.-H. Lin, and Y.-C. Wu, "A Versatile Kit for Teaching Intelligent Mobile Robots," *Next Wave in Robotics, Communications in Computer and Information Science*, vol. 212, pp. 42-49, Springerlink, 2011.

[25] Applied Power Electronics Conference and Exposition (APEC) 2012, the 26th annual international Micromouse contest, Feb. 6, Orlando, Florida, http://www.apec-conf.org/participating-in-apec-mainmenu-261/participating-in-micromouse-mainmenu-242, accessed on February 8, 2012.

Hsin-Hsiung Huang (M' 2010) was born in Taiwan in Oct. 1974. He received the M.S. and Ph.D. degrees in the Department of Information Computer Engineering and Institute of Electronic Engineering from Chung Yuan Christian University, Taoyuan, Taiwan, in 2000 and 2008, respectively. His work is in algorithm–related fields, such as the applications of line-following maze robots for the shortest path problems and EDA algorithms for the VLSI, the floorplanner and performance-driven routing with obstacles.
He is currently an Assistant Professor in Department of Electronic Engineering, Lunghwa University of Science and Technology in Taoyuan in Taiwan. From 2000 to 2002, he was a hardware engineer designing Ethernet products at Accton Corporation, Hsin-Chu, Taiwan. From 2002 to 2003, he served as a research and development engineer and focused on chip design for the 10/100/1000 Mbps Ethernet MAC at TM-Technology Corporation, Hsin-Chu, Taiwan.
Dr. Huang has also been an oversea member of the Institute of Electronics, Information and Communication Engineers (IEICE) since 2009, and has published in various IEEE conferences, among them ISCAS, MWSCAS and ISIC.

Juing-Huei Su (S'87-M'93-SM'08) was born in Tainan, Taiwan on February 17, 1965. He received his B.S., M.S. and Ph.D. degrees all in Electrical Engineering, from the National Taiwan University, Taipei in 1987, 1989, 1993, respectively. From 1993 to 1995, he served as a military officer in the army. In 1995, he became a senior engineer in the Taian Electric Co. Ltd. Since 2007, he has been a professor in the Department of Electronic Engineering, Lunghwa University of Science and Technology. He is now interested in developing his own learning platforms for automatic control and robotic education. His research interests also include robust control theory, power electronic systems, and embedded control system implementations.

Chyi-Shyong Lee received the B.S. and M.S. degrees in Electrical Engineering from National Taipei University of Technology, Taiwan, and the National Tsing Hua University, Taiwan, in 1979 and 1985, respectively.
From 1985 to 1988, he served as a Lecturer in the Hwa Hsia Institute of Technology, Taiwan. He was a Lecturer in the Department of Electronic Engineering, Lunghwa University of Science and Technology, Taiwan, from 1989 to 2007, and is now an Assistant Professor. Currently, his research interests include digital control of power electronic systems and the applications of microcontrollers and embedded systems.