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# LINE TRACKING MOBILE COMPETITION ROBOT AS AN EMBEDDED SYSTEM DESIGN COURSE PROJECT

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**Abstract**

The line tracking control of a mobile competition robot is carried as an embedded system design course pivot project. The project is suitable for Problem and Project Based Learning methodology, and satisfies most of program outcome criteria stated by ABET-09 and EUR-ACE-08 on engineering design. Furthermore, the project motivates students for learning high technology tracks and encourages them for graduate studies such as mechatronics and robotics. The project is carried in parallel to Problem and Project Based Learning approach in Fall 08-09. It is based on the control of forward/backward movement and steering motors of a toy-car installed with a microcontroller which reads track position sensors and decides on which way to run the motors, by software in C language. Analog sensor readings require digital filter design and considerable design of test experiments before using them in a control loop.

**Keywords:** Line Tracking Competition Robot, Embedded System Design Project, Engineering Accreditation Criteria, Problem and Project Based Learning.

## 1. Introduction

In recent years, well known accreditation institutions, specify serious program outcome criteria on engineering design such as *undergraduate program outcome criteria* of *Accreditation Board for Engineering and Technology* (ABET) [1] and *personal programme outcomes for the bachelor level* states that first cycle graduate EUR-ACE (2008) [9], as shown in Table 1. This trend is parallel to the Problem and Project Based Learning (PBL) which has gained importance during the last couples of decades as the new trend in learning methodology in Science and Engineering Education, as stated by Kolmos (2009) [14].

According to Kolmos, the learning approach in PBL means that learning is organized around problems, which is a central principle for the development of motivation. A problem initiates the learning processes, places learning in context, and bases learning on the learner's experience. The learning is carried through in projects, and it is a unique task involving more complex and situated problem analyses and problem solving because it is also project-based. The *contents approach* especially concerns interdisciplinary learning, which may span across traditional subject-related boundaries and methods. *The learning outcomes* support the relation between theory and practice since the learning process combines problem solving methods with the analytical approach using theory in the analysis of problems. The *social approach* is team-based learning that considers the learning process as a social act where learning takes place through discussion-rich communication, where the students learn to share knowledge and organize the process of collaborative learning. It is a participant-directed learning, which indicates a collective ownership of the learning process and, especially, the formulation of the problem. PBL is a much more demanding method and often requires

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organizational changes in order to practice more complex projects compared to the other well-known learning methods such as active learning, inquiry-based learning, experiential learning, co-operative learning, and case-based learning those not fulfilling all of the learning principles [14].

**Table 1.** Criteria from ABET and EUR-ACE, those supporting Problem Based Learning Approach.

| **EUR-ACE 1.cycle outcomes** | **ABET program outcomes criteria** |
|---|---|
| *Individual and team work* (Function effectively as an individual, and as a member or leader in diverse engineering teams) | An ability to function on multi-disciplinary teams, |
| *Ethics* (Understand and commit to professional ethics and responsibilities and norms of engineering practice) | An understanding of professional and ethical responsibility, |
| *Communication* (Communicate effectively on intermediate engineering activities with the engineering community and with society at large, by being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions) | An ability to communicate effectively, |
| *The engineer and society* (Demonstrate understanding of the societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to engineering practice) | The broad education necessary to understand the impact of solutions in a global and societal context, |
| *Project management and finance* (Demonstrate an awareness and understanding of management and business practices, such as risk and change management, and understand their limitations) | An ability to use the techniques, skills, and modern scientific and technical tools necessary for professional practice |
| *Environment and sustainability* (Understand the impact of engineering solutions in a societal context and demonstrate knowledge of and need for sustainable development) | An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability |

The DARPA grand challenge competition has proved that competitions have a very significant role in developing the attention of the competitors on high technology. The *Defense Advanced Research Projects Agency* (DARPA), a military organization, aims to maintain the technological advantage of the US military from the encouraged and new ideas between the initiators with fresh perspectives. DARPA is known with many innovative technological projects such as ARPANET, the origin of Internet. DARPA started to organize a professional level robotic competition with the aim to initiate usage of autonomous mobile robot vehicles in human environment. The first DARPA Grand Challenge Competition took place in March 2004. It was open to organizations, business, university and the school teams. Only 15 percent of applicants were ready in the competition field. The best vehicle managed to run only 5 percent of the complete route before failing. One million dollars grand prize was transferred to next competition because no one completed the route. The next Grand Challenge was hold in Nevada, on desert and mountain roads on October 8, 2005. From over 132 applicants, 23 finalists competed on a twisting, unpaved course. 22 of 23 vehicles traveled further than the 7.4 miles, a real success compared to the 2004 competition. 2005 DARPA Grand Challenge Program Manager R. Kurjanowicz [15] evaluated the competition as a great success and explained the primary reason for the success by the composition of the teams —the students, engineers, scientists, and backyard mechanics— all inventors who brought fresh ideas to solve a very difficult technical problem. They were individuals, but learned to work together in teams. Unlike other prize events, the DARPA Grand Challenge set a specific date for the competition, and all the teams spent countless long hours overcoming setbacks to be there for the final event. The success of DARPA Grand Challenge proved us the importance of competitions to motivate engineering design teams.

The *Science and Innovation Club* in *Eastern Mediterranean University* (EMU) has established in 2007 by the seamless efforts of leading students from Arts and Science, and Engineering Departments including a team of robotics hobbyists. This student club collected modest interest in EMU Spring Fair, and started the first ideas of organizing a robotics competition. The first international robotics competition of Northern Cyprus namely the *International Joint Robotics Competition* (IJRC) by EMU of TRNC, Shiraz University of Iran, Boğaziçi, Süleyman Demirel, and Middle East Technical Universities of Turkey held on May 2008 at EMU [12]. IJRC-08 was composed of a set of intermediate and advance level of competitions. The relatively easier branches —Line following, Car race, Fight (to survive on an elevated platform), and Cooperated Fight— collected quite many competitors while more difficult categories —Solo and Cooperative Labyrinth Discovery competitions— did not attract any competitors. In overall, the organization can be accepted as a successful initiation of an annual robotics competition, since the goal of IJRC was to encourage the students to involve in robotics competitions. It granted to the participants of the tutorials an opportunity to become familiar with robotics as an interesting field of research and study where exchanging of ideas is very important. IJRC-09 competitions took place at Süleyman Demirel University, Turkey.

IJRC-08 applicants are supported to construct their robots by a set of tutorial sessions, demonstrations, competitions and demos, each being only 45 minutes, including the following topics:

a) On the Competition, How to get Prepared, and Costs Involved;
b) A Simplified Introduction to Electronics (Transistor, diode, LED/LCD-displays, measuring devices etc.);
c) Introduction to Suitable Microcontrollers (AVR 8-bit/32-bit, 8051);
d) PC Interfacing (Port Protocols, Parallel, Serial, USB, Windows XP/Vista/Linux Port communication);
e) Simplified Image Processing (Color Detection, Path Recognition, Object Recognition);
f) Programming for Microcontrollers (C, IC Programming, PIC Programming);
g) Control (Feed forward, Feedback, On-Off, PID, Servo Control, PM-DC motors, PWM);
h) Embedded/HLL Programming (C++ for Microcontrollers, BASIC);
i) Sensors (Infrared Detection, Range Finder, Acceleration, Force, Torque, Velocity, Pressure, and Shaft Encoders);
j) Motors and Actuators (DC, Servo, Stepper, Driving Circuits, PWM);
k) Embedded Boards (ICOP, PC104, WinXPe, Linux Embedded);
l) Mechanics (Gears, Materials for Gears);
m) Dissecting a Robot (Line following, SUMO, CLD).

The training modules of the tutorials cover almost all of the technical knowledge the trainees may need for constructing their own mobile robots. In this respect, IJRC-08 created a very effective curricular and extra-curriculum activity opportunities to learn mechatronics principles through PBL. We explained our methodology and procedure in preparing the tutorials to construct embedded controllers for simple competition oriented robots, especially for those who want to have a quick start without any background knowledge about embedded controllers and robotics at FISER-09 [20].

Mechatronics is a young branch of engineering that boils the mechanics, electronics and control software in the same pot to design and develops various devices, instruments and systems. Billingsley wrote that mobile robots are a fascinating application of mechatronics [2]. A competition robot is a typical mechatronics device based on three main components: a) Mechanical structure that carries the body and electro-mechanical parts such as actuators and motors, as well as transmitting the desired motion to the necessary elements, b) Electronics that enables usage of several sensory elements, and drivers for actuators, c) Computational power generated by the embedded processor which gives the programmed intelligence to the mechatronics device. Building a competition robot from available components requires a wide range of skills even if it is built by the ready-made kits. Some of them are electronics for the motor drivers, power supplies, sensors and microcontroller interfaces; building the mechanical parts such as the platform with a frame to carry the whole system, and the covers to protect the components from the unexpected environmental effects; and programming a microcontroller to get the desired actions from the robot. Two important skills that cannot be developed from reading books and attending tutorials are patience and the willingness to learn. Both are absolutely essential for competitors to build and prepare their own working robots for the competition as stated by McComb at all [17].

An embedded system is a microprocessor-based system that is built to control a function or range of functions and is not designed to be programmed by the end user. The embedding of programmable processors into equipment and consumer appliances started at early 1970s, much before the production of PC. Major part of microprocessor and microcontroller production is consumed in embedded system applications. There are countless simple embedded system applications such as home thermostats, laundry and dish washing machines, intruder alarm systems, etc., improving our daily life. Higher end embedded system applications such as cellular phones and car electronics requires high-speed, and distributed processing by several microcontrollers. A modern car may have over 50 microcontrollers controlling functions such as engine management systems, electronic anti-lock brakes, traction control and electronically controlled gearboxes, airbag systems, electric windows, air-conditioning and so on, composing a complex embedded system.

The next five sections contain the following issues. Second section states education level of the students who register to the embedded system design course; the third section describes the current state of ESD course; the fourth section explains the major components of the line tracking mobile robot project including the learning and social approach. The fifth section gives the evaluation of the learning outcomes and assessment of the design project. The last section contains a short conclusion of the paper.

## 2. Education Level of the Students Involved in Project

IJRC was an extra-curriculum activity suitable to PBL methods, and the tutorials “Control” and “Programming for Microcontrollers” were prepared and presented considering a large spectrum of interested students, BS and MS, since there was no information about the distribution of the competitor candidates from the Art and Science and Engineering Faculties

[4], [5]. In contrast to this case, the design project team member candidates of Embedded Systems Design (ESD) course are at least sixth semester students at Eastern Mediterranean University Computer Engineering Department (EMU-CMPE), and have quite uniform formation on digital design and computer architecture track because of the prerequisite course requirements on Embedded System Course. The students are well equipped with basic science and mathematics knowledge, including linear algebra, differential calculus, statistics, and discrete mathematics. They took three 3 credit-hour courses to improve their communication skills in English, including report writing and technical presentation. At this stage, they need a design practice to concentrate their knowledge in solving a real world engineering problem.

## 3. EMU-CMPE Embedded System Design Course

The Embedded System Design course at EMU-CMPE department was started at Fall 2005 semester as a 4 cr-hr. area elective course with seven 2-hr lab sessions. According to the course outcomes, successful students must be able to:

i) Learn basic hardware architecture of modern low/medium and microcontrollers,
ii) Understand fundamental software architecture of the microcontroller based embedded systems,
iii) Design, and use user-processor interface with LCD displays, keypads, and buzzers,
iv) Use assembler and C programming for stand-alone embedded system microcontrollers,
v) Apply timing methods in embedded system design using instruction count and timer units,
vi) Understand and apply interrupt management, servicing, and hierarchical interrupt structures.
vii) Configure and use in applications various in-circuit facilities such as ADC, and PWM,
viii) Build embedded networks with serial communication, ix) apply the basic system design concepts on a design project.

The course is intended to satisfy the following program objectives i) identify, formulate and solve computer engineering and science problems through application of an adequate knowledge of mathematics, basic sciences and engineering tools ii) design and implement systems in their particular field; iii) communicate their ideas effectively that will enable them to collaborate with their team members and with the international community in their respective field; iv) apply modern engineering tools and techniques innovatively; and v) prepare students for graduate study in the related fields. In this connection, ESD course satisfies in a great extent the following undergraduate program criteria to be attained by the graduates:

a) an ability to apply knowledge of mathematics, science, and engineering,
b) an ability to design and conduct experiments, as well as to analyze and interpret data,
c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,
d) an ability to function on multidisciplinary teams,
e) an ability to identify, formulate, and solve engineering problems,
f) an understanding of professional and ethical responsibility,
g) an ability to communicate effectively,
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice,
l) a knowledge of probability and statistics, mathematics through differential and integral calculus, discrete mathematics, basic sciences, computer science, and engineering

sciences necessary to analyze and design software, and systems containing hardware and software components,

m) an ability of multilingual communication.

To accomplish these course objectives and outcomes, almost 50 percent of the lectures and labs of the course is dedicated to conduct design oriented projects, such as controller design of a washing machine, a refrigerator, an elevator system and a traffic signalization system. We experienced that for the efficiency and success of the projects they shall be divided to several stages, and each stage must be assigned as a section of the project. These properties make ESD the best course to apply the Problem and Project Based Learning approach and methods.

## 4. Major Components of the Line-Following Mobile Robot Project

### 4.1. Physical parts of the Mobile Robot

The design project involves physical prototype implementation of the line tracking robot starting with a non-holonomic toy car that uses a steering mechanism similar to most vehicles in the traffic. It was installed with two dc-motors to move the platform forward and to steer it toward left- or right-sides. The first mobile robot of this kind was implemented as a graduation design project by senior CMPE students, Dundar and Cango, using on-off control for the steering motor driven by L293D H-bridge drivers [8]. The applied control function was a combinatorial Boolean function of five CNY70 optical sensor inputs, to decide on four motor control output signals: forward, backward, left turn, and right turn via the rules written in if-then-else constructs.

### 4.2. Microcontroller based system design

Microcontrollers are the core of the embedded system to implement the control algorithms required for an embedded system application. A microcontroller is a dedicated programmable computer in a chip that sends control signals to the indicators and actuators of the robot. It is impossible to control the motion of a competition robot without a microcontroller which works as the computer of the robot. In this respect, a microcontroller is an inevitable item of a successful competition robot. One or more microcontrollers are embedded in a typical competition robot to implement several intelligent control algorithms on collected sensory data. Additional to the microcontroller design, the systematic methods, procedures and algorithms obtained by control theory is necessary to build stable control systems of a robot. A variety of microcontroller families are suitable for the competition robots, each of them has a different machine or assembly language. A rich literature on some of the suitable microcontrollers is available such as Bates [3], Bräunl [6], Ibrahim [10], [11], Jivan et al [13], Predko [18], Pont [19], and Wilmshurst [21].

Microcontrollers have different families based on their producers and their goal. Some of the well known microcontrollers for mobile robotic applications are 8051, Motorola M68332 and Microchip PIC16/18. From the large set of suitable microcontroller families, we decided to use PIC16/PIC18 family for its availability in local markets as well as availability of freely distributed educational development tools such as compilers and integrated development environments (IDE). In programming PIC microcontrollers the most important reference is the device datasheet by Microchip [16]. Huge amount of application sheets and sample programs are available in the manufacturers' web site "www.microchip.com". C program can be conveniently coded in MPLAB IDE as a CC8E project. Thereafter, the code needs compilation to HEX file, and the hex code is transferred to PIC16F452 using an IC-programmer-device.

### 4.3. Physical System Components

The sensors and motors as input/output peripherals should be managed by the microcontroller. The sensors collect the signals from the environment, and send them to the microcontroller for processing. Depending on the result of the processing, the microcontroller sends appropriate signals to the actuators for the next movement. A PIC18F452 microcontroller was preferred in all of these projects because of more than sufficient program and register space, low power consumption at high processing speeds, two level interrupts, A/D converters, PWM, Timer, serial communication features, and large number of i/o pins which are essential for convenient testing and development. Similar graduation design projects were carried testing several steering and speed control algorithms for three optical sensors, remembering the direction of the track even after the sensors are completely out of track.

In the last project, Yalçın and his team [22], used analog readings from the CNY70 optical sensors, converted the readings to binary signal after a low pass discrete filtering. The team considered the vehicle speed critical to take the turns without leaving the track, and managed the speed control by PWM. The developed analog reading method for CNY70 decreased the power consumption of the sensor LEDs five times relative to the nominal value by compensating the dark-level, which requires design of test and measurement methods to set many parameters for filtering the readings in the design.

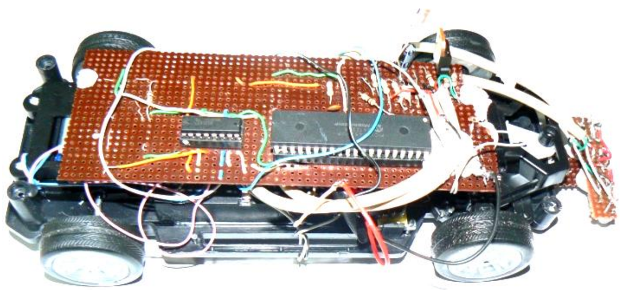

**Fig. 1.** Typical physical implementation for the line following mobile robots at ESD courses.

### 4.4. Microcontroller Software in C Language

Many embedded system authorities are in agreement on the benefits of C programming language for the following reasons as listed by Zurell K. [23]. It helps to abstract the architecture and keep from getting lost in opcode sequences and assembly coding. It makes your program portable within and between the microcontroller families, which can be useful to reduce the price as well as to port the application to more improved microcontrollers. It reduces the cost of project by reducing the programming time by available library functions and simplifying the documentation efforts. It reduces implementation time, and allows you to spend more time on algorithm. It reduces the debugging time because C codes are much compact and easier to grasp than assembly codes.

Creating new coding projects in C are an easy and routine task. C is a well standardized mid-level modular programming language and very compact compared to the assembly, making the documentation easier. C is widely used in industry to program microcontrollers. If a designer faces to a problem during the microcontroller programming it can be solved by surfing through the internet and finding available online sources and even discuss with other experienced people.

C is also common in many other fields of science and engineering. Most of the scientists and engineers are familiar with C as a well known programming language. We can expand its benefits further considering the much shorter learning time of C language compared to the assembly languages. With these superior mid-level properties C language is the common language in the embedded system industry, with over 60 percent, followed by all assembly languages and other high level languages such as C++ and Java. C programming language is a mid-level coding language with high level features for accessing hardware. Most C compilers also allow the assembly codes to be embedded into the C source codes.

Along with a C compiler, code developers need an Integrated Development Environment (IDE) and a hybrid circuit simulation environment which support their C compiler. The tools are introduced at the labs, and lecture hours for fast and simple coding and debugging of the microcontrollers and peripheral control circuits.

### 4.5 Control Theory Related Application Knowledge

A microcontroller manages the control of all peripheral components of the robot. The On-Off and Proportional Integral Derivative (PID) control are two well known control methods suitable for the line tracking purpose. PID is the classical solution to reduce the offset and overshoot of the second order systems. In the simulations, only a modification of the microcontroller code is sufficient to apply PID and on-off control to the RC circuit only by modifying the coding of the microcontroller.

The control tutorial [4] prepared for IJRC-08 serves perfectly well for this purpose. In the tutorial, instead of summarizing the control theory, the usage of DC and stepper motors were described with examples. The concepts of open-loop and closed-loop control, the concept of feedback sensors, on-off control, proportional (P), integral (I) and derivative (D) control methods were explained with effects on the control loop stability. Pulse-width-modulation (PWM) and its implementation for a DC motor control were included into the demonstration section with application samples of P, PD, PID and on-off line tracking control applications.

### 4.6 Timer, Interrupts, ADC, PWM and Serial Communication Features

Physical sensors feed analogue signals to the ADC input of the microcontroller. ADC converts them to digital values to be processed by the microcontroller to control the system components like motors, LED and counters. Timing is an important factor for the implementation of the precise digital filters, and proper interrupt management simplifies the operation of the control systems. PIC18F452 contains two general purpose timers, a two-level interrupt service system, two extra timers connected to a PWM, an 8- or 10-bit Analogue to Digital Converter (ADC), and a UART for serial data communication. The design team shall i) select the time periods for control and filtering to configure the timers and interrupt services; ii) decide the precision and the configuration, of the ADC for the requirements of the system, iii) filter the sensor inputs for better accuracy, iv) apply a control law to decide steering and forward movement motor voltages, v) for a linear motor voltage use PWM either by internal PWM circuit or by soft methods, vi) use serial communication port of the microcontroller to design several test and debugging experiments and software. These features are main topics of the course contents, and supported by the experiments carried out during the lab hours.

### 4.7. Learning and Social Approach of the Design Projects

The effort for building a competition robot is not in the affordable magnitude by a single student with only 20 hours effort even if all materials are ready for the design. This fact naturally forces the students to work in teams of minimum three, maximum five members, which satisfy the team-based learning feature of PBL, and ABET. The teams are expected to have contact hours to discuss problems related to their progress, which verifies the team based learning process. From these contacts we noticed that most of the team members were very close friends prior to the ESD course, mostly because they have similar hobbies and preferences, which is not the case for other design projects of the course.

The learning approach of our design activity is a consequence of the line tracking problem specified by IJRC. The design and implementation of a competition robot has no trivial solutions, and requires the combinational utilization of the material and intellectual resources such as differential calculus, statistics, and design of test experiments, discrete time digital filters and control systems to get the best performance in the competitions. Both the design and the implementation require well organized team-project management where learning is an essential component for improving the design to the successful product. The competitive features of the project motivates students for learning high technology tracks such as mechatronics and robotics, which significantly satisfies one of the program objectives by preparing and supporting students for graduate study in the related fields.

## 5. Evaluation of the Learning Outcomes and Design Projects

Evaluation of the success of a one-shot action is possible with interviews rather than statistical analysis, as Cohen et al. [7] wrote about the evaluation process in educational research. The carried design practice for the line tracking mobile robot design succeeded to satisfy most of course learning outcomes. The success is verified by the written communication skills by writing the preliminary and final reports, as well as the oral communication skills assessed during the report presentations along with a video-recorded demonstration.

Development of sufficient level of motivation is essential ingredient in problem and project based learning. In this respect, the positive effect of the developed motivation is seen as the increasing interest to the Embedded System Design course.

## 6. Conclusion

IJRC-08 competitions raised an opportunity of new design projects, on line-tracking mobile robots, to be conducted in embedded system design courses at EMU-CMPE department. This project is used in parallel to problem/project based learning methodology that satisfies recent design related program output criteria of accreditation institutions, ABET and EUR-ACE. By its competitive character, this project motivates the students to learn high technology tracks and encourage them for higher studies on mechatronics and robotics.

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